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Application of the Triboelectric Method for the Ongoing Assessment of the Quality of Reclaim in Mechanical Reclaimers

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Abstract

The method of the ongoing assessment of the reclaim quality originating from the mechanical reclamation is described in this paper. In the process, the triboelectric system of measuring amounts of dust in the dedusting part of a reclamation device was applied. Based on the online measurements of the amounts of dust generated in the spent sand-reclamation process and the post-process determinations of the ignition losses and granular structures of the removed dust, the proper work parameters of the experimental reclaimer were selected. The allowable value of the ignition losses as well as the main fraction of the reclaimed matrix being similar to fresh sand was assumed as the main criteria of the positive assessment of the process. Within the presented investigations, a periodically operating device for rotor-mechanical reclamation was developed. The possibility of changing the intensity and time of the reclamation treatment as well as the triboelectric system of the dust-amount measuring were applied in this device. Tests were performed for the spent moulding sand with phenol-resol resin Carbophen 5692 hardened by CO_2. This sand represents the moulding sand group with a less harmful influence on the surroundings for which the recovery of the quartz matrix utilising the reclamation requires stricter control of the parameters of the reclamation process and reclaim quality.

Keywords: Reclaim, Reclamation process, Regeneration, Foundry engineering, Phenol resin, Moulding sand

1. Introduction

The notion of the recycling of moulding sand matrices occurs during the process of making castings in sand moulds using disposable sands whose binders are chemically hardened by various resins. Matrix recycling is an important problem in the rational economy of moulding sands, which are the main materials of moulding and core sands with chemical binders.

Considered in this aspect is the circulation of the mass matrix that occurs after the technological process of making a casting that is related to its recovery from spent sands (its schematic presentation is shown in Figure 1). Symbols I-IV mark the individual stages of matrix recycling (crucial for technological processes in foundry plants) that are related to the casting quality and the proper economy of the foundry materials.

The reclamation of the spent matrix (i.e., its release from the spent binders) constitutes the stage that decides on the properties of the reclaim applied – as a total or partial substitute for fresh quartz sand in moulding sands with resin binders. For economic reasons, the mechanical reclamation method is the most often applied in practice. In this method, the spent materials are removed from the grain surfaces due to the rubbing, grinding, and crushing processes occurring in the given device.

The published papers of Boenisch [1], R. Dańko et al. [2-4], Łucarz [5], Leidel, [6], Lewandowski [7], and others [8-13] treat mechanical reclamation processes as certain ways of releasing moulding sand matrices from the coatings of spent bonding materials (which occur regardless of the reclamation method). Up until now, a model allowing for the quantitative description of the effects occurring in the process of releasing matrix grains from bonding material coatings has not been developed. Attempts to determine the destruction mechanisms of binder bonds due to thermal influences were described in Cruz N. et al. [14] and Dańko R. [3]; however, these did not allow for a quantitative description of the reclamation process. Investigations of the process of matrix release from the coatings of spent binding materials are presented in Dańko J. et al. [2], Dungan R. S. et al. [15], Fan Z. et al. [16], Ghormley S. et al. [17] and Holtzer M., Kmita A. [18], as are the assessment methods of the release and purification degrees based on the amounts of gases that are generated in the reclamation process the described methods constitute a supplementation of the applied instrumental methods for assessing the reclaim quality. These allow us to determine the reclamation degrees of spent sands with binders as well as the efficiency of the reclamation devices with an accuracy that is sufficient for practice. Model investigations of the strengths of moulding sands with various bonding materials were carried out by Dańko R. [3, 4]. Although the results of these works are not directly related to the mechanisms of releasing matrix grains from the coatings of spent bonding materials, they constitute an important element for the theoretical discussions on the destruction mechanisms occurring in mechanical and thermal reclamation processes.

During the mechanical reclamation process of spent sands with organic binders, the total purification of the matrices (which occurs in the thermal reclamation of these sands) is not achieved. This limits the reclaim application to a certain degree – mainly for making new moulding or core sands with the same binder as was used with spent sand. However, the relatively low costs of this method and the possibility of its application to practically every kind of spent sand are the reasons that the mechanical reclamation of spent moulding and core sands is the most often used.

On account of the extended variety of reclaimed spent sands, a device in which the quality of a recovered matrix would be systematically monitored over consecutive work cycles has not been developed up to the present. A possibility of applying an unconventional system in relation to spent sands with organic binders was presented by R. Dańko [3, 4]. He developed a research set-up that measured online amounts of dust generated during a given reclamation cycle with determined parameters of a reclamation treatment (the intensity of influencing the matrix, dedusting the blowing through rate) and connecting these values with the forecasted ignition losses of the reclaimed matrix. The suitability of the method assessing the reclamation process with the application of the triboelectric system of measuring the amount of dust was positively verified for spent sand with a Kaltharz U404 resin. Moulding sands with furan resins are presently being supplanted by moulding sands with phenol-resol resins in several foundry plants, as they are less harmful to the environment [18]. A quartz matrix recovery by the reclamation is more difficult in this case and requires particular care in controlling the reclamation treatment parameters and reclaim quality. To this aim, investigations leading to the verification of this method for spent sands with a phenol-resol resin (Carbophen 5692) are presented in this paper.

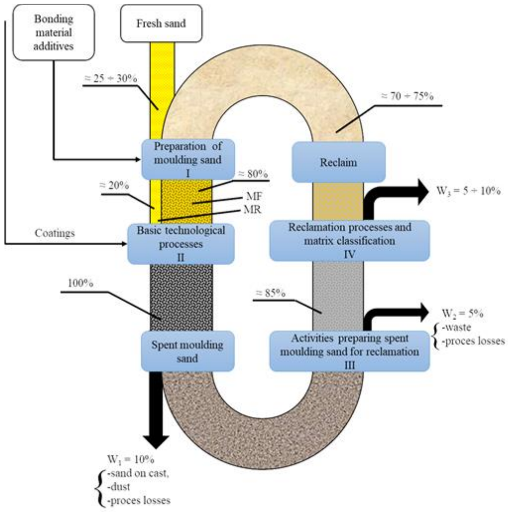

Fig. 1. Diagram of recycling process of moulding sand matrix with resins: I – preparation of moulding and core sand matrices; II – basic process steps: preparation of moulds and cores, pouring, solidification, and cooling of castings, shaking out castings and moulding sand; III – crushing and preparing moulding sand consumed in matrix-reclamation process; IV – matrix-reclamation process, dust extraction, and separation of technologically useful grains [4]

2. Preliminary investigations

Spent sand from domestic foundry plants was subjected to preliminary tests. The preparation of the sand contained the separation of metal contaminants, the crushing of the lumps, and sieving through a 3-mm sieve. The fresh moulding sand composition assumed a 2.9% fraction of the Carbophen 5692 resin in relation to the sand matrix amount, while the ignition loss in the homogeneous sample of the spent sand prepared for the tests was 2.73%.

After its preparation, the spent sand with the Carbophen 5692 resin was subjected to treatment in the AT-2 testing device for the grinding-crushing operation (Fig. 2) – a dimensionally reduced model of the centrifugal rotor reclaimer. The variability range of the rotor rotational speed, which determines the intensity of the grinding-crushing influence and chooses the reclamation treatment times of the sample (2 kg), is presented in Figure 3.

The preliminary investigations were aimed at finding whether a linear dependence of the ignition losses on the dust contents occurs for the whole range of the applied parameters (shown in Fig. 3) for the spent sand with the Carbophen 5692 resin that was subjected to the reclamation treatment.

A detailed programme of the investigations contained the reclamation treatment of the prepared spent sand samples as well as the determination of the following:

– ignition losses of matrix after reclamation treatment process;
– dust content in reclaim;

– ignition losses of post-reclamation dust;
– grain-size analysis of post-reclamation dust utilising laser diffraction;
– morphology of matrix surface immediately after reclamation treatment and pneumatic classification.

