# Effective Removing of Light Impurities from an Aggregate in SEL Separator

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## Abstract

*The aim of the paper is a work characteristics of innovative technological circuit for production and beneficiation of minerals aggregates. Investigative programme included separation of chalcedonite aggregate with particle size range 2-4 mm, 2-8 mm and 8-16 mm, upstream separated into regular and irregular particles. Tests were conducted in a dedicated separation device of light fractions (SEL) constructed in in HTS Gliwice, within the frames of "Formator Puls" project.*

**Keywords:** *mineral aggregate, SEL separator, chalcedonite, regular grains, pilot plant*

## Introduction

Enrichment of mineral aggregates is aimed at increasing their qualitative characteristics so they could meet specific standards or requirements required for a specific purpose of further industrial utilization. This process important, in particular, for gravels, broken carbonate rock aggregates or other aggregates, as well as waste (e.g. from building industry), which may be of inadequate quality due to high heterogeneity in terms of strength, water absorption, porosity, content of impurities and particle shape. Enrichment process can be carried out among others by taking advantage of the differences in apparent densities between defective and normal particles as well as differences in the strengths of individual grains. These methods are usually associated with the processes of comminution, classification, beneficiation and washing. Therefore, it is sometimes assumed that extensive enrichment processes occur simultaneously, e.g. in impact crushers (dry cleaning of aggregates from clay and organic materials) (Mazela 1998), hydraulic classifiers and jigs (removal of weathered particles with lower densities or different values of settlement velocities) (Osoba 2007), as well as in mechanical and high-pressure washing devices (Saramak et al. 2020). This applies especially to gravel aggregates, especially of glacial origin, with a clay coating on individual particles, which can be removed in washing and crushing operations. The results of recent investigations also indicate the possibility of carrying out the enrichment process by utilizing such characteristics of the grained material as shape, density and buoyancy in the water medium. This approach is based on patented technologies for the production of regular and irregular aggregates (PL 233689 B1, PL 233318 B1) (Gawenda 2014, Gawenda 2015 a, b, c).

Gravity enrichment in jigs is a simple separation method using in separation of various mineral resources and waste, and at the same time it is efficient and effective in the separation of materials with a relatively large difference in density (e.g. coal from gangue). It is also a method with a relatively low negative impact on the natural environment and has a high economic efficiency, which makes it a prospective separation method (Marx et al. 1999). The enrichment process in the jig takes place as a result of the separation of the feed into fractions of different densities. It can be carried out in air, water or other liquid medium, lighter than the ingredients of the raw material. Materials with different densities are characterized by various values of settlement velocities for a given medium, in which its vertical pulsating movement of the medium flow is generated (Stępiński 1969). As a result of the separation operation, after some time a layer of material forms on the sieve, separated into fractions according to the settlement velocity of individual particles. Finally, product fractions with greater homogeneity in terms of density, and thus higher commercial value, can obtained. If the feed contains light impurities, like roots, leaves, coal, amber, they will also be in the top layer of the jig.

The accuracy of the separation process is influenced by a number of factors, like the particle size and densimetric composition of the feed, efficiency, hydrodynamic conditions, the amount of bottom water fed, design solutions (i.e. a method of collecting of heavy product), and others. The most important parameter determining the efficiency of the jig separation process is the densimetric composition of feed. When the content of the higher-density fraction is greater than the throughput of the device, some portion of such material goes to the lighter product, which worsens the separation efficiency. As a minimum particle size that can be directed to the jig should be considered the value, below which the efficiency of its enrichment by other methods will be greater (Gawenda et al. 2019; Surowiak et al. 2020, Stępiński 1969).

## Materials and methods

The main purpose of presented investigative programme was evaluation of the enrichment efficiency for a chalcedonite aggregate separated in selected particle size fractions and with different operating parameters of device in an innovative technological circuit for the production of regular aggregates and for cleaning of mineral aggregates from light organic impurities, such as wood and coal. The solution is based on the invention entitled Układ urządzeń do produkcji kruszyw oraz sposób produkcji kruszyw (patent No. 233318 B1), applicable

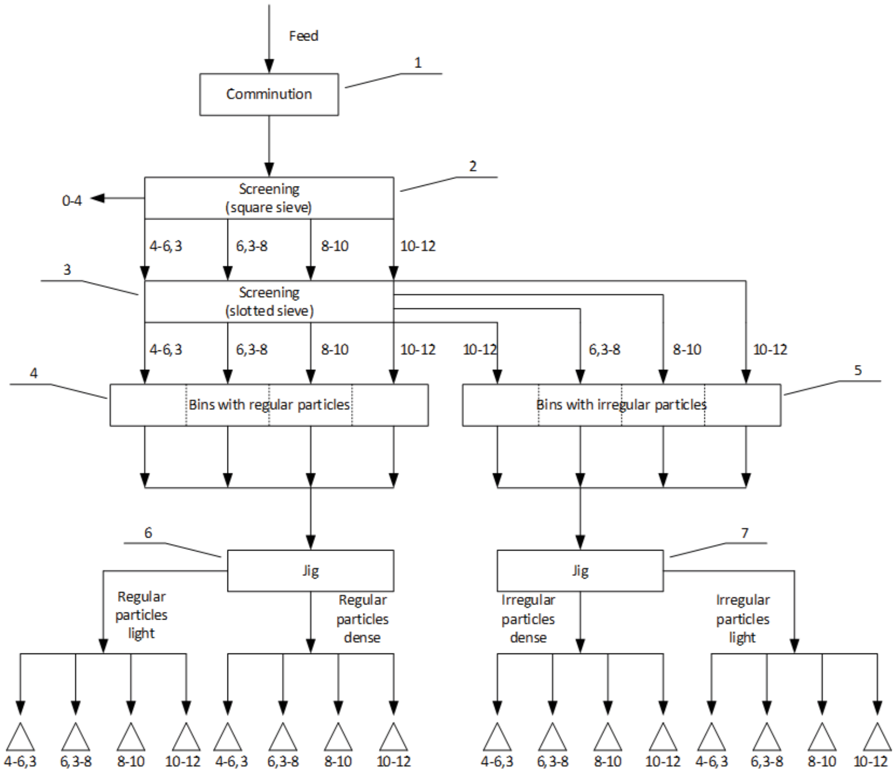


Fig. 1. Technological circuit for aggregate production with diverse physical and mechanical characteristics according to a patent 233318 B1
Rys. 1. Układ do produkcji kruszyw o zróżnicowanych parametrach fizykomechanicznych według patentu 233318 B

in the production of regular and irregular aggregates. As a result, it was possible to produce separately four types of aggregates with any particle size range, i.e. regular (cubic) and irregular (non-cubic) aggregates of low and high density, or regular and irregular aggregates free of light contaminations.

The method of aggregate production presented in Figure 1 is aimed at crushing of a feed materials in a crusher (No. 1) and classifying into narrow particle size fractions in a screen (No. 2), and then subjecting to a further separation process in a screen equipped with slotted screens (No. 3) in order to obtain separately regular and irregular particles, by directing them to tanks no. 4 and 5. Next, in the process gravity separation (pulsating jigs, air jigs or air classification tables – no. 6 and 7), lighter particles can be separated from heavier ones. The main purpose of separation of material into narrow particle size fractions is elimination of particles with equally settling velocities prior to separation process, as such particles are of a negative impact on the separation sharpness according to density. The accuracy of the separation process in a stream of pulsating medium depends on many factors, including: the particle size and densimetric composition of the feed, amount of feed material fed to the jig, hydrodynamic conditions, i.e. the pulsation regime, the amount (speed) of the bottom water fed, machine design solutions such as the method of discharge heavy product and others.

The achieved result of separation and the degree of washing of aggregate from organic impurities depends mainly on certain operating parameters, which can be adjusted in order to achieve the most favorable effect of the process course. The basic parameter of enrichment process is the feed flow rate, that is an amount of the material mass that flows through the device in a given time period. It is also related to the unit load of the separator - the mass of material per a unit of working area, which values should be between 2 and 35 tons per square meter multiplied by hour ($Mg/(m^2*h)$). An increase in value of unit load affects a decrease in the separation efficiency and an increase in probable dispersion and imperfections indices, the lowest possible value of which indicates for a more precise separation. In the evaluation of the testing programme, the influence of selected factors related to the feed properties (size, shape and type of grains), hydrodynamic parameters of the separator's operation (water flow rate, frequency and amplitude of pulsations) as well as machine design (setting the height of the heavy fraction collection threshold) on the effect of washing of the aggregate product from organic impurities, was analyzed (Surowiak et al. 2020; Marx et al. 1999; Stępiński 1969).

The testing circuit consists of the SEL (separation device for light particles enrichment) device, which is a machine that utilizes water as a working medium for cleaning the aggregate from contaminants - mainly organic (Fig. 2). The contaminated material enters a water-filled working chamber of the machine, which creates a wave motion of the water, as a result of what the contaminants are washed out and float on the surface of the water, and then are discharged through the first overflow threshold. The jump of pulsation range is from 50 mm to 140 mm and the pulsation frequency is approximately from 60 to 90 cycles per minute. The separator is equipped with 4 polyurethane screens with 2 mm slots, the total length of which is 1160 mm and the width of 150 mm, creating a working surface of the bed 0.174 $m^2$. The maximum efficiency of the device reaches 2.750 Mg per hour, and the maximum water requirement is 5.5 $m^3$ per hour. The product collection system is equipped with two water tanks, which previously separates from the heavy fraction (aggregate) products from water on a sieve and the light

Fig. 2. Testing circuit SEL (AGH UST in Cracow)
Rys. 2. Stanowisko badawcze SEL (AGH w Krakowie)

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| Parameter | Unit | Value |
|---|---|---|
| Water flow rate, Q | [dm$^3$/s] | 1.3, 1.8, 2.1 |
| Pulsation | [1/min] | 60, 70, 80, 90 |
| Jump of bellows | [mm] | 50, 80 |
| Height of the light product threshold | [mm] | 150 |
| Height of the heavy product threshold | [mm] | 135, 165, 180 |
| Content of impurities in products | [%] | 0.01 – 0.89 (1,36) |

fraction (organic pollutants) on the bag filter, and the water is collected in the tanks and then pumped to the main supply tanks. In this way, the flow of water through the machine is a closed system, which significantly reduces water consumption and eliminates its leakage outside the system.

The chalcedonite aggregate, previously crushed in a jaw crusher operating in a closed circuit, constituted the material for all tests. Following narrow particle size fractions were distinguished from the material: 2.0-4.0; 4.0-6.3; 6.3-8.0; 8.0-10.0; 10.0-12.0; 12.0-14.0; 14.0-16.0 mm, which were then separated into regular and irregular particles by means of appropriately selected slotted sieves, according to the procedure described in the literature (Gawenda, Lubaczewska 2019; Gawenda 2015a and b). In this way, the following samples were selected for testing programme:

Sample 1.1: 2 - 4 mm, 100% regular particles
Sample 1.2: 2 – 4 mm, 100% irregular particles
Sample 1.3: 2 – 4 mm, 50% regular particles
Sample 2.1: 2 – 8 mm, 100% regular particles
Sample 2.2: 2 – 8 mm, 100% irregular particles
Sample 2.3: 2 – 8 mm, 50% regular particles
Sample 3.1: 8 – 16 mm, 100% regular particles
Sample 3.2: 8 – 16 mm, 100% irregular particles
Sample 3.3: 8 – 16 mm, 50% regular particles

In further analyses samples with regular particles will be denoted generally as samples x.1, samples with irregular particles as samples x.2, and samples with 50% of regular particles as samples x.3. Analogous denotation will be used for categorization of samples according to size in general: samples 1.x for 2-4 mm, samples 2.x for 2-8 mm and samples 3.x for 8-16 mm.

Prior the tests, the material was deliberately contaminated with a light fraction in the form of wood roots and carbon particles in the amount of 2%. The list of all changeable parameters with individual values was presented in Table 1. There was accepted a constant height of the light fraction threshold (150 mm) and samples for analyses have been collecting for 10 seconds after the separator's operating conditions had stabilized. The experiment was carried out on the basis of the factorial experiment methodology for four variables, each had from 2 to 4 levels of variation.

## Results and discussion

### ***Effects of size and shape of particles on the washing process efficiency***

Figure 4 shows the results of relationships between impurities content in the heavier (lower) product of separation and particle size distribution separately for samples x.1, samples x.2 and samples x.3. These relationships show that chalcedonite products with regular particles and particles size 2.0-8.0 mm contained more impurities (0.3%), comparing samples 1.x and samples 3.x. for Q = 1.8 and Q = 2.1 dm$^3$/s (Figs. 4a, 4b). Samples 1.x were characterized by more favorable results, impurities constituted approx. 0.05% for both values of Q (Fig. 4c,

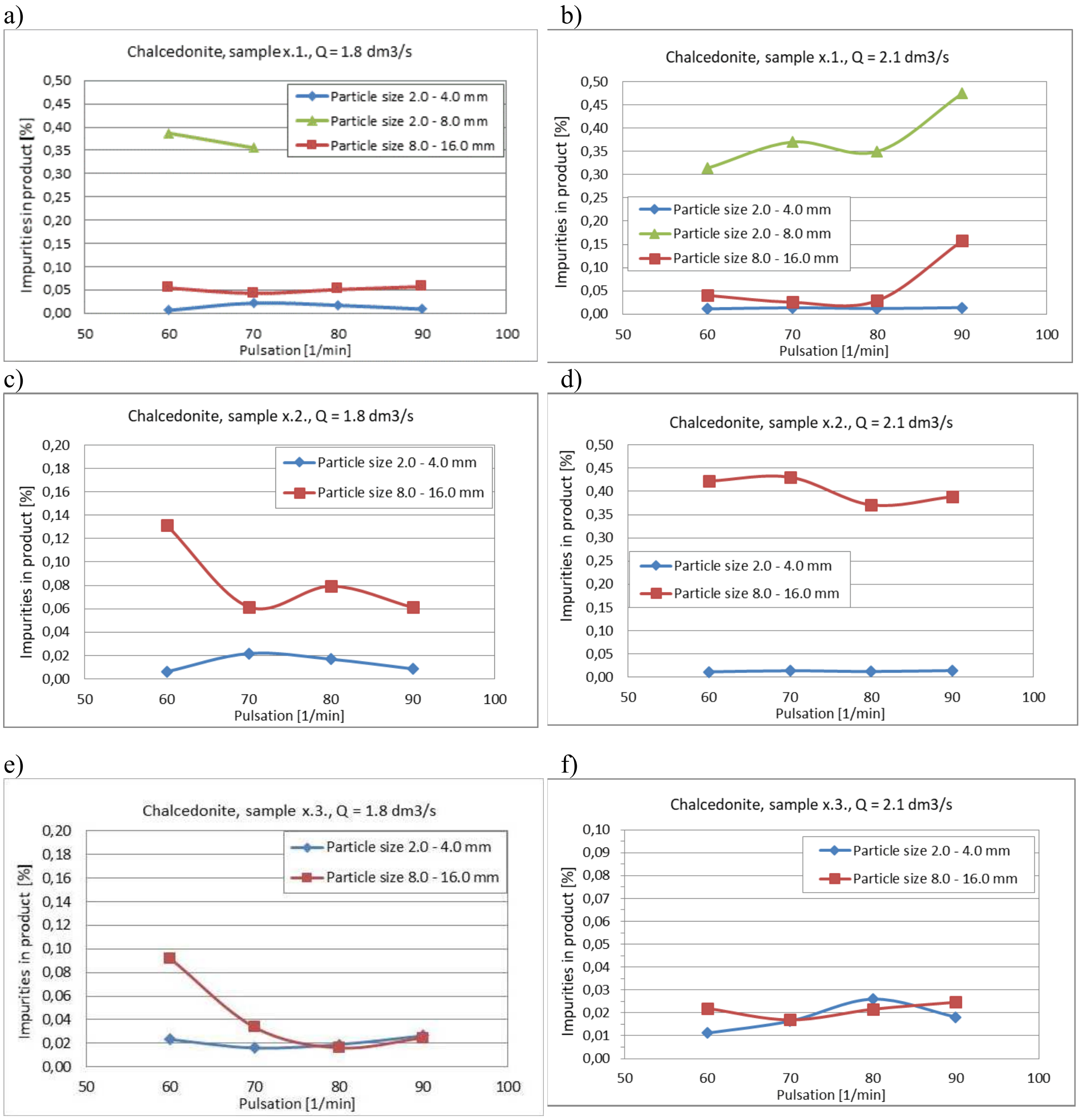


Fig. 4. Effect of size and shape of particles on impurities content in the product
Rys. 4. Zależność wpływu wielkości i kształtu ziaren na udział zanieczyszczeń w produkcie

4d). For the sample 3.2. higher impurities were observed in the product, approx. 0.35% for Q = 2.1 dm$^3$/s and 0.13% for Q = 1.8 dm$^3$/s. For the sample 1.x. the content of impurities was very low – below 0.03% for all cases. In sample 3.x. the proportion of impurities in the heavy product was similarly low, while for the 60 cycles per minute and the Q = 1.8 dm$^3$/s was higher than 0.09% ( Figs. 4e, 4f).

### *Effect of flow rate of water and threshold value on the washing process efficiency*

Figures 5-7 present the results effect of the flow rate of water to the separator on the content of impurities in the final product, for the height of the heavy product collection threshold, respectively 13.5 and 16.5 mm. For regular particles in particle size 8-16 mm (sample 3.1.), the highest values of impurities were observed for the maximum water flow (2.1 dm$^3$/s) and the threshold height 13.5 cm (Fig. 5). Irregular particles, in turn, were better washed for the higher value of threshold (i.e. 16.5 cm) for both settings of the water flow rate. The impurities contents in these products were below 0.15% for all pulsation ranges (Fig. 6) and even in some cases below 0.05%. For samples 3.2. and 3.3. it was more advantageous to operate with a higher threshold value (16.5 cm), however, an increase of the flow rate water from 1.8 to 2.1 dm$^3$/s did not affect significantly the content of impurities in products.

### *Effect of jump and pulsation frequency on the washing process efficiency*

Figures 8-10 show the effect of the pulsation frequency on impurities content in products for the samples 1.x., depending on the water flow rate Q. The height of heavy product threshold was 18 cm, and the jump 5 cm. It was easy to notice that all samples were washed very well in all ranges of pulsation frequency and water flow rate. Only for the sample 1.2. at pulsa-

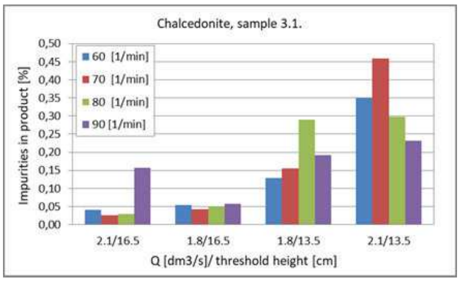


Fig. 5. Effect of water flow rate Q on quality of products – sample 3.1

Rys. 5. Wpływ natężenia przepływu wody do separatora na ilość zanieczyszczeń w kruszywie – próbka 3.1

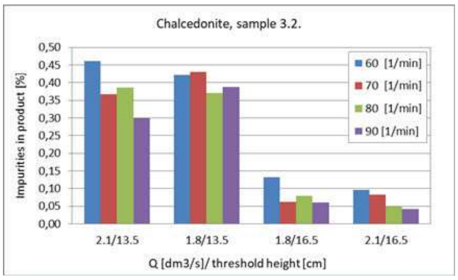


Fig. 6. Effect of water flow rate Q on quality of products – sample 3.2

Rys. 6. Wpływ natężenia przepływu wody do separatora na ilość zanieczyszczeń w kruszywie – próbka 3.2

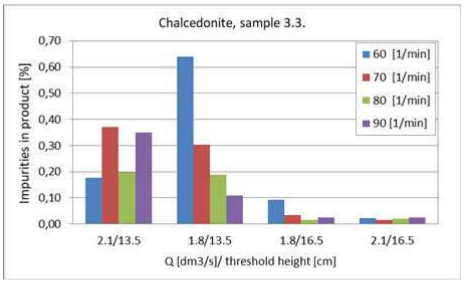


Fig. 7. Effect of water flow rate Q on quality of products – sample 3.3

Rys. 7. Wpływ natężenia przepływu wody do separatora na ilość zanieczyszczeń w kruszywie – próbka 3.3

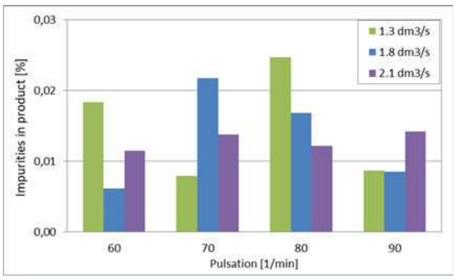


Fig. 8. Results for sample 1.1., jump = 5 cm, threshold = 18 cm

Rys. 8. Wyniki dla próbki 1.1., skok 5 cm, próg 18 cm

tion frequency 60 and 70 cycles per minute and the maximum water flow, the content of impurities was higher by over 0.5%. In the case of minimal water flow (i.e. 1.3 $dm^3/s$), the content of impurities was very low, and equaled even zero for sample 1.2. Therefore, it can be concluded that for the fine particles (2-4 mm) enriched in the SEL separator, it is advantageous to prepare regular and irregular particles separately, because it allows for very thorough cleaning with reduced water consumption.

Figures 11-13 show effects of enrichment for coarser particles in the wider particle size range, which can be considered as favorable. For the pulsation of 60 cycles per minute, the content of impurities in the product exceeded 0.5% only in one case (Fig. 13). For coarse particles, it is more advantageous to run the process with a higher height of heavy product collection threshold, and for that case the water flow rate can be reduced to 1.8 $dm^3/s$.

## Summary and conclusions

The results of investigations show that application of enrichment operations in jigs separately for the feed material containing regular and irregular particles makes it possible to obtain the product aggregate with improved qualitative characteristics and a homogeneous particle shape. A detailed analysis of results shows that thanks to appropriate preparation of feed ma-

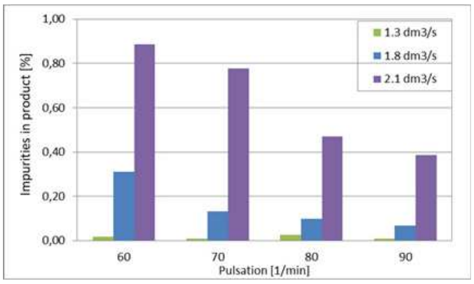


Fig. 9. Results for sample 1.2., jump = 5 cm.
Rys. 9. Wyniki dla próbki 1.2., skok 5 cm

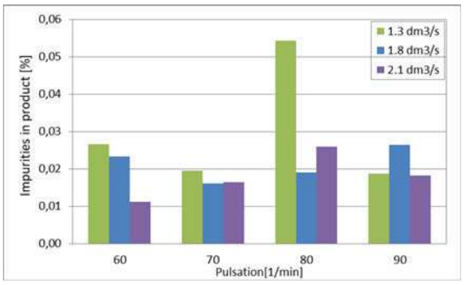


Fig. 10. Results for sample 1.3., jump = 5 cm.
Rys. 10. Wyniki dla próbki 1.3., skok 5 cm

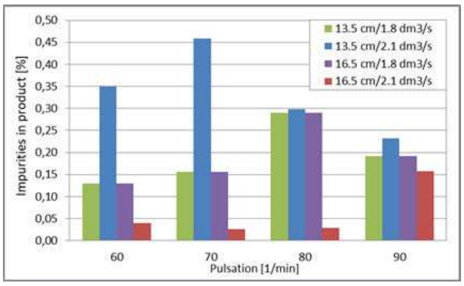


Fig. 11. Results for sample 3.1., jump = 8 cm
Rys. 11. Wyniki dla próbki 3.1., skok 8 cm

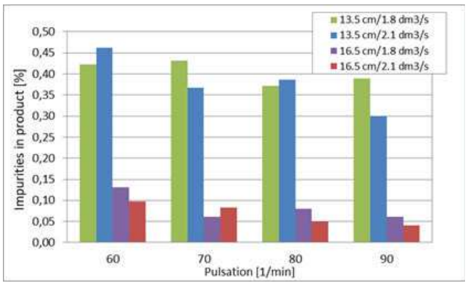


Fig. 12. Results for sample 3.2., jump = 8 cm
Rys. 12. Wyniki dla próbki 3.2., skok 8 cm

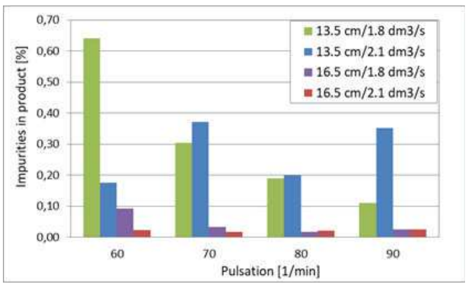


Fig. 13. Results for sample 3.3., jump = 8 cm
Rys. 13. Wyniki dla próbki 3.3., skok 8 cm

terial prior the enrichment, i.e. classification into narrow particle size fractions and into regular and irregular particles, and by controlling the separation process in SEL through specific adjustments of selected parameters (jump, pulsation frequency, water flow rate), it is possible to obtain high purity products. It can be also achieved a reduction of impurities content from 2% (for feed material) to even 0% (for specific products).

By examining the impact of the particles size and shape on effectiveness of enrichment process the accuracy of cleaning the aggregate from impurities, it can be concluded that it is more advantageous to separate particles in terms of shape, as well as classification into fractions of a narrower particle size range. A higher setting of the threshold gives better results in terms of removing of organic impurities from samples with wider particle size fractions, i.e. 2.0-16.0 mm. On the other hand, in the case of a narrower fraction (2.0-8.0 mm) and finer particles, it is more advantageous to carry out the process at low water flow rate Q and with a low height of the product collection threshold. Here, in addition to a very low impurities content in products, an advantage is also the limitation of the water flow rate through the circuit.

The results of conducted tests for coarse particles within particle size fraction 8-16 mm showed that the value of pulsation jump in separating device should be set at 8 cm. For fine particles, finer than 8 mm, good enrichment results were achieved for lower pulsation jump (5 cm). Even better results in terms of purity of products and water consumption were achieved in separation of the material in terms of shape.

Artykuł jest wynikiem realizacji projektu w ramach konkursu NCBiR: konkursu nr 1 w ramach Poddziałania 4.1.4 „Projekty aplikacyjne" POIR w 2017 r., pt.: Opracowanie i budowa zestawu prototypowych urządzeń technologicznych do budowy innowacyjnego układu technologicznego do uszlachetniania kruszyw mineralnych wraz z przeprowadzeniem ich testów w warunkach zbliżonych do rzeczywistych". Projekt współfinansowany przez Unię Europejską ze środków Europejskiego Funduszu Rozwoju Regionalnego w ramach Działania 4.1 Programu Operacyjnego Inteligentny Rozwój 2014-2020.

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*Efektywne usuwanie frakcji lekkiej z kruszywa w separatorze SEL*

Celem artykułu jest charakterystyka pracy innowacyjnego układu technologicznego służącego do produkcji i uszlachetniania kruszyw mineralnych. W ramach badań przetestowano proces uszlachetniania kruszywa chalcedonitowego o uziarnieniu 2-4 mm, 2-8 mm i 8-16 mm rozdzielonego na frakcje z ziarnami foremnymi i nieforemnymi w specjalnie skonstruowanym i zabudowanym w laboratorium separatorze frakcji lekkiej – SEL zbudowanym przez HTS Gliwice w ramach projektu Formator Plus.

**Słowa kluczowe:** *kruszywo mineralne, separator SEL, chalcedonit, ziarna foremne, instalacja pilotażowa*