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# TECHNOLOGY OF MANUFACTURE OF LIGHT CERAMIC AGGREGATE FROM POWER PLANT ASHES IN ROTARY FURNACE OPERATING IN STREAMWISE SYSTEM

# TECHNOLOGIA PRODUKCJI LEKKIEGO KRUSZYWA CERAMICZNEGO Z POPIOŁÓW ELEKTROWNIANYCH W PIECU OBROTOWYM PRACUJĄCYM W UKŁADZIE WSPÓŁPRĄDOWYM

A b s t r a c t

A band drier for drying granulated power plant ashes was designed, constructed and verified. Its mechanic operation was checked and basic working parameters such as amount and temperature of drying gases and total capacity of the installation were determined. A streamwise rotary furnace with radial air supply was also designed and built. The usability of the furnace for burning and sintering of ceramic aggregates from ashes of different contents of carbon was checked experimentally. A way of attaining stationary working conditions was found and the productivity of the installation was determined.

*Keywords: recycling of power plant ashes, sintered aggregates*

S t r e s z c z e n i e

Zaprojektowano i zbudowano taśmową suszarnię do suszenia zgranulowanych popiołów elektrownianych, sprawdzono jej działanie pod względem mechanicznym, określono podstawowe parametry pracy, takie jak ilość i temperatura gazów suszących oraz wydajność urządzenia. Zaprojektowano także i zbudowano współprądowy piec obrotowy z promieniowym podawaniem powietrza do jego wnętrza. Sprawdzono jego przydatność w procesie wypalania i spiekania kruszywa ceramicznego o różnej zawartości węgla w popiele, określono sposób dochodzenia do warunków stacjonarnych, wyznaczono wydajność urządzenia.

*Słowa kluczowe: recykling popiołów elektrownianych, kruszywa spiekane*

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## 1. Introduction

The amount of professional power industry wastes accumulated in Poland up to now attains nearly 500 million Mg. It is an enormous burden for the natural environment. From the economic viewpoint it would be most profitable to reuse them in a suitable technologic application.

Among a number of known methods of managing and use of power plant ashes their transformation into light ceramic aggregates is nowadays the most prospective. The main domains of application of such aggregates include road building – for formation of road embankments, for ground leveling and drainage, and house building – as a filler for light construction concretes.

The production and use of such aggregates means, on one hand, the elimination of dumps accumulated and, on the other hand, limiting the degradation of the environment caused by gaining naturally occurring aggregates.

Owing to the recommendations of the European Union and statement on 30% contribution of recycling materials in road building, the technology gives a chance for universal use of ceramic aggregates. It is also an incentive for building a number of plants working on a base of local sources of spent dusts and ashes.

The technologies of production of light ceramic aggregates hardened by hydrothermal treatment, developed in the 1960s, have not been universally applied in practice because of high costs of production and unsatisfactory properties of the products [1]. The interest of Polish market in porous ash-based aggregates has not come back as after 1995, when the production of license-based light sintered aggregate “Pollytag” was started.

Sintered ceramic aggregates can be produced in beds of immobile granules by sucking or blowing air through the layer of granular material. The process is usually realized on sintering belts. Sintering can also be performed in mobile beds with air blow. Such a variant of the process can also be carried outin a shaft or rotary furnace. Although the investment costs in the two procedures are similar, the technology of sintering aggregates in a mobile bed is much cheaper in running the process. Besides, use of sintering belt for burning granulates that contain sludge or other harmful waste materials would require the use of an installation for treatment of combustion gases.

The technologies of manufacture of sintered ash-based porous aggregates, developed after 1950s, have not been implemented until now mainly because of difficulties in channelizing the granular material in the furnace shaft, in preventing the formation of sinters that disturb the movement of material in the furnace, and in elimination of irregularities of air flow in the furnace shaft. For these reasons research is continued on developing a construction which would retain the most important features of shaft furnace, i.e. the autothermicity of running the process and possibility of destruction of harmful waste substances, and which would provide a natural ease of running the process, would give a possibility of changing and controlling many process parameters, and which, like rotary furnace, would not be sensitive to wide corrections in the charge composition.

For these reasons an attempt has been made in the Department of Inorganic Technology and Ceramics of the Faculty of Chemistry, Warsaw University of Technology, in collaboration with a group of outer investors [3, 4], to develop an inexpensive and reliable technology for manufacture of sintered a ceramic aggregate, in which the process of sintering would be carried out with no external fuel addition. The main stage of such a technology consists in the process of burning and sintering of aggregate in a specially designed setup based on rotary furnace supplied with essential features of shaft furnace [5]. In such a furnace the conditions suitable for complete destruction of volatile harmful substances will be attained by the change of traditional countercurrent system the flow of phases into a streamwise flow. It enables a significant increase of the duration of stay of harmful substances within the hot zone of the furnace. The autothermicity of the process will be attained by application of unique, radial supply of air for burning and sintering of raw granulate, instead of the traditional supply of air parallel to the axis of the furnace.

Owing to the proposed system of media flow the reaction conditions in the furnace charge will remind those existing in the shaft furnace. Besides, the autothermicity of the process will be assisted by damming up of the layer of charge in the furnace and minimizing of heat losses. The losses of heat through furnace armor will be eliminated due to appropriate layer of insulation, and the stream of heat carried away with combustion gases will be controlled by e.g. the degree of filling the furnace tube with the charge material.

## 2. Experimental

The technology of production of light sintered aggregates includes four essential operations: composing of the charge of raw materials, granulation of the charge, drying of the granulate, and burning and sintering of the material grains.

It has been assumed that the charge mixtures will be composed of any ashes available, including both those rich in carbon taken directly from the filters and those taken from storage yards. Loamy mineral materials such as clay or bentonite, but also some spent materials such as fermentation sludge, paint shop wastes, refinery wastes, carbonaceous shales, coal slime, fine-grained slag, etc. may be used as binding materials in the process of agglomeration of ashes. It has also been assumed that technologic problems arising from excessive and variable contents of combustible substances in the charge, inadmissible in many technologic solutions, will easily be eliminated in the sintering installation owing to its unique design and organization of media flow. It follows from the above that troublesome stages of the proposed technologic solution will lay in drying the raw granulate and in burning and sintering of the ceramic aggregate. These operations will be carried out in specially designed installations. It follows also that building of the first aggregate-producing plant with sintering of ashes in autothermic rotary furnace must be preceded by large laboratory scale studies necessary to gather experimental data necessary for development of premises for the design of productive installations. The mixtures for granulation and agglomeration of the charge were composed on the basis of former studies [6]. The following three mixtures were composed with the use of bentonite "Specjal 45" as binding material:

– 96,5% by weight of power plant ashes, containing 5% by wt. of carbon and 3,5% by wt. of bentonite, calculated as dry substance, in amount of 4 Mg,
– 96,5% by wt. of power plant ashes, containing 10% by wt. of carbon and 3,5% by wt. of bentonite, calculated as dry mass, in amount of 10 Mg,
– 95% by wt. of dry ash, obtained in combustion of sludge, and 5% by wt. of dry bentonite, in amount of 3 Mg.

The latter mixture, which does not contain combustible matter, was sintered with addition of 10% by wt. of carbon. The charge was prepared in 100 kg portions in a drum mixer and collected in boxes at the side of granulator.

The process of agglomeration was carried out on a granulation plate of diameter 1500 mm fitted with a device for controlling the angle of inclination and for smooth control of the rotational speed (see photo in Fig. 1). The powders were humidified with the use of three sprinkling nozzles. Depending on the kind of ashes used and particular charge prepared the powders were granulated from initial humidity within 8–20% up to final one within 22–25%. The speed of granulation was higher for more humid mixtures. Maximum productivity of the granulation plate was 500 kg/h of dry granulate.

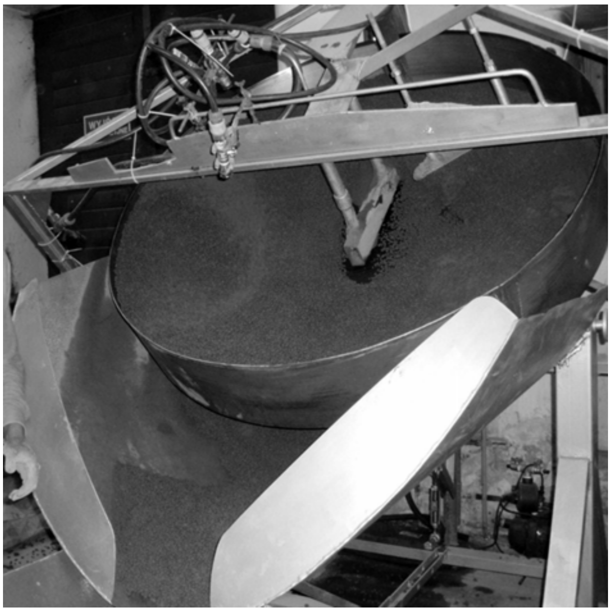

Fig. 1. View of granulate plate

Rys. 1. Widok talerza granulacyjnego

The belt drier proposed for drying the granulated product is 6000 mm in length, about 1000 mm in width, and roughly 1500 mm in height. The drier consists of 44 module boxes with sieve bottoms fixed to two chains supplied with rolling wheels. The chains are driven by chain wheels fixed on a drive shaft provided with bearings. The system is driven with a 3 kW gear-motor suspended on a shaft. The drier has been divided into 5 heating zones 800 mm long bordered with tin pyramids fitted with gas inlet connector pipes. Each zone comprises 3 module boxes filled with the granulated material. The thickness of the layer of granulated material on the belt may be 200 mm. The sealing between the mobile module boxes and tin pyramids is of frictional type with ground surfaces and controlled pressure. The structure of the drier is shown in Fig. 2, and the view is presented in the photograph in Fig. 3.

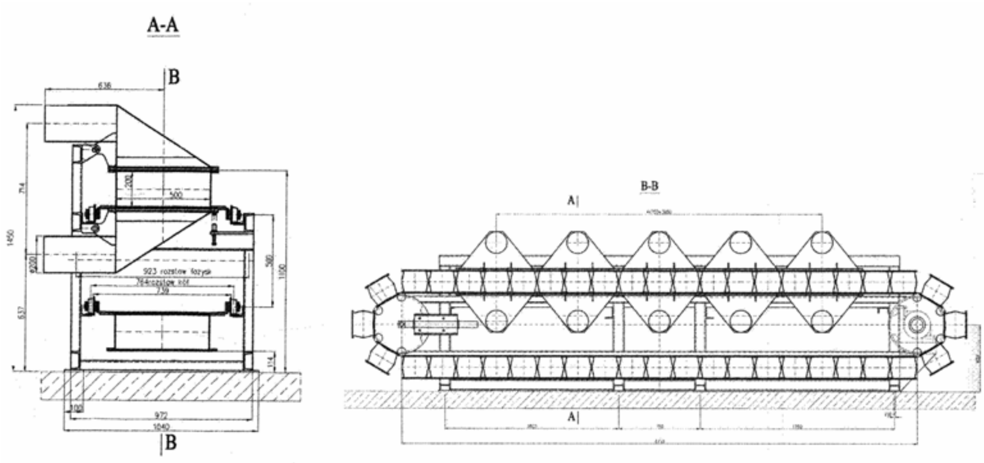


Fig. 2. Structure of the drier

Rys. 2. Schemat budowy suszarni

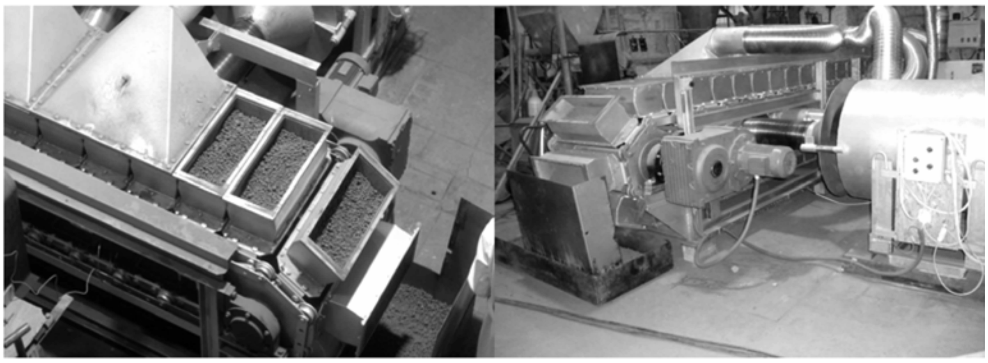

Fig. 3. Photographs of the drier

Rys. 3. Zdjęcia suszarni

In the studies presented here both the drier of granulated material and the rotary furnace worked as separate units, as the available premises and assets gave no possibility to combine the two processes and use the hot combustion gases from the rotary furnace for drying the granulated material. For this reason it was necessary to provide the drier with a source of hot combustion gases. Use was made of a small steel boiler with refractory lining fitted with a two-stage Riello BS2D gas burner of power controlled in the range 35––91 kW, fed in our case with a set of 3 liquid propane cylinders. The same burner was then used for preliminary heating of the rotary furnace. Besides, the drier was fitted with two blowers adapted to work with hot gases. The drier works in the countercurrent system. In the last hot zone the combustion gases are passed through the layer of granulated material from the bottom upside in order to avoid condensation of water vapor on the bottom of module box, and in the other zones the gases flow downside to eliminate capture of granules. Each blower serves two drying zones. A part of water vapor is condensed out of the gases leaving the second zone and the gas is then passed to the chimney. The first drying zone was disconnected because of too small capacity of the exhaust blower, thus the final drying capacity was markedly reduced.