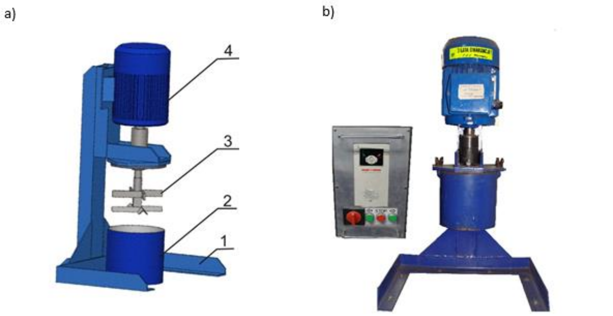

Fig. 2. (a) General scheme of AT-2 rotor testing device for grinding-crushing operation (1 – base; 2 – container of reclaimed sand; 3 – rotor of impact-grinding set; 4 – motor); (b) General view of device

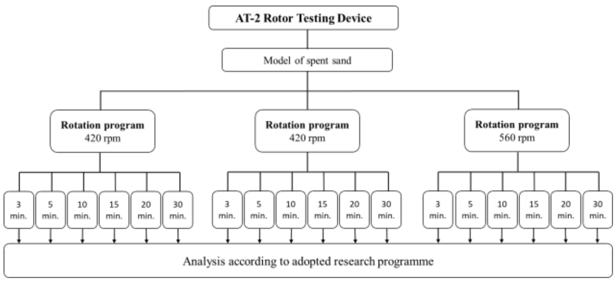

Fig. 3. Variability range of reclamation treatment parameters of spent sand with Carbophen 5692 resin.

The assessment of the reclamation degree of the spent moulding sand of a known ignition loss before reclamation can either be directly determined by determining the ignition losses of the reclaimed sample (under the given conditions) or indirectly based on forecasting the ignition losses of the ready reclaim. This forecasting should be verified by measuring the amount of dust that is generated during the process and determining the organic material (resin) contents in the dust that is exhausted from the reclaimer.

In this second case, Equation 1 is used for determining the forecasted subprocess ignition loss of the SP(R) reclaim:

$$SP_{(R)} = SP_{(mz)} - 0.01 \cdot SP_{(P)} \cdot P_R \tag{1}$$

where:
SP(mz) – ignition loss of spent sand before reclamation (%);
SP(P) – average ignition loss of dust (%);
PR – the amount of dust exhausted from the reclaimer (% as related to the sand amount in reclaimer).

The results of the performed investigations of the ignition losses of the matrix obtained by the reclamation treatment of the spent sand with the phenol-resol resin (Carbophen 5692) for a wide range of parameters (see Fig. 3) in the AT-2 device after the pneumatic classification are graphically presented in Figure 4.

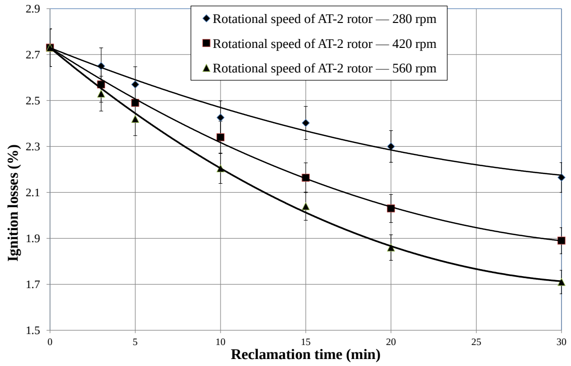

Fig. 4. Influence of reclamation treatment and rotational speed of reclaimer rotor on ignition losses of reclaims obtained by reclamation of spent sand with Carbophen 5692 resin (in AT-2 test device and subprocess pneumatic classification). Investigations of the reclamation treatment time on the morphology of the grain surfaces and the amounts of post reclamation dust

The data analysis allows us to notice that increasing the time and intensity of the reclamation operation (changing the rotational speed of the reclaimer rotor system) results in a decrease in the ignition losses of the obtained reclaims (which translates to the better release of the matrix from the coatings of the spent binders). The most pronounced effect of the matrix purification was achieved at the maximum intensive reclamation treatment (n = 560 rpm) and at a time equal to 30 min. Based on the ignition losses, however, it can be indicated that the degree of the matrix release from the spent binder equals 22-44% within the whole range of the reclamation treatment parameters in the test device in the case of the sand with the Carbophen 5692 resin. These values are lower than the analogical values obtained earlier for the spent sand with the Kaltharz U404 resin.

Shown in Figure 5, the morphology of the surfaces of the spent sand grains as well as of the reclaim (obtained from the spent sand with the Carbophen 5692 resin) allows us to notice indentations left by destroyed intergranular joints (which happened during their preliminary crushing – Fig. 5a) and barely visible traces of these joints (which were covered up during the secondary reclamation of the matrix – Fig. 5b).

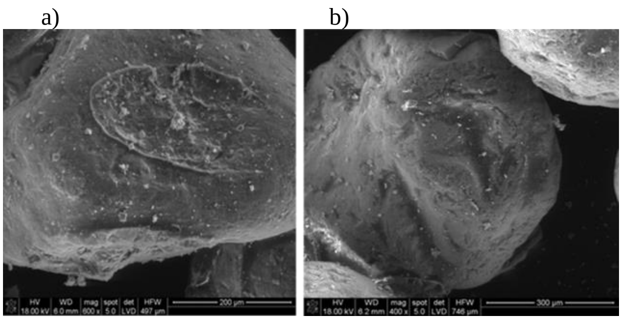

Fig. 5. Morphology of matrix grain surface of sand with Carbophen 5692 resin: a) spent sand – magnification 600x; b) matrix after reclamation treatment in AT-2 device and dedusting in fluidization column. Rotor rotations: n = 560 rpm; time: τ = 30 min; magnification – 400x

The dependence of the amount of dust generated during the reclamation process of the tested spent sand on the reclamation time regarding the three rotational speeds of the reclaimer rotor system is presented in Figure 6. It can be noticed that increasing the reclamation treatment time and the rotor rotational speed causes an increase in the amount of dust in the reclaim. This dust is the product of the combined influences of the elementary operations (rubbing, grinding, and crushing) occurring during the dry mechanical reclamation.

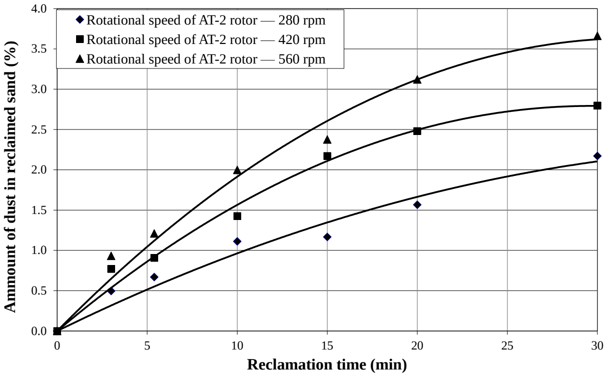

Fig. 6. Dependence of amount of after-reclamation dust generated in reclamation treatment process of tested spent sand on reclamation time and rotational speed of AT-2 rotor system

The morphology of surfaces of the dust particles generated in the reclamation process is presented in Figure 7.

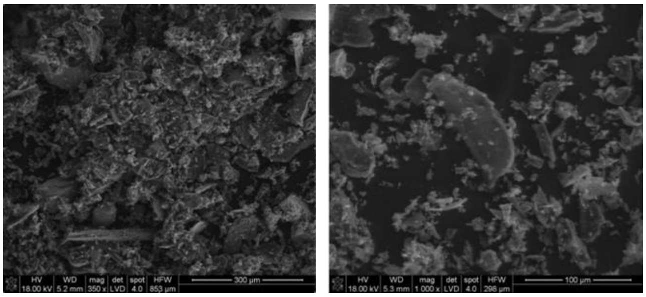

Fig. 7. Morphology of surfaces of dust particles generated during mechanical reclamation process of tested spent moulding sand. Rotational speed of rotor system of AT-2 device – 420 rpm; reclamation time – 15 min; standard conditions of pneumatic classification. Magnification: 350x (left); 1,000x (right)

A joint list of the obtained results in one cumulated diagram as well as their linear approximations is presented in Figure 8. In order to perform the approximations during the test, the ignition loss value of the dust formed during the process was determined; its average value was 29.27%. An example of the curve showing the grain content of the dust utilising an Analyssette 22 NanoTec laser grain size meter is presented in Figure 9.

