A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 56 2011 Issue 4
DOI: 10.2478/v10172-011-0133-6

J. SOKOŁOWSKI*, K. ŁUCZAJ**, P. URBAŃSKA*

FABRICATION OF LIGHT CERAMIC AGGREGATE BY AUTHOTHERMAL SINTERING OF POWER PLANT ASHES IN THE ROTARY FURNACE

AUTOTERMICZNE SPIEKANIE POPIOŁÓW ELEKTROWNIANYCH W PIECU OBROTOWYM

The inexpensive and reliable technology of the production of ceramic aggregate from coal ash, coal dust and mineral cement (clay, bentonite) optionally organic cement has been developed. The tecchnology is based on the method of sintering in high temperature. The conception of workings and the way of performance of the dryer of the humid aggregate and the rotary furnace in which the process will be carried on with no addition of the external fuel have been also developed. The implementation studies, partly granted by European Union, have been continued. The studies consisted ass follows: the laboratory research into the drying of coal ash granules, the compilation of technical parameters for the performance of a new shaft dryer by building semi-commercial model and defining parameters of working, the studyon the sintering in modernized semi-commercial rotary furnace. Currently process desing for final technical installation are being developed.
Keywords: sintered aggregate, rotary furnace, power plant ashes

Opracowano tanią i niezawodną technologię wytwarzania kruszywa ceramicznego z pyłów i popiołów po spaleniu węgla oraz lepiszcza organicznego, metodą spiekania w wysokiej temperaturze, a także koncepcję działania i sposób wykonania suszarni wilgotnego granulatu oraz pieca obrotowego, w którym proces taki będzie prowadzony bez dodatku paliwa zewnetrznego. Obecnie trwają prace wdrożeniowe, współfinansowane przez Unię Europejską, w ramach których przeprowadzono laboratoryjne badania suszenia surowych granulatów popiołowych, określono założenia techniczne do budowy i pracy nowej suszarni szybowej do suszenia takich granulatów, zbudowano jej półtechniczny model i określono parametry pracy, a następnie wykonano badania procesu spiekania na zmodernizowanym, półtechnicznym piecu obrotowym. Obecnie opracowywane są założenia procesowe dla docelowej instalacji technicznej.

1. Introduction

A huge burden on the environment is furnace waste from industrial electricity agglomerated in landfills which amount is estimate at more than 500 billion of tones. Cost of recycling would be more beneficial. Among numerous ways of utilization of furnace ash is production of light sintered aggregate mainly for building, road construction and draining foundations. This is the reason why the aim of our research is to create technology of production of light ceramic aggregate competitive in price towards natural aggregate.

As a result of 8-year-research carried out both on laboratory and semi-commercial scale an inexpensive and reliable technology of production of aggregate has been created. The production is based on sintering ceramic aggregate from furnace ash, dust and mineral binder (clay, bentonite) in high temperature. The concept of operation and performance of the dryer of moist granules as well as the rotary furnace of unique construction [1], in which the process will be carried on without the outside fuel, has also been created.

In the further period the research of realization of the production of light fly ash aggregate was granted by European Regional Development Fund. The aggregate is named LSA after the name of the company which carries out the implementation. The project also included additional research and development work of particularly important processes of the technology of drying and sintering coal ash granules.

* WARSAW UNIVERSITY OF TECHNOLOGY, FACULTY OF CHEMISTRY, DEPARTMENT OF INORGANIC TECHNOLOGY AND CERAMICS, 00-664 WARSAW, 3 NOAKOWSKIEGO STR., POLAND
** LSA SP. Z O. O.

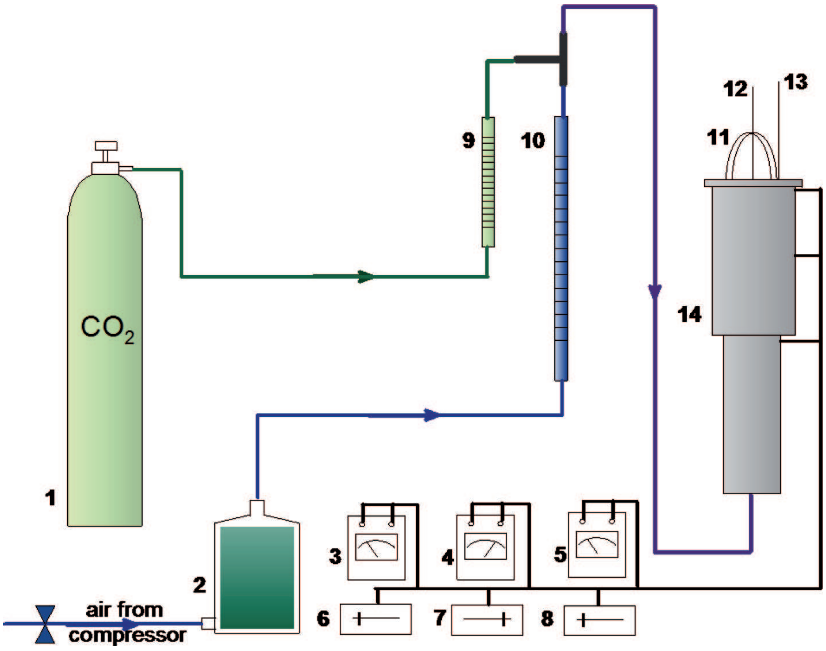

Fig. 1. The scheme of the installation for drying coal ash granules: 1 – gas cylinder, 2 – bottle with silica gel, 3,4,5 – ammeters, 6,7,8 – autotransformers, 9,10 – rotameters, 11 – basket, 12,13 – thermocouples, 14 – oven

2. Range of research

The research of the drying process of coal ash granules were carried on laboratory and semi-commercial scale.

The aim of the laboratory research was to determine which of the possible media air or combustion gases is beneficial, what rate of flow of drying gases can be applied in the process and what temperature of drying gases cannot be exceeded to prevent autoignition of granules assuming that the content of unburnt coal in fly ash is within 8.5-12% by wt.

The process was performed using the apparatus which scheme is showed in Fig. 1. Terms of the process were as follows:

– Drying granules were made of ash, the contents of unburned coal in ash were 8.5; 10; 12% by wt;
– Drying media were hot air and hot combustion gases with 20% content of carbon dioxide in air;
– Rates of flows were 1500, 2000 and 2500 dm^3/h;
– Research was carried out on a part of the layer 150 mm high.

The representative sample of moist coal ash granules of known weight was placed in the basket. Drying media flew through the oven to heat up, then through the basket and flew out in the air. The sample was weighed at specific time intervals. The moisture content was calculated based on the weight loss.

3. Results of the laboratory drying process

Exemplary drying curves of granules with 10% content of coal in the flow of air and composition of air and carbon dioxide are showed in Fig. 2 and Fig. 3.

Figure 4 shows curves of increase of temperature in time which were used to determine the autoignition temperature of granules with 8.5% content of coal in the air flow. Figure 5 shows adequate curves for granules with 10% content of coal in the flow of air and carbon dioxide composition.

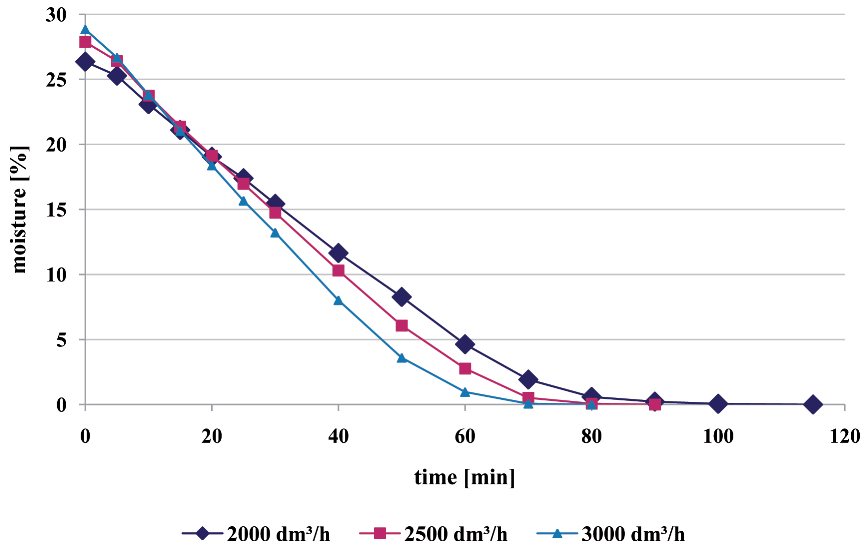

Fig. 2. Drying curves of granules with 10% content of coal in the flow of the air