The running of the drying process depended on the following essential parameters:

– method and rate of moving the belt with containers,
– amount of wet granulated material,
– temperature of combustion gases fed to the last drying zone.

Depending on setting of the system of drive control of the drier the movement of the drier belt might be either continuous, at a definite speed, or in strokes by 3, 2 or 1 box in definite intervals. For operational reasons, i.a. for the ease of loading raw granulated material, we have chosen the stepwise move of the belt. Basing on determination of humidity of the dried material we have accepted as optimum the stroke by one box every 3–4.5 min., depending on initial humidity of the charge. It appeared also that for good final dryness of the charge the thickness of the layer of granulated material should not exceed 150 mm. The frequency of moving the drier belt depends also on temperature of combustion gases entering the last drying zone. So e.g. for granulated ashes containing 10% by weight of carbon the temperature must not exceed 340ºC, otherwise spontaneous ignition of charge grains might occur. In the case of granulated ashes from sludge the inlet temperature of combustion gases was set to 420ºC, and the frequency of shifting the drier belt was reduced to 2 min. To sum up the results of tests with drying of granulated power plant ashes, one may assume that the productivity of the drier is about 160 kg/h of the dry material. The yield may be increased by 20% with all the drying zones engaged.

The drier constructed in the proposed version proved to be a reliable installation easy in maintenance. The simple, friction method of sealing the drier boxes in contact with the casing of drying zones proved fully correct. In the future the efficiency of the drier can be increased by insulation of metal surfaces of the last two drying zones.

Aiming at burning and sintering ceramic aggregates we have designed and constructed a parallel flow rotary furnace 3000 mm in length and 1500 mm in outer diameter. The furnace consists of a boiler steel cylinder of wall thickness 15 mm. The furnace is supplied with two rolling rings, a toothed wheel of furnace drive, and two manifolds for air blow along with gate valves and cams controlling the valve opening. From the inlet side the furnace is closed with an end plate provided with four holes for loading the charge. The plate is screwed down to the body of the furnace. The other end of the furnace, the side of outlet of the ceramic aggregate, is closed with an outlet head supported on the furnace bearer frame. The furnace is driven with a 2.2 kW gear-motor supplied with an open toothed gear. The furnace rotates on four support rollers, two per rolling ring, mounted on the bearer frame. The position of the furnace is secured by two resistance rolls acting on the rear rolling ring, two blowers mounted on the furnace body blow the air into the furnace through two manifolds, each supplied with a system of twelve nozzles. The structure of the furnace is shown in Fig. 4.

From the inside the furnace is lined with a two-layer lining: a layer of insulation concrete of thickness 100 mm and a working layer of refractory andalusite concrete of thickness 150 mm. Hence the inside, working diameter of the furnace is 1000 mm. Besides, the furnace is provided with two annular baffles changing its inner cross-section, in 1/3 of its length and at the end, to the diameter of 550 mm for damming-up the charge. The first baffle divides the furnace into a part designed for ignition of the granulated material and start of burning, and the other part in which complete combustion of carbon and sintering of the charge take place after addition of air from the second manifold. The view of the furnace is shown in the photograph in Fig. 5.