The performed investigations indicated maintaining the linear dependence of the ignition losses on the dust content for the whole range of the reclamation treatment regardless of the treatment intensity or its realization time. Thus, the resulting content of the dust generated during the process is the factor allowing to determine the loss of ignition of the reclaimed sand. This is the effect of releasing matrix grains from the coatings of spent binders; this represents the general potential of the matrix purification degree from the spent bonding material. The results presented in Figure 8 confirm the correctness of the research thesis expressed by Equation (1) and can constitute the basis for forecasting the ignition losses of reclaims obtained from spent sands with organic binders. This forecasting is performed based on the determined amounts of dust generated during the reclamation process at simultaneous access to the data concerning the initial ignition losses of this spent sand as well as to the average values of the ignition losses of the dust that is exhausted from the reclaimer workspace.

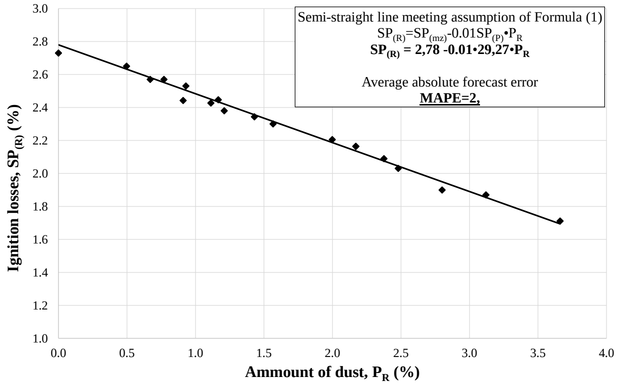

Fig. 8. Cumulated dependence of ignition losses of reclaimed matrix (after pneumatic classification) on content of dust generated during reclamation treatment in AT-2 testing device

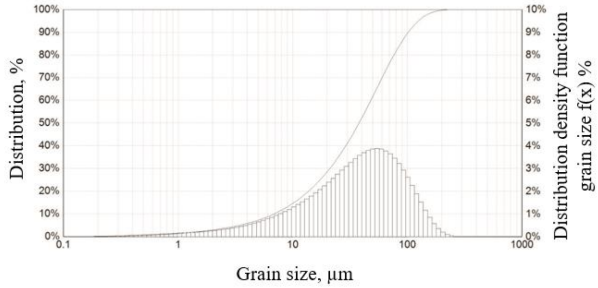

Fig. 9. Grain characteristic of after-reclamation dust from mechanical reclamation process of spent sand with Carbophen 5692

3. Research set-up for performing investigations with application of triboelectric measurement system

The positive results of preliminary tests created the basis for realizing the mechanical reclamation set-up that is equipped with the experimental measuring module that allows for current control of the reclaim quality based on measuring the amount of dust generated during the reclamation process. The research subject was the designed and constructed RD-6 experimental mechanical reclaimer equipped with a rotor grinding-crushing system and with an electronic system for measuring the amounts of dust emitted during the reclamation process. The set-up for measuring the airflow rate in the dedusting system was an integral element of the whole measuring system.

The system of measuring the amounts of dust generated during the reclamation process contained two independent measuring lines: a PM 103 triboelectric dustmeter for monitoring the dust concentration in the dedusting system of the experimental reclaimer, and an ASG system for monitoring the airflow rate in the dedusting system of the experimental reclaimer.

The scheme of the device is presented in Figure 10.

