Research Over Bio-Flocculation Application in Sedimentation of Mineral Suspension

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Summary

The velocity of mineral suspensions sedimentation, especially the fine-grained ones is important issue concerning densification and filtration processes in industrial plants and wastewater treatment plants. Many factors influence on sedimentation velocity. They are connected, i. a., with characteristics of water where the process occurs and addition of speeding agents – flocculants. Currently the most known and used on large scale are synthetic flocculants. They are chemical compounds of efficient activity but relatively expensive. It is known that during wastewater treatment process the metabolic changes occur causing that microorganisms living in activated sludge produce slimy substance which chemically is like polymers.

The purpose of the investigation presented in the paper is to check the possibility of applying the activated sludge originated from municipal sewage treatment plant and biomass of blastomyces of the sort Rhodotorula *as the agents speeding the sedimentation of coal slime wastes up. The paper presents the results of laboratory tests – tests of coal slime wastes sedimentation on the basis of which the sedimentation velocity and parameters of condensed sludge (mean final densification and solid phase contents in sludge) were calculated.*

The investigation presented in the paper confirmed the possibility of application of microorganisms to mineral suspensions flocculation.

Keywords: sedimentation, bio-flocculation, sedimentation velocity, coal slime wastes

Introduction

In process of mechanical cleaning of wash waters originating from processes of beneficiation of various sorts of materials in processing plants the processes of thickening and filtration of suspensions are being used. Usually, these are suspensions of concentrates and wastes characterizing by fine granulation. Their ultrafine particles settling velocity is low (Krawczykowska et al. 2005, Thomas et al. 2014). According to rules of closing water-sludge system the technological waters are being clarified what means that solid phase is separated to allow their another technological application (Nowak 1982). To process of sedimentation of suspensions being the first part of water-sludge management, in purpose of process accelerating, the synthetic flocculants are used which purpose is to lead solid phase particles to concentrator underflow and then its thickening as well possibly best clarification of overflow.

Mineral suspension sedimentation velocity depends mainly on solid phase contents and particle size. Ultrafine particles of sizes close to colloidal dimensions sediment with low velocity because they move in various directions in suspension. To accelerate sedimentation process and raise efficiency of thickening the special chemical substances, so-called flocculants, are added to suspension causing creation of particles aggregates. Such constructed aggregates behave like particles of bigger sizes and sediment much easier. Thanks to application of flocculants is possible to efficiently accelerate time of overflow clarification and underflow thickening in concentrator. The flocculants can be organic origin compounds as well synthetic agents. The natural origin agents feature with high consumption being equal to from several even to several dozen grams per 1 Mg of substance. These are mainly polysaccharides and organic colloids. Polysaccharides are known also as starch agents produced from potato starch. Organic colloids created on the basis of glue and resins can be applied in acid environment, featured with high efficiency, but their solubility is limited and hard to perform. Synthetic agents feature with much lower consumption – from several grams per 1 Mg of solid phase – however, their price is high. To this group of agents the compounds produced from polyacrylamides, esters and fatty acids. These compounds have polar structure (anion, cation or anion-cation) or apolar structure (no ionic). Anion agents are being used mainly to clarify and thicken suspensions of alkaline or neutral reaction and cation ones in acid environment. No matter what type of flocculent is in use it is crucial to select its optimal dose because too much amount of flocculent can cause sudden growth of suspension viscosity what negatively influence on sedimentation process efficiency.

Introduction of flocculants to industrial technologies changes course of sedimentation process considering both quantity and quality. In short time is possible to completely separate solid phase from liquid. However, economic reasons (price of flocculant) causes searching for new methods and compounds which would give satisfying technological effects for lower price. More and more often the scientific researches with application of microorganisms to mineral suspensions flocculation (Vijayalakshmi and Raichur 2002, Blaschke et al. 1994) as well to flotation as modifying agents (Hołda and Młynarczykowska 2014, Smith and Miettinen 2006) are conducted. It was stated that during sludge cleaning processes such metabolic changes occur which cause microorganisms being present in activated sludge to produce slimy substance which chemically behaves like polymers (Szulicka 1980).