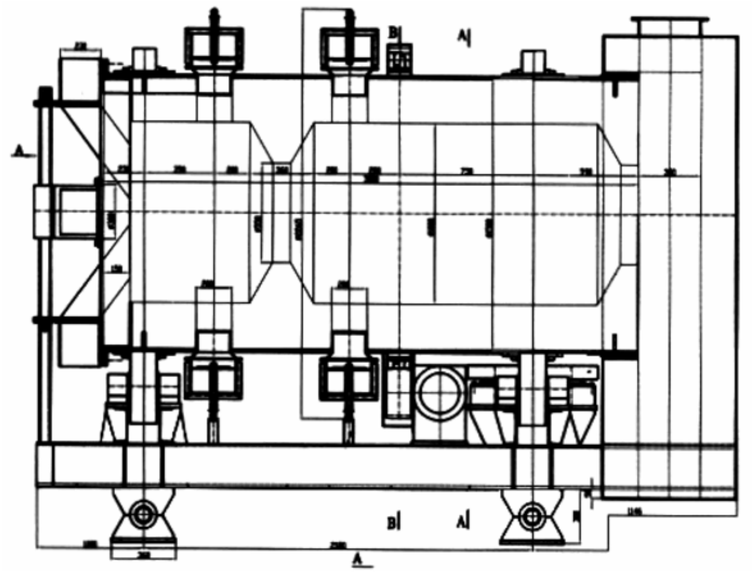

Fig. 4. Structure of the furnace

Rys. 4. Schemat budowy pieca obrotowego

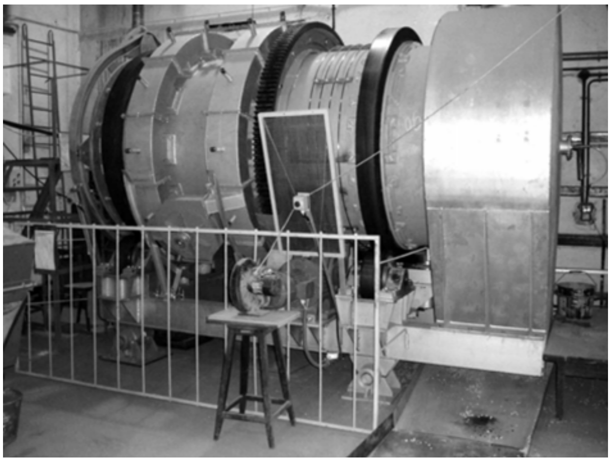

Fig. 5. Photograph of the furnace

Rys. 5. Zdjęcie pieca obrotowego

Each burning eventwas started by heating the furnace to a temperature of roughly 600°C with the use of a gas burner. The process of preheating lasted for 6–7 hours, then the burner was removed and dry granulated material was loaded to the furnace. The air blowing through a layer of charge in the first part of the furnace was also started by means of the blower. After the first furnace chamber was filled the granulated material started to pour to the second, longer part of the furnace, to which air blowing by the blower on the second manifold was started after about a half an hour. The sintered granulated material was poured out from the outlet chamber, open at the bottom, and the combustion gases were carried away to the chimney after being passed through a cyclone separator. The run of the process of burning and sintering was observed through an inspection window in the wall of the rear chamber of the furnace.

The process of burning and sintering was controlled by:

– the speed of rotation of the furnace,
– the rate of feeding crude granulated material into the furnace and mass of charge in a single batch,
– amount of air blown to individual manifolds, from which the outlet was possible only through the nozzles covered with a layer of charge,
– change of drought of the chimney ventilator,
– extent of filling the furnace with the granulate.

In the control of work of the furnace use was also made of:

– a controller with an invertor for smooth regulation of speed of rotation of the furnace,
– graduated valves on inlet manifolds of the blowers feeding air to the furnace and combustion gases to the chimney,
– four thermocouples for measurement of gas temperature at the border between furnace lining and layer of moving charge,
– thermocouples measuring the temperature of combustion gases at the furnace axis in front of the outlet chamber and temperature of gases in front of the exhaust blower,
– possibility of analysis of combustion gases in the end part of the furnace, in front of the outlet chamber.

Unfortunately, there was no possibility to measure the temperature of granulated material inside the furnace. Because of the specificity of the process such a measurement would only be possible with the use of optical measuring instruments. However, having some experience in studies of such processes it is possible to evaluate the conditions existing in the furnace by observation of the color of granules and the ease of their movement which shows the beginning of sintering. The sintering of power plant ashes should be carried out in a semi-reducing atmosphere [7]. Observation of little blue flames appearing momentarily due to carbon monoxide burning out on the surface of rolling granules is a proof of properly settled gas atmosphere inside the furnace.

The operation of filling the furnace with granulated material and attaining stable conditions of running the process lasts 5–6 hours and it needs 2.5–3 Mg of the charge to be fed. For this reason an observation of progress of the experiment and continuous intervention is absolutely necessary at this stage of the process.

Five burning and sintering experiments have been carried out until now. The aim of first two experiments was to dry and burn the refractory lining of the furnace. The first process was carried out exclusively with heating the furnace with a gas burner, and in the second process after the preliminary heating with a gas burner the furnace was filled with the granulate and then charcoal was added to the charge in order to obtain a high temperature roughly 1200ºC necessary for burning of the lining.

The aim of the third experimental process was to obtain a ceramic aggregate from power plant ashes. Initially, the furnace was fed with a granulate containing 5% by weight of carbon, then a granulate containing 10% of carbon was used because of burning out of the charge layer. Despite that, the first ignition zone extinguished quickly after the gas burner was removed, and in the second zone, the zone of burning out and sintering, the temperature of the charge decreased steadily without attaining the sintering temperature. We assumed that the situation arouse from insufficiently low degree of filling the furnace with the granulate (below 50%). For this reason, before starting the next process, the rear part of the furnace was lifted and, in addition, the outlet opening was supplied with a discharge orifice. As an effect, the furnace had a negative inclination by 1.3° (2.29%) and the outlet orifice had a diameter of 200 mm. As a result, more than 75% filling of the furnace was obtained in the fourth sintering experiment. The dry granulate fed to the furnace contained 10% carbon in the ashes, and the process of burning and sintering was carried out for 10 hours. The yield obtained was 500 kg/h. The temperature curves recorded in the experiment are shown in Fig. 6.

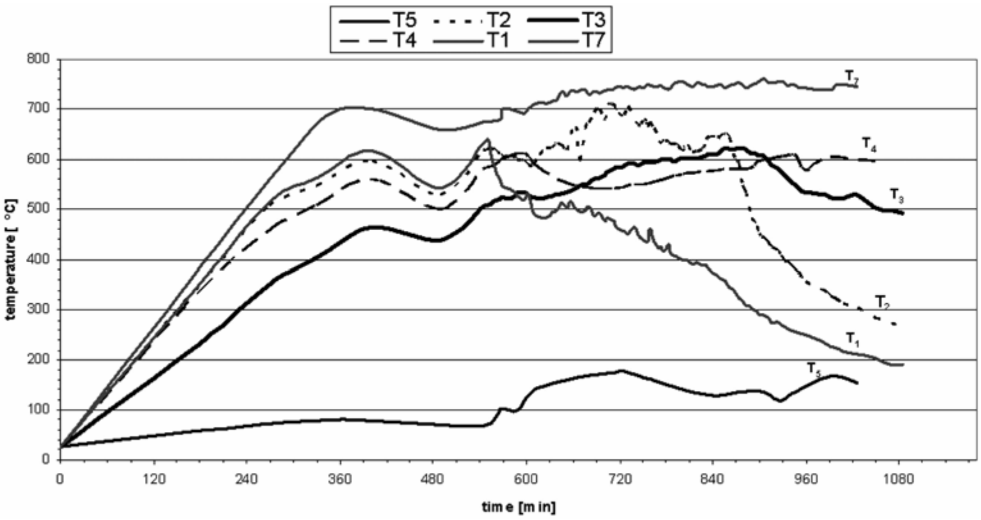


Fig. 6. Temperature curves of sintering of the light ceramic aggregate: $T_1$, $T_2$, $T_3$, $T_4$ – temperatures of refractory inner wall of the furnace chamber, $T_5$ – temperature of exhaust fumes, $T_7$ – temperature of the tail gas

Rys. 6. Krzywe spiekania lekkiego kruszywa ceramicznego: $T_1$,$T_2$,$T_3$,$T_4$ – temperatury ściany pieca, $T_5$ – temperatury gazów kominowych, $T_7$ – temperatury gazów spalinowych

After about 6 Mg of sintered granulate was obtained, charge containing 5% carbon in the ashes started to be fed into the furnace. In spite of the high damming of material in the furnace the temperature in the ignition zone started to drop quickly leading to rapid extinction of the layer of charge. It should be remembered that cold material was fed to the furnace, whereas in the assumed technologic process the raw material will be fed directly from the drier at a temperature about 300°C. Such conditions will enable burning and sintering ashes poor in carbon.

## 3. Summary

A streamwise rotary furnace in the proposed design version, after some corrections increasing the degree of filling its body with raw granulated material, enabled obtaining a ceramic aggregate from power plant ashes, rich in carbon, in yields of the order of 500 kg/h. In a commercial scale process involving the use of hot crude granulate as the charge it will be possible to process also power plant ashes of low content of carbon and to increase the overall productivity of the process.

First experimental processes of burning and sintering enabled detection of some design errors interfering with proper functioning of cams that control opening and shutting the valves of inlet of crude granulate to the furnace and of valves closing the inlet of air to individual nozzles of radial inlet of air.

After several further experimental processes it will be possible to determine the dimensions of target installations of the drier and furnace intended for a plant of assumed productive capacity.

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