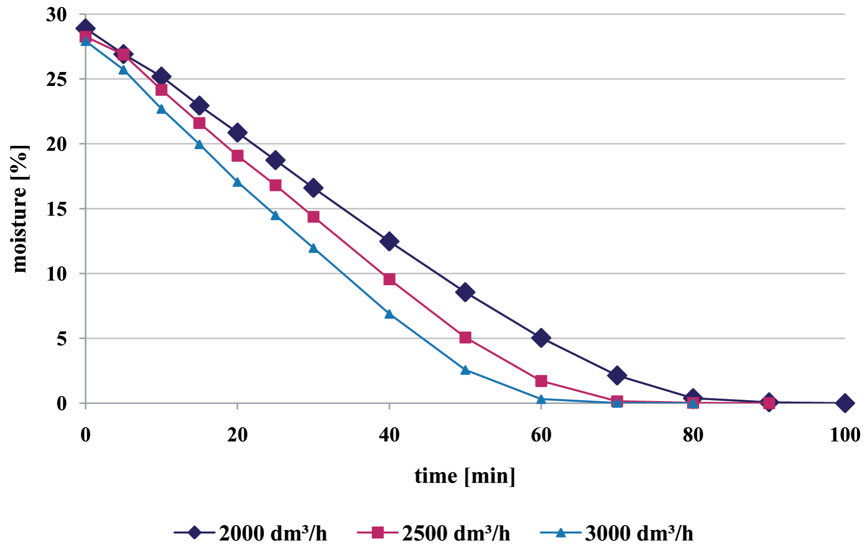

Fig. 3. Drying curves of granules with 10% content of coal in the flow of the composition of air and carbon dioxide

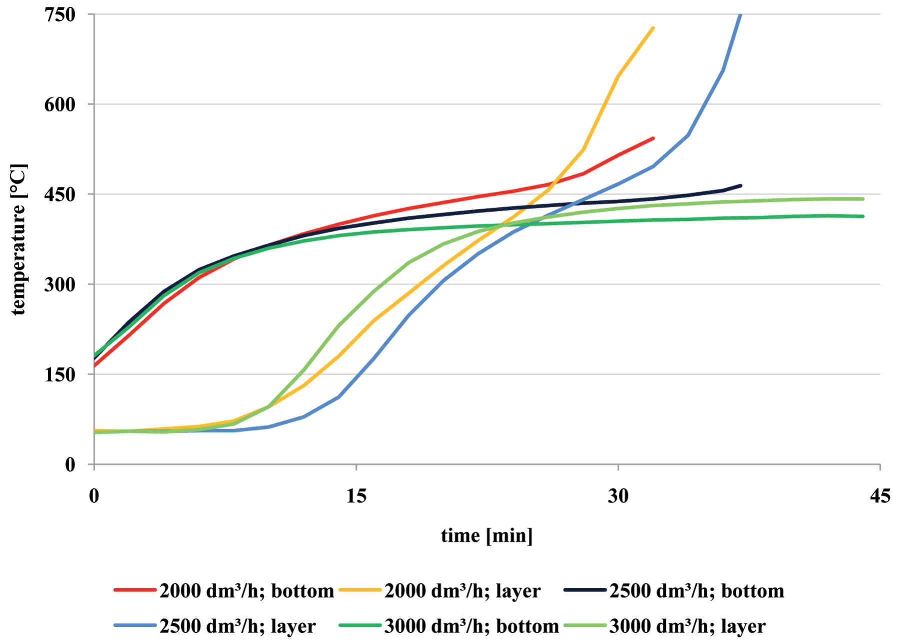

Fig. 4. Determination of the autoignition temperature of granules with 8.5% content of coal in the air flow