The paper presents results of investigating sedimentation of coal slime wastes with application of new agents accelerating process of mineral suspensions sedimentation – bio-flocculants in form of yeasts from sort *Rhodotorula* and activated sludge originating from municipal sewage treatment plant.

Sedimentation curve as graphical presentation of suspensions settling process

The sedimentation curve serves to evaluate course of suspensions sedimentation. In purpose of plotting such curve is necessary to analyze process of suspensions settling. This process is based on observations of phenomena occurring during sedimentation conducted in laboratory scale. The investigation is performed by filling glass cylinder of proper scale with suspension of certain concentration. Such prepared suspension is then mixed. It is important that particles are located evenly along whole length of the vessel and the dilution is possibly the same on the whole surface of sedimentation vessel. After some time, the individual sedimentation zones are being created in the vessel, which are:

– Zone located in upper part of the vessel being called clarified water zone. It is particularly important because is located directly above obscurity limit which the basic measure of sedimentation test;

– Zone of even collective sedimentation which is located below clarified water zone;

– Interim zone;

– Compression zone which is observed at the vessel's bottom. It is characterized with particles close range and the significant growth of suspension density is observed. In this zone particles are located in close range between themselves and sedimentation seems to be stopped. However, it occurs but much slower, particles fall into place under influence of gravity and pressure of particles located above filling spaces between themselves. With time, interim zone and zone of even collective sedimentation vanishes completely and only clarified water and settled sludge can be observed which stops moving after a while (Bandrowski et al. 1995, Koch and Naworyta 1992).

Using the sedimentation curve is possible to calculate settling velocity according to formula:

$$v_{sed} = \frac{\Delta h}{\Delta t} \tag{1}$$

where: V_{sed} – settling velocity, Δh – difference between extreme points of way passed by suspension, Δt – difference of times between extreme points of way passed by suspension.

To evaluate sedimentation process, apart from settling velocity, the sludge parameters are used, which are among others final concentration and solid chase contents.

Mean final concentration βk of sludge is calculated according to the equation:

$$\beta_k = \frac{\beta_p \cdot h}{V_o} \tag{2}$$

where: β_p – initial concentration, h – sludge height, V_o – mean sludge volume.

Solid chase contents α is calculated on the basis of following equation:

$$\alpha = \frac{\beta \cdot \rho_s}{\rho_s \cdot \rho_c + \beta(\rho_s - \rho_c)} \tag{3}$$

where: β – concentration, ρs – solid phase density, ρ_c – liquid density.

Experimental part

Investigations of sedimentation process were performer by means of bio-flocculants in form of yeasts from sort *Rhodotorula* and activated sludge originating from mechanical and biological municipal sewage treatment plant "Ruptawa". Sedimentation tests were performed on wastes of coal slime of granulation < 0.315 mm originating from flotation of coking coal from of the Polish mines. The measurements of settling velocity of coal slime wastes by initial concentrations: 20, 30, 40 and 60 g/dm^3 without bio-flocculant addition – so-called zero samples "0". Then, the sedimentation tests with addition of bio-flocculants were performed. The amounts of bio-flocculants were 2, 10 and 20 cm^3/dm^3 with presence of yeasts of sort *Rhodotorula* and activated sludge for all initial concentrations.

Preparation of bio-flocculants

The biomass of yeasts of sort *Rhodotorula* were selected to laboratory investigations, which were isolated from soil and implanted to fungi cultivation. As cultivating subgrade wort was used – natural culture being extract from barley malt, being produced in first stage of beer production. After implantation of sample on cultivating subgrade it was incubated in temperature of 28°C in incubator during 7 days. After this time the obtained colonies were re-incubated on new culture which was wort solid with 3% agar. The obtained clean yeasts were incubated individually on new culture and incubated in purpose of obtaining high amount of biomass of reproduced microorganisms.