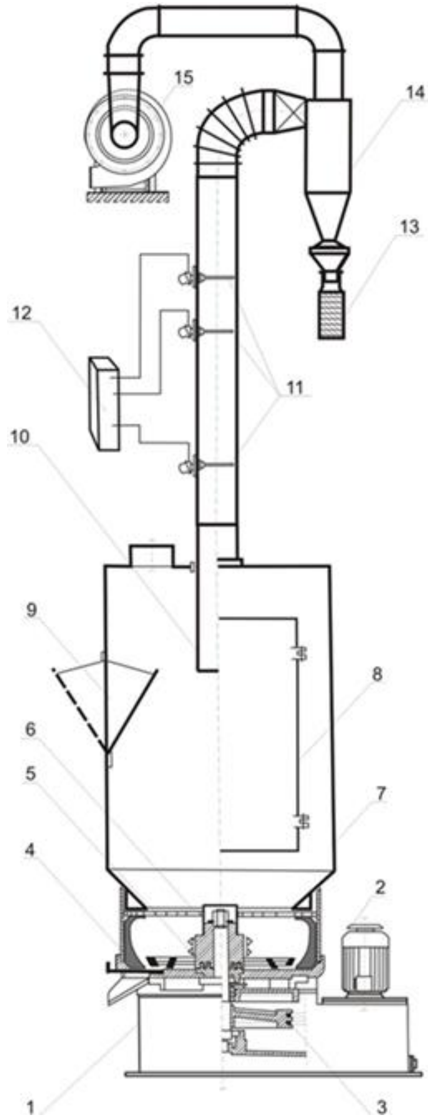

Fig. 10. Scheme of RD-6 experimental rotor reclaimer equipped with triboelectric dustmeter for automatic online measurements of dust amounts generated during grinding-crushing treatment of matrix and airflow rate in dedusting system: 1-base, 2-drive motor, 3-belt transmission, 4-reclaimer ring, 5-rotor with grinding-crushing elements, 6-air-guide vanes, 7-casing of dedusting chamber, 8- inspection door, 9-charge gate, 10-telescopic dedusting conduit, 11-triboelectric dust meter with a system of rate measuring in the dedusting system, 12-converter, 13-dust reception, 14-cyclone, 15-exhaust fan

Both of the monitored values allowed us to determine the flow intensity as well as the mass of the dust collected during the reclamation process cycle of a known amount of spent sand.

The whole setup also contained a temperature transducer with a PT100 sensor with analogue output of 4-20 mA and a temperature measuring range of 0° to 100°C, a 4-20 mA signal converter for a ModbusRTU interface, and an RS232/RS485 converter.

The measurement transducers utilise the method of measuring the amount and rate of the dust output based on the conversion of the electric current formed due to the transported dust particles in the dedusting conduit channel hitting and rubbing the measuring probes. Signals from the probes reaching the transducers are recalculated into concentration (the TrueRMS value of the electric current) and rate by utilizing the time shift between the signals on the two probes. The signal sampling velocity as well as the time of the individual measurements (proportional to the numbers of samples used in the calculations) influence the measurement accuracy.

A schematic presentation of the measuring system utilizing only the ASG rate-measuring transducer can be seen in Figure 11.

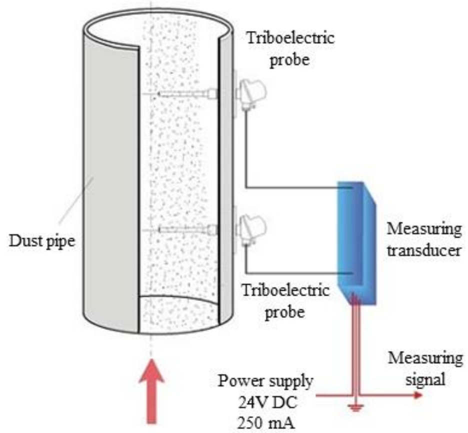

Fig. 11. Scheme of set-up for measuring dust rates with ASG measuring transducer

Probes are installed in parallel to each other and perpendicular to the flow direction. Their signals are measured by the converter and then their shift and TrueRMS values by utilising DSP algorithms, which are transferred into the rate and concentration of the dust output.

4. Experimental tests performed in the reclaimer RD-6

Investigations of the matrix-recycling process were performed for the spent sand with the Carbophen 5692 resin (the same as was applied in the preliminary tests). Each time, 6 kg of the spent sand was introduced into the reclaimer bowl.

The aim of the experimental tests was to determine whether the applied method for measuring the amounts of dust generated during the reclamation treatment can be applied to forecasting the quality of the reclaim. In the case of the RD-6 device, five measuring cycles were performed (these are described below).

During each cycle, the amount of dust generated in the process from 6 kg of the charged sand was measured. On this basis, the forecasted ignition loss of the reclaim was determined knowing the initial ignition loss of the spent sand and the ignition losses of the dust that were determined in the preliminary tests. This value was verified by the experimental tests, which were measurements of the ignition losses of the samples after the following reclamation times: 1, 5, 10, and 15 minutes.

Investigations of the matrix recycling were performed with various combinations of work parameters in the experimental reclaimer.

METHOD I – rotational speed of rotor system n = 280 rpm; treatment time τ_{rec} = 15 min; airflow rate in dedusting system v_{ded} = 8.5 m/s.

METHOD II – n = 420 rpm; τrec = 15 min; v_{ded} = 8.5 m/s.

METHOD III – n = 560 rpm; τrec = 15 min; v_{ded} = 8.5 m/s.

METHOD IV – rotational speed n was changed during reclamation treatment:

– Cycle 1: τ_{1rec} = 0-1 min, n_1 = 280 rpm;
– Cycle 2: τ_{2rec} = 1-10 min, n_2 = 420 rpm;
– Cycle 3: τ_{3rec} = 10-15 min, n_3 = 560 rpm.

Total reclamation time τ_{rec} = 15 min; airflow rate in dedusting system v_{ded} = 8.5 m/s.

METHOD V – rotational speed n was changed during reclamation treatment:

– Cycle 1: τ_{1rec} = 0-1 min, n_1 = 280 rpm;
– Cycle 2: τ_{2rec} = 1-5 min, n_2 = 420 rpm;
– Cycle 3: τ_{3rec} = 5-15 min, n_3 = 560 rpm.

Total reclamation time τ_{rec} = 15 min; airflow rate in dedusting system v_{ded} = 8.5 m/s.

The results show the changes in the geometrical dimensions of the matrix that are represented by the average arithmetic diameter da of the reclaimer grains recovered in the recycling process (which was performed according to Methods I-V in the RD-6 experimental reclaimer) are graphically presented in Figure 12.

For comparison, the value of the average grain arithmetic diameter da of fresh sand is marked in the diagram. The set of process parameters that are above diameter da (marked by the horizontal line) determines the range of the reclamation treatment parameters that are acceptable within the realized I-V methods. As the result of which, the matrix is released from the coatings of the spent binders. The set of parameters that are below this line causes their degradation to occur; simultaneously with the purification of the matrix grains, this unfavourably influences the yield of the recycling process.

The results of the reclaim ignition losses that were determined on the basis of the dust amount measurements in the dedusting system are presented in Table 1. These were recalculated in accordance with Equation (1), with the value of the ignition loss of the reclaim determined by the direct experimental measurements realized on the reclaim samples taken from the reclamation device. A very good correlation of these results can be noticed.

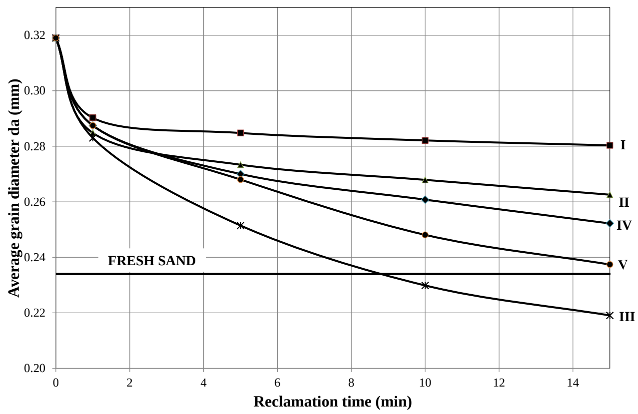

Fig. 12. Results of average arithmetic diameter da of reclaimed grains obtained during reclamations performed by Methods I-V

The online monitoring of the numbers of grains removed from the reclaimer in the air flux as a time function allowed us to determine the changes in their numbers during the spent sand reclamation treatment (performed by the given method). A cumulated diagram of the dust amount time functions measured by utilising the PM 103D triboelectric dustmeter for the I-V recycling methods described above are presented in Figure 13.

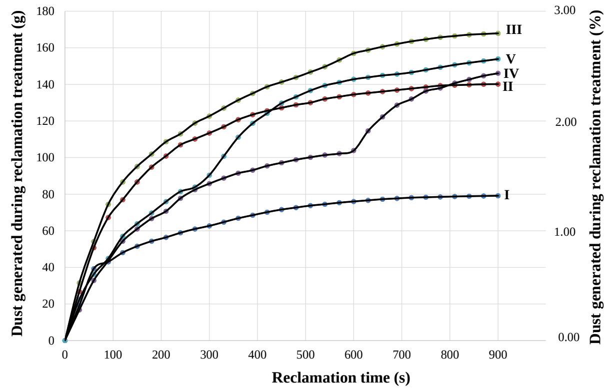

Fig. 13. Cumulated diagram of dust amounts in air removed from experimental reclaimer prepared based on online monitoring of matrix recycling utilising PM 103 triboelectric dustmeter (Methods I-V)

The data listed in Table 1 illustrate the values of the forecasted ignition losses of each reclaim determined by measuring the amount of dust removed from the device during the classification process (indirect measurement) as well as the values of the verifying measurements (direct measurements). In the majority of the cases, the value of the direct measurement is slightly lower than the one that is determined based on the indirect measurement. An opposite situation was noticed in three cases only: after a reclamation time of 15 minutes in Reclamation Methods III, IV, and V. The probable reason for this fact can be the crushing of the matrix grains occurring after this time, as it influences the ignition loss value of the dust removed during the classification process. This hypothesis will be subjected to verification in successive planned investigations.

Table 1.
Data concerning ignition losses of reclaims determined on basis of indirect measurements of amounts of dust in dedusting system and direct experimental measurements.

Recl. time	Ignition loss indirect measurement			Ignition loss direct measurement			Error of forecasting		
min	%			%			%		
RECLAMATION METHOD I-III									
	I	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**
1	2.59	2.53	2.51	2.57	2.52	2.48	0.77	0.80	1.21
5	2.47	2.23	2.18	2.43	2.23	2.17	1.65	0.45	0.46
10	2.42	2.13	2.02	2.36	2.10	2.00	2.54	1.43	1.00
15	2.39	2.10	1.96	2.34	1.06	1.98	2.14	1.94	1.01
RECLAMATION METHOD IV-V									
	IV	**V**		**IV**	**V**		**IV**	**V**	
1	2.62	2.60		2.60	2.57		0.76	1.17	
5	2.37	2.34		2.36	2.33		0.42	0.43	
10	2.27	2.08		2.25	2.06		0.89	0.97	
15	2.07	2.03		2.09	2.05		0.95	0.98	

5. Summary

The idea of dust monitoring during the reclamation process in a rotary device and its use to control the reclamation intensity within a given cycle was patented by D. Boenisch (1991) [1]. The application of this patent by the Vogel & Schemmann company consisted of using photoelectric measurements of dust amounts in a rotary reclaimer dedusting system (of periodical operations) for differentiating the reclamation treatment intensity within a given cycle. Thus, this monitoring was used for the recovery of bentonite and coal dust from spent moulding sand during the first phase of the process realized at a low reclamation intensity that was controlled by slow rotations of the drive motor.

The concept of the correlation of the ignition loss in spent moulding sand after casting knocking out with the monitoring of emitted dust with regard to its use for forecasting and control of the matrix purification degree presented in this publication is original and does not have scientific references.

The system of the RD-6 experimental reclaimer used in our investigations differs in its construction of the reclaiming and dedusting elements, the measuring method of the emitted dust, and the conversion of the control signal into the recycling intensity of the sand matrix treatment.

The results of previous investigations of the author were utilized in this paper. They concerned the correlation of the ignition losses of a reclaimed quartz matrix with the amount of dust generated during the reclamation process of spent homogeneous self-hardened moulding sands with synthetic resins. This allowed for the development of the concept and the performance of the preliminary realization of the online control system of the matrix-recycling process [4].

The results presented in this paper allow for the statement that the method applied for measuring the amounts of dust that are generated during the reclamation treatment of spent sand with a resol resin can be applied to forecasting the quality of the reclaim obtained in the device of the rotor mechanical reclamation of a periodical operation. The correlation of the dust amounts and the determination of the potential values of the ignition losses in spent sand (after the casting knocking out) by simulating the distribution of the temperature fields in a mould together with the data concerning organic binder degradation as a temperature function create the bases for forecasting the pathways and the final purification degree of matrix grains from organic binder remains.

Acknowledgements

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