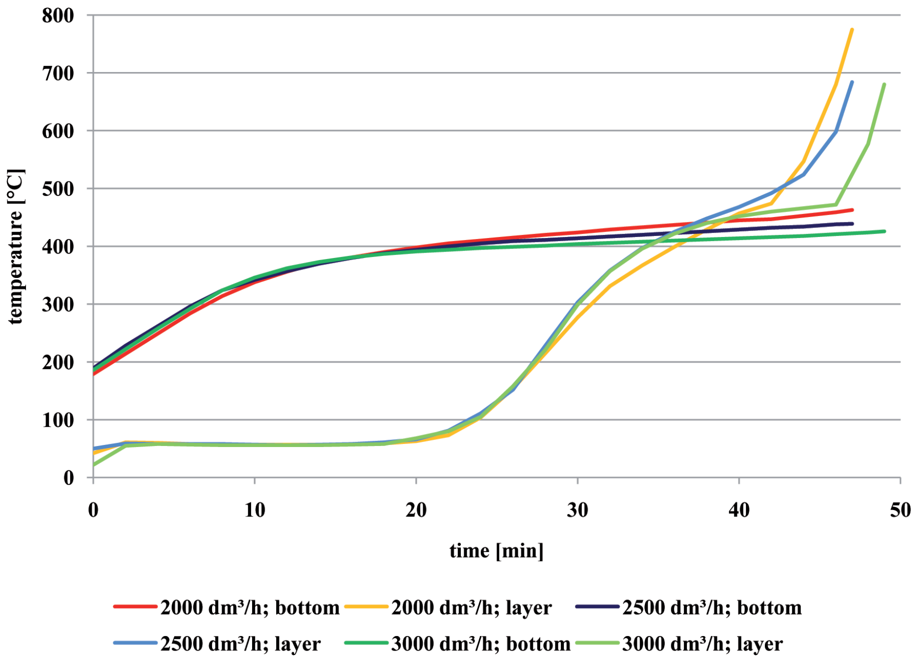

Fig. 5. Determination of the autoignition temperature of granules with 10% content of coal in the air and carbon dioxide flow

4. Conclusions of the laboratory research

1. The most beneficial effect of the drying process was achieved at flow rates of 2500 and 3000 dm^3 per hour. Low flows unnecessarily lengthen the time of drying while higher flows caused cracking of granules because of too rapid remove of moisture.
2. Drying in combustion gases runs faster than in the air.
3. No influence on the process of drying was observed within studied contents of unburnt coal.
4. Increase of the flow of drying gases generates more intensive glowing of granules and displacement of the layer of glowing granules upwards from the bottom of the basket.
5. The content of carbon dioxide in drying gases reduces the intensity of glowing.
6. Granules autoignite when the temperature of drying gases is above 420°C.
7. There is a considerable risk of autoignition when the temperature of drying gases at the intake is about 340-350°C.
8. The content of coal in studied ash (8.5-12%) has no essential influence on change of temperature of autoignition whereas increases the intensity of glowing proportionally with the content of coal. At flows of 2000 and 2500 dm^3 per hour lower content of coal increases the autoignition temperature.

5. Research of drying process in semi-commercial scale

The aim of semi-commercial studies was to develop the construction of new dryer for drying fly ash granules which have low mechanical strength. The efficiency of the dryer is similar to previous belt dryer. The new dryer, showed in Fig. 6, has smaller overall dimensions, is easier to isolate and lend itself to be placed directly above the charging hole of the rotary furnace. The next aim was to built the dryer and to dry granules of the content 8, 10 and 12% of coal in fly ash. It allowed to determine the parameters of the construction of the dryer and to define brief design for technical dryer.

As a fundamental solution unlike current shaft dryer with mobile shelves was proposed. It has a modular construction and consists of locks to feed/carry off granules and shelves which are the drying zone. Patent claim [2] includes its construction and functioning.

The dryer was feed with hot combustion gases from liquid propane-fired or coke-burning heater. The temperature of combustion gases was lower than autoignition temperature determined during laboratory studies. Humid combustion gases containing saturated water vapour were carried off the dryer by centrifugal fan.

Fig. 6. View of the new dryer

During the studies it were determined essential parameters to dry the charge: volume velocity of hot combustion gases, efficiency and compression of fan and efficiency of the dryer. These parameters will allow to design industrial dryer. The studies also showed that it is possible to reduce the number of shelves in the drying zone what will significantly decrease the capital cost of the dryer.

6. Sintering process

The aim of the research was to determine: the inside structure of the rotary furnace, favourable positions, number of positions to deliver air to the furnace, technique of delivery of cold and hot air to the furnace, sintering process when the furnace is supplied with blistering air, hot granules and energy, as well as material balance of the furnace.

To realize the plan the rotary furnace of 3 meters length of drum and 1.5 meters of inside diameter was used. The furnace with two-layered insulating concrete lining of 100 millimeters thickness and andalusite concrete of 150 millimeters thickness was build of ST-4 steel. The furnace was fed with cold granules and cold air delivered by blowers placed on the drum and rotating together with the drum. The air was delivered radially by two rows of nozzles, twelve nozzles in each row. Inside the furnace it were two division walls piling up granular material in the shaft.

Analyzing the results of the research carried out using this furnace it was admitted that the construction of the furnace cannot be regarded as final.

The rotary furnace in its first version had two division walls limiting its inside diameter by 33%. The walls were placed in 1/3 length of the furnace – near the charging hole and at the end of the furnace. The walls piled up sintered granules so that it was possible to increase over 50% of filling of the furnace with the material. First baffle additionally lifted the level of granules in the first compartment and hold them longer within the influence of the first row of nozzles until ignition.

The observation of the influence of the first division wall on the burning and sintering process of power plant ashes indicated essential interferences in the movement of material lengthwise which were caused by that division wall itself. Interferences were not compensated by the easiness of ignition of granules in the first compartment above the first row of air nozzles. The division wall caused major grinding of the ash granules generating large amount of dust. In turn the dust caused excessive agglomeration of granules in the farther part of the furnace.

That is why one of the task was to demolish the first division wall and to replace it with three blades made of acid resistant steel placed inside the furnace. Their function was to move the granules to the end of the furnace where the first row of nozzles was situated.

It seemed to be interesting to observe how the elongation of the zone of the intensive burning and sintering would influence the process and maybe increase the efficiency of the furnace. Because of that the third row of twelve nozzles of 120 millimeters diameter each was installed. The volume of delivered air was regulated by the flap covering a part of the suction port of each fan. Throttling of the centrifugal fan during suction caused decrease of the compression. It made impossible to determine the volume of delivered air. To obtain reliable data about the volume of delivered air to the furnace it was required to generate throttling of the air flows. Fans rotating together with the furnace were excluded. It required to seal the space between stationary fans and rotating surface of the drum. Applied seal was a compression gland which feed force was regulated.

In the rotary furnace in The Department of Inorganic Technology and Ceramics in Warsaw University of Technology, mainly because of the blowers delivering the air, it was not plan to supply the nozzles with heated air flow. Taking under consideration complex use of heat in the industrial instillation, it is obvious that the furnace will be fed with hot air especially in the zone of charging hole of crude granules. While collecting data to design technical furnace it would be beneficially to carry on the research when at least one row of nozzles is supplied with hot air. That is why it was decided to make the air heater and include it into the series of machines delivering air to the first row of nozzles. It became quite easy when the set of blowers was stationary. The heater was situated above the furnace and heated the air flow to the temperature 280-320°C.

Mechanical start-up of the furnace after reconstruction with gases thrust was held on 28th January 2011.

7. Conditions of burning process

The burning process started with heating the furnace with gas burner. During the heating, the shaft of the furnace was filled with burned granules to obtain relatively high thermal inertia of setup. At that time there was only one chimney fan switched on which carried off combustion gases from the furnace. After heating the lining of the furnace and inert granules up to 400-450°C began slow dosage of granules. The intensity of flux of the charge was gradually increased. Simultaneously the centrifugal fans were switched on. They dosed small amount of air through the nozzles in the first or in the first and the second row. When the level of the granules in the shaft of the furnace was close to the nozzle mouth of the burner, placed in the axis of the shaft, the burner was switched off and removed. From that moment the proper burning process began. It was supported only by the heat of burning coal in the granulated ash.

During the burning and sintering process it was possible to control:

- rotational speed of the furnace,
- intensity of the flux of delivered crude granules,
- temperature of the granules, from ambient temperature to about 200°C,
- air flows delivered to particular rows of nozzles and the temperature of air delivered on the first row, from ambient temperature to about 300°C,
- chimney draught,
- inclination of the shaft of the furnace. During all the burning processes the furnace was placed horizontally in relation to the foundation of the room.

Moreover it was possible to measure:

- temperature at the contact lining – granules, in four points of the shaft of the furnace,
- temperature of the combustion gases at the end of the furnace,
- temperature of the combustion gases in front of chimney fan,
- concentration of particular components in the combustion gases and excess air number λ as a result parameter.

When the burning process is conducted correctly the content of carbon monoxide should be as low as possible and the excess air number λ should be lower than 1,6. The analysis of the combustion gases were made since the second burning process.

The sintered granules were made of three kinds of ash which had the different content of the coal – 8.57%, 10.54% and 12.02% by wt.

In the Figs. 7-9 are showed exemplary curves of the fourth burning process. During the process 1200 kg of the granules with the content of coal of 8.5% by wt. and 1100 kg of the granules with the content of coal of 12% by wt. were treated in the process. Samples of the aggregate were drawn after every process for further research.

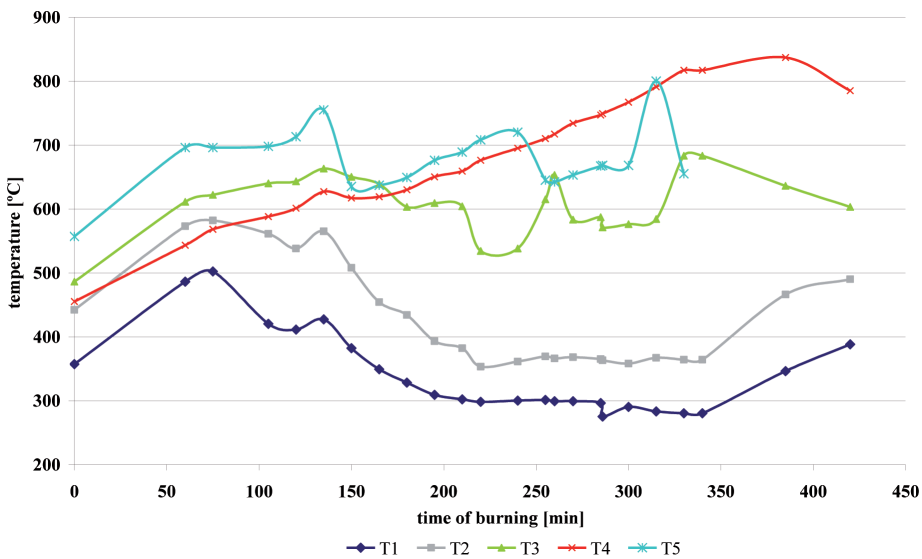

Fig. 7. The change of temperature in respect to time of burning

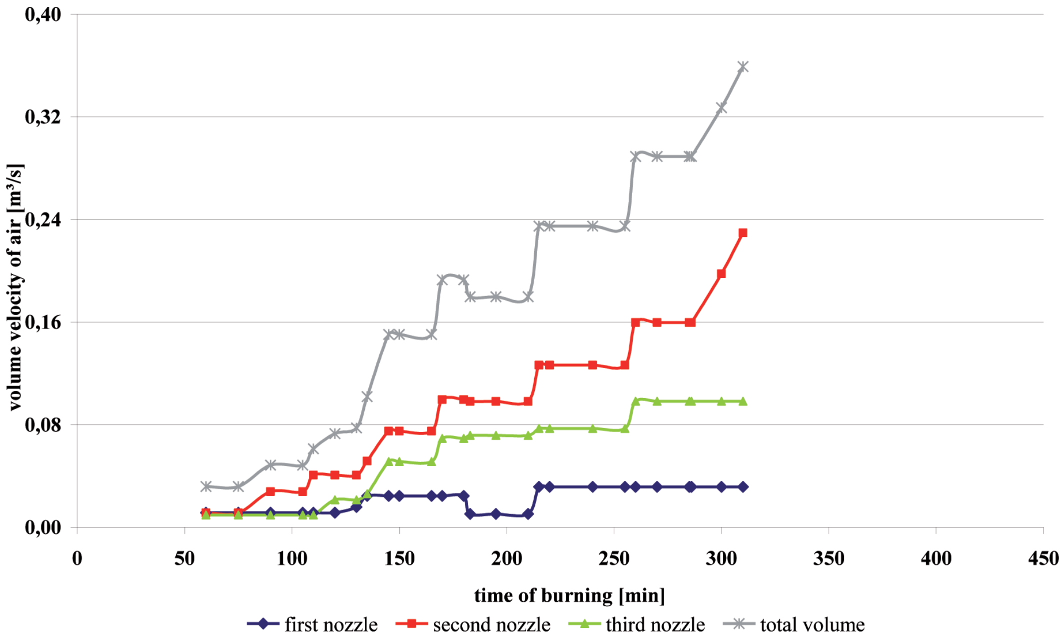

Fig. 8. Air flows delivered to the furnace

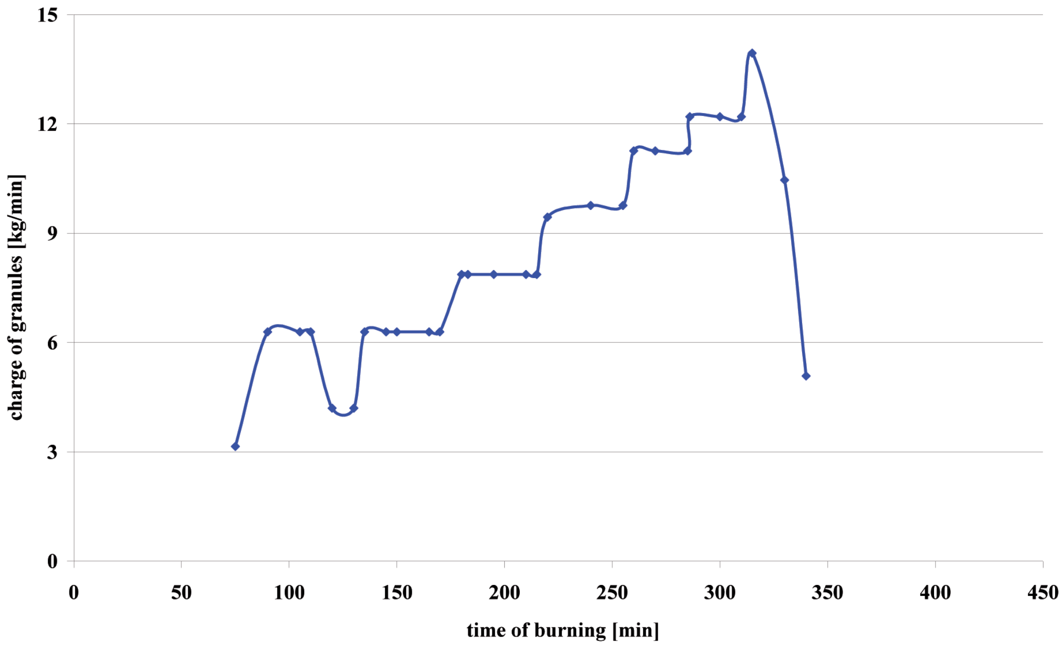

Fig. 9. Flux of granules delivered to the furnace

8. Conclusions of the research of burning process

On the basis of analysis it is possible to make general observations which should be considered for industrial instillation.

1. The fundamental solution is to feed the furnace with air delivered from the stationary section of nozzles. It is proposed to deliver the air through the front gate of the shaft. Then the main seal would be one for all the rows of nozzles delivering air between the stationary gate and rotating collar welded on the drum.
2. Stationary gate will make easier feeding of hot and crude granules from dryer directly into the furnace, above the lengthwise axis, favouring to obtain high level of filling of the furnace.
3. Because of the carbon residue in the aggregate made of ash of 12% content of coal (fourth burning) it is proposed to substantially elongate the zone of sinter-

ing in industrial furnace or to elongate less and to add one more row of nozzles.

4. The construction of back diaphragm of the shaft should allow to periodically open it during the burning and remove the sinter of large diameter.
5. Blades receding glowing granules are indispensable part of the inside construction of the furnace because they allow for fast ignition of granules.
6. Analyzing the conditions in which the burning processes were carried out and the efficiency of sintering, it is possible to estimate the overall dimensions of industrial rotary furnace. Its outside diameters should be 2,6-3,2 meters long, lining 250-350 millimeters thick and the length of the furnace should be 7-11 meters.

Because of the confidentiality of the technology particular data were solely recounted in the reports concerning successive steps of the project. Nevertheless some aspects of this technology has been partially presented in the literature [3-6] and conferences.

REFERENCES

[1] Pat. pol. no 196842 and Pat. UE no 1515925 (2008).
[2] Patent application P-393175 (2010).
[3] J. Sokołowski, Chemical Industry 84/2, 110-113 (2005) (in Polish).
[4] J. Sokołowski, Chemical Industry 84/3, 192-196 (2005) (in Polish).
[5] J. Sokołowski, K. Łuczaj, A. Szudarska, Pol. J. Chem. Tech, 165-174 (2008).
[6] J. Sokołowski, K. Łuczaj, Chemist 6 (supplement), 157-160 (2009) (in Polish).

Received: 20 March 2011.