The second bio-flocculant used to investigation was activated sludge originating from municipal sewage treatment plant. Activated sludge is complex biological system in which physical processes and biochemical reactions occur. The sewage treatment is supported in some aspect by chemical agents what furthers natural environment and minimize costs of plant activity. In macroscopic sense, activated sludge is slimy, easily settling suspension of fluffy structure. Fluffs of activated sludge are constructed from many, various microorganisms mainly heterotrophic zoogleal bacteria (Zooglea ramigera) which are associated with protozoas, settled and creepy ciliates, rotifers, nematodes, earthworms and filament bacteria (mainly of specimen Sphaerotillus natans and Beggiatoa sp.).

The biomass fraction of microorganisms themselves is about 5–20% of fluff volume, the remaining 80–95% are substance of colloidal character which are polymers produced by these microorganisms, so-called exopolymers – outside cell polymeric substances (EPS). The composition of bacterial exopolymers is mainly polysaccharides (including mucopolysaccharides), proteins, nuclide acids and others. These components are responsible for structure and properties of fluffs, especially flocculation, settling and hydration. Both, quantity and chemical composition of polymers produced by certain bacteria can be changed under influence of various environmental factors (Błaszczyk 2007, Gala et al. 2011). So, it is crucial to select properly and use adequate activated sludge as bio-flocculant.

Microscopic evaluation of activated sludge's fluffs used in experiments, conducted in laboratory of sewage treatment plant "Ruptawa", indicated their irregular shape, compact structure, weak durability, sludge biotic index (SBI) of II class and domination of creepy and predatory ciliates, as well small diversity of specimens and small amount of bacteria what indicates that the quality of sludge is average. The dominant filament was Microthrix parvicella (0.6).

Such prepared bio-flocculants served to perform investigations of sedimentation of coal slime wastes.

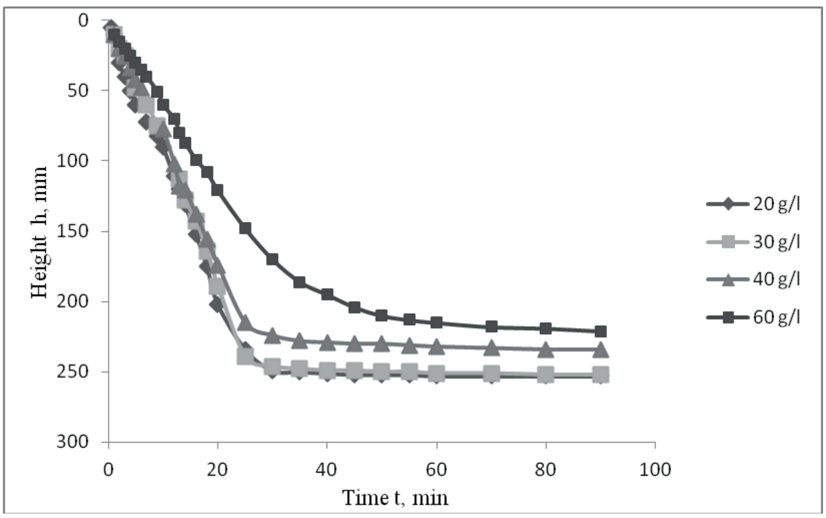

Fig. 1. Curve of coal slime wastes settling, without bio-flocculants addition (sample "0")

Rys. 1. Krzywa osadzania odpadów mułu węglowego bez dodatku bioflokulantów (próba „0")

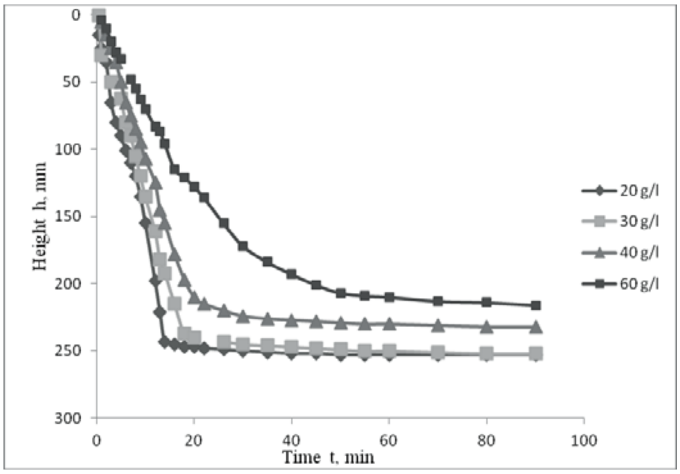

Fig. 2. Curve of coal slime wastes settling, with addition of blastomyces of the sort *Rhodotorula* in amount of 2 ml/dm^3

Rys. 2. Krzywa osadzania odpadów mułu węglowego z dodatkiem drożdżaków z rodzaju *Rhodotorula* w ilości 2 ml/dm^3

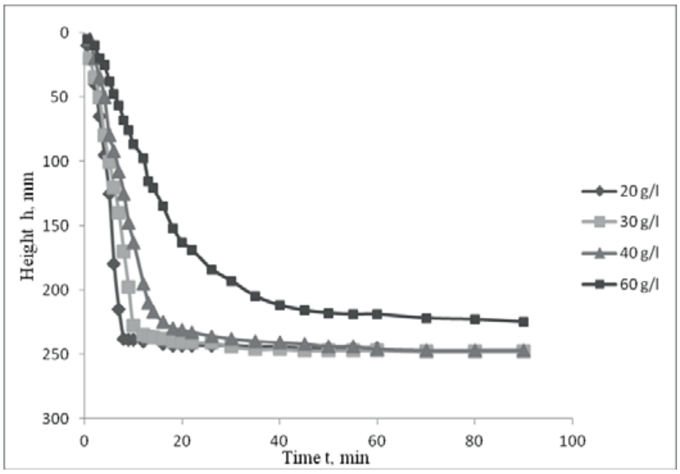

Fig. 3. Curve of coal slime wastes settling, with addition of blastomyces of the sort *Rhodotorula* in amount of 10 ml/dm^3

Rys. 3. Krzywa osadzania odpadów mułu węglowego z dodatkiem drożdżaków z rodzaju *Rhodotorula* w ilości 10ml/dm^3

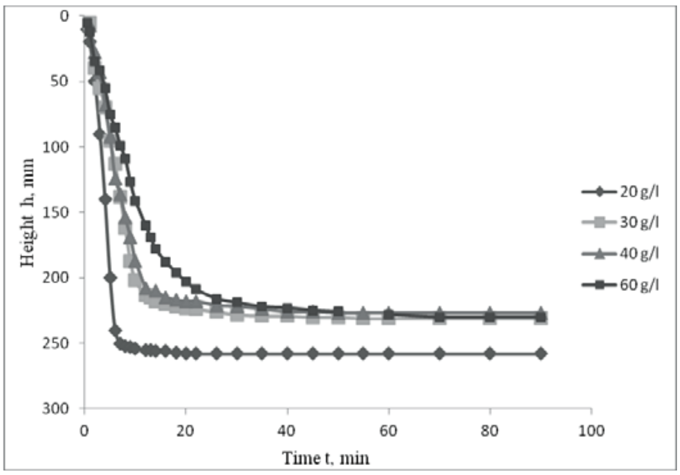

Fig. 4. Curve of coal slime wastes settling, with addition of blastomyces of the sort *Rhodotorula* in amount of 20 ml/dm^3

Rys. 4. Krzywa osadzania odpadów mułu węglowego z dodatkiem drożdżaków z rodzaju *Rhodotorula* w ilości 20ml/dm^3

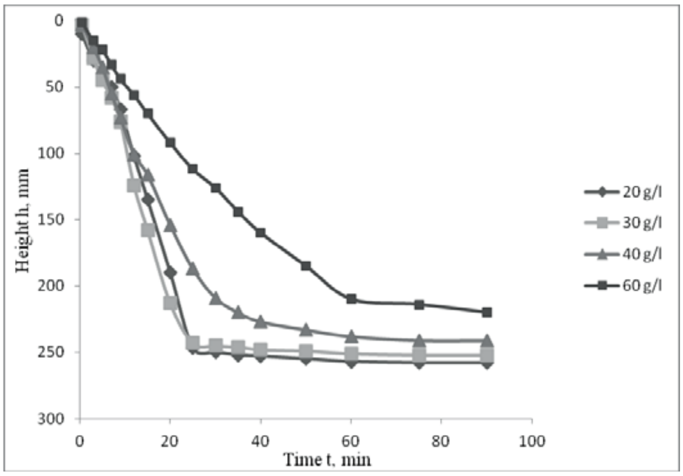

Fig. 5. Curve of coal slime wastes settling, with addition of activated sludge in amount of 2 ml/dm^3

Rys. 5. Krzywa osadzania odpadów mułu węglowego z dodatkiem osadu czynnego w ilości 2 ml/dm^3

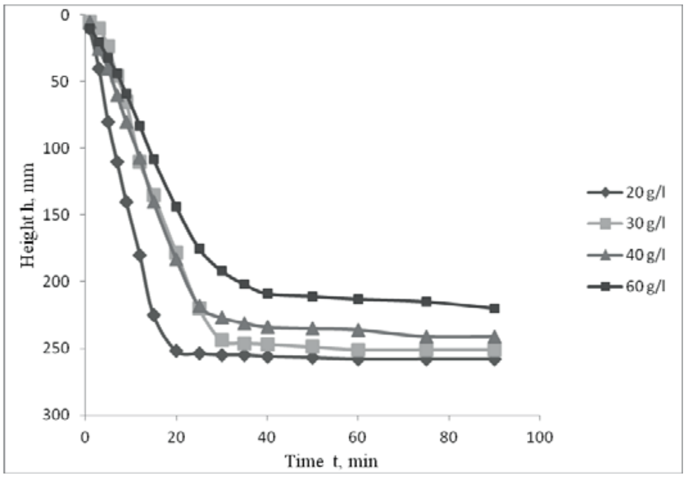

Fig. 6. Curve of coal slime wastes settling, with addition of activated sludge in amount of 10 ml/dm^3

Rys. 6. Krzywa osadzania odpadów mułu węglowego z dodatkiem osadu czynnego w ilości 10 ml/dm^3

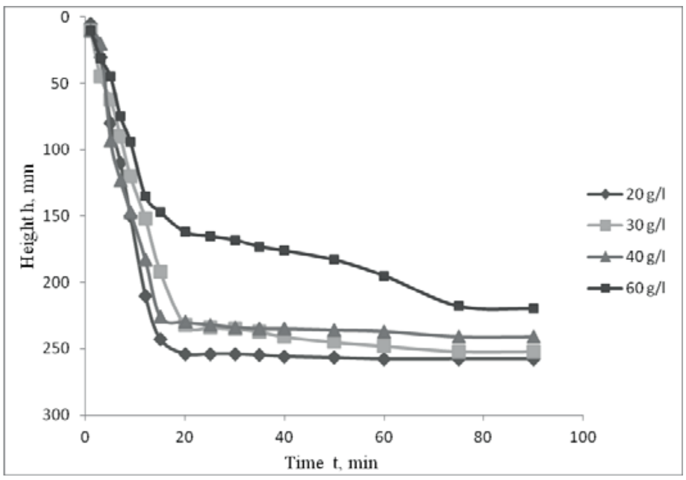

Fig. 7. Curve of coal slime wastes settling, with addition of activated sludge in amount of 20 ml/dm^3

Rys. 7. Krzywa osadzania odpadów mułu węglowego z dodatkiem osadu czynnego w ilości 20 ml/dm^3

Tab. 1. Results of coal slime wastes settling for sample "0" and with addition of bio-flocculants in amount of 2 ml/dm^3

Tab. 1. Wyniki osadzania odpadów mułu węglowego dla próby „0" i z zastosowaniem bioflokulantów w ilości 2 ml/dm^3

Suspension concentration, g/dm^3	Sample „0"			Sample with addition of yeasts of sort *Rhodotorula*			Sample with addition of activated sludge		
	$v_{sed,}$ m/h	$\beta_{k,}$ g/dm^3	$\alpha_{k,}$ %	$v_{sed,}$ m/h	$\beta_{k,}$ g/dm^3	$\alpha_{k,}$ %	$v_{sed,}$ m/h	$\beta_{k,}$ g/dm^3	$\alpha_{k,}$ %
20	0,61	450	39	1,01	476,2	39	0,58	450	37,5
30	0,57	450	41	0,73	500,0	41	0,65	450	37,5
40	0,51	397	40	0,65	444,4	37	0,45	372	31,9
60	0,33	324	34	0,36	235,3	21	0,24	324	28,3

Tab. 2. Results of coal slime wastes settling with addition of bio-flocculants in amount of 10 ml/dm^3

Tab. 2. Wyniki osadzania odpadów mułu węglowego z zastosowaniem bioflokulantów w ilości 10 ml/dm^3

Suspension concentration, g/dm^3	Sample with addition of yeasts of sort *Rhodotorula*			Sample with addition of activated sludge		
	$v_{sed,}$ m/h	$\beta_{k,}$ g/dm^3	$\alpha_{k,}$ %	$v_{sed,}$ m/h	$\beta_{k,}$ g/dm^3	$\alpha_{k,}$ %
20	1,82	555,5	44	0,92	450	37,5
30	1,34	517,2	42	0,54	473	39,1
40	1,03	434,8	36	0,53	499	40,8
60	0,46	241,0	22	0,41	437	36,6

Tab. 3. Results of coal slime wastes settling with addition of bio-flocculants in amount of 20 ml/dm^3

Tab. 3. Wyniki osadzania odpadów mułu węglowego z zastosowaniem bioflokulantów w ilości 20 ml/dm^3

Suspension concentration, g/dm^3	Sample with addition of yeasts of sort *Rhodotorula*			Sample with addition of activated sludge		
	$v_{sed,}$ m/h	$\beta_{k,}$ g/dm^3	$\alpha_{k,}$ %	$v_{sed,}$ m/h	$\beta_{k,}$ g/dm^3	$\alpha_{k,}$ %
20	2,51	526,3	43	1,02	450	37,5
30	1,31	294,1	26	0,70	534	43,2
40	1,10	377,3	32	0,69	372	31,9
60	0,77	281,7	25	0,56	324	28,3

Discussion of results

The results of sedimentation tests for various concentrations of coal slime wastes suspension without addition of bio-flocculants, so-called sample „0”, are presented on Fig. 1. Figs 2–4 present sedimentation curves for the variant in which bio-flocculants were yeasts of type *Rhodotorula* in doses, respectively, 2, 10 and 20 ml/dm^3, while results of coal slime wastes sedimentation with addition of bio-flocculant in form of clean activated sludge are shown on Figs 5–7.

Basing on sedimentation curves the settling velocity was calculated, considering straight fragment of curve to calculation. For each test the parameters of thickened sludge were calculated, which were final concentration of sludge and solid phase contents. The results of calculations are presented in Tables 1–3.

Shape of sedimentation curves and their inclination angles indicate that settling velocity of coal slime wastes suspension lowers with growth of initial concentration.

Analyzing the calculated parameters of sludge and suspension settling velocities in samples without addition of bio-flocculants and with their use in form of yeasts of type *Rhodotorula* as well activated sludge it can be noticed that addition of bio-flocculants in amount of 2 ml/dm^3 causes small growth of suspension's settling velocity for low initial concentrations (for 20 and 30 g/dm^3). For higher initial concentrations, 40 and 60 g/dm^3 the settling velocity grows by higher doses of bio-flocculants, while bio-flocculant in form of yeasts of type *Rhodotorula* causes better results than bio-flocculant in form of activated sludge. For initial concentration 20 g/dm^3 the triple growth of settling velocity was observed by dose of 10 ml/dm^3 and quadruple growth of settling velocity by dose of 20 ml/dm^3 of bio-flocculant in form of yeasts of sort *Rhodotorula*. For other concentrations, 30, 40 and 60 g/dm^3 the growth of settling velocity was about double for this bio-flocculant. The bio-flocculant in form of activated sludge from municipal sewage treatment plant influenced not significantly on settling velocity of coal slime wastes.

Furthermore, the growth of final concentration (βk) and solid phase contents (αk) in thickened sludge with growth of bio-flocculants doses amounts was observed. Comparing with sample “0”, the growths of final concentration and solid phase contents were achieved for bio-flocculant in form of yeasts of sort *Rhodotorula* in amount of 10 ml/dm^3. However, this was not observed in all cases.

The observed better efficiency of bio-flocculant acting in forms of yeasts of sort *Rhodotorula* than activated sludge in purpose of coal slime wastes sedimentation can be explained by slightly worse qualitative parameters of this sludge what was shown by its macroscopic evaluation.

Summary

The investigations of application of new sources accelerating sedimentation process indicated that certain group of microorganisms exist which causes flocculation of mineral particles. In conducted experiments it was proved that applied bio-flocculant in form of yeasts of type *Rhodotorula* causes acceleration of particles settling velocity in mineral suspension and gives better final effects of obtained sludge comparing to applied activated sludge from municipal sewage treatment plant. However, it should be remembered that process efficiency is achieved by ensure adequate conditions to grow for microorganisms. Bio-flocculation is innovative method of applying microorganisms to processes of mineral suspensions sedimentation allowing to significantly minimize the costs because such bio-flocculants occurs commonly and their cells can be taken from soil, water and air. It is worthy to continue the investigations in this direction.

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Badania nad wykorzystaniem bioflokulacji w procesie sedymentacji zawiesin mineralnych

Prędkość sedymentacji zawiesin mineralnych, a szczególnie tych drobno uziarnionych, stanowi ważne zagadnienie w procesach zagęszczania i filtracji w zakładach przemysłowych i oczyszczalniach ścieków. Na prędkość sedymentacji wpływa wiele czynników związanych m.in. z właściwościami materiału, charakterystyką wody, w której odbywa się proces oraz od dodatku środków przyspieszających - flokulantów. Dotychczas znanie i stosowane na szeroką skalę są flokulanty syntetyczne. Są to związki chemiczne o skutecznym działaniu lecz stosunkowo drogie. Wiadomo, że w procesie oczyszczania ścieków zachodzą przemiany metaboliczne w wyniku których mikroorganizmy występujące w osadzie czynnym wydzielają śluzowatą substancję, która chemicznie ma charakter polimerów.

Celem badań zaprezentowanych w artykule jest sprawdzenie możliwości zastosowania osadu czynnego z oczyszczalni ścieków komunalnych oraz biomasy drożdżaków z rodzaju Rhodotorula *jako środków przyspieszających sedymentację odpadów mułu węglowego. W artykule przedstawiono wyniki badań laboratoryjnych – testów sedymentacyjnych odpadów mułu węglowego w oparciu, o które wyliczono prędkość sedymentacji oraz parametry zagęszczonego osadu: średnie zagęszczenie końcowe i zawartość fazy stałej w osadzie.*

Zaprezentowane w artykule badania potwierdziły możliwość zastosowania mikroorganizmów do flokulacji zawiesin mineralnych.

Słowa kluczowe: sedymentacja, bioflokulacja, prędkość sedymentacji, odpady mułu węglowego