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Changes in Sewage Sludge Filtration Efficiency under Variable Conditioning Factors

Zmiana wydajności procesu filtracji osadów ściekowych przy zmiennych czynnikach kondycjonujących

One of the methods used to dewater sewage sludge is pressure filtration. The method allows for obtaining sewage sludge with substantially lower water content. This method has been mainly used for sludge that is difficult to dewater. The pressure filtration process depends on the type of filtration material, pressure, and filtration properties of the sewage sludge. Conditioning process is used to improve dewaterability of the sludge. Conditioning agents used in the process include organic substances, such as polyelectrolytes and structure-forming substances (e.g. cement or ash). It is very important to choose the optimal dose of these substances that allows for the improvement in properties of the sludge, first of all easiness of water release, change in viscosity and sludge structure. The experiment was conducted using the fermented sludge conditioned with organic substances, i.e. medium and strong cationic polyelectrolytes and structure-forming substances (cement and ash) in order to improve sludge dewatering efficiency before filtration. Properly chosen doses improved the properties of the sludge, and, consequently, increased dewaterability. The dewatering method used in the study was pressure filtration at two different pressures of 0.4 and 0.8 MPa, using BT 72/80 cotton fabric. The best filtration efficiency of 7.52 kg/m^{2}h was obtained for sludge conditioned before dewatering using a chemical method by adding C496 polyelectrolyte.

Keywords: **sewage sludge dewatering, pressure filtration, conditioning, filtration efficiency**

Introduction

Conditioning of sewage sludge is aimed to change its structure (larger flocs of sludge and more free water spaces) and properties (increased susceptibility to dewatering). With these processes, part of water is transformed from the bound form into free water or semi-bound water, which is easier to remove with less energy consumption. The following methods can be used for conditioning at different stages of the technological process:

- chemical methods,
- thermal methods,
- mechanical methods,
- unconventional methods (ultrasonic and electromagnetic fields).

One of the aims of conditioning is to increase the susceptibility of sludge to thickening and dewatering. It is almost always used before mechanical dewatering, and less frequently before gravity thickening processes [1, 2]. Sludge conditioning can be performed in different ways. It can begin from accelerated sedimentation through the flocculation process in the purification process and be continued in the sludge thickener, where, with addition of a suitable sedimentation or flotation agent, the content of solids optimal for dewatering is obtained, and ends with sludge dewatering [1]. Different final effects are achieved by using the same dewatering equipment depending on the conditioning method. For this reason, it is recommended to consider the advantages and disadvantages of using individual processing methods, taking into account the following effects:

– obtaining clear liquor,
– increased efficiency of dewatering devices,
– achievement of a higher degree of phase separation (separation of suspended substances from free water).

Increased sewage sludge dewatering efficiency can be achieved by adding polymers or lime, gypsum, ash, diatomaceous earth, and by freezing and thawing or heating the dewatered substances.

In addition to traditional coagulants, polyelectrolytes have also been used in mechanical sludge dewatering technologies for pre-treatment of the sludge, which is particularly useful in the case of the sludge that is hard to thicken or fermented sludge. Faster and easier sedimentation is achieved by combining small particles into larger groups (flocs) in the flocculation process [3, 4].

During the examinations of dewaterability of sewage sludge conditioned with polyelectrolytes in the pressure filtration process, the polyelectrolyte dose is chosen based on filtration resistance, taking into account also capillary suction time. Christensen et al. [5] used a pressure filtration process to dewater sewage sludge that contained oil, ash, lime and alumina salts conditioned with different polymers. These researchers found that the relationship between capillary suction time (CST) and specific resistance was very similar. The results obtained by Taya and Jeyaseelan [6, 7] are consistent with these findings. However, the authors failed to find a significant correlation between the above dewatering indices and their physical properties, such as particle size. A study published by Chang et al. [8] found that such a relationship exists since these researchers demonstrated an increase in CST with an increase in particle size. The examinations of sludge conditioned using polymers demonstrated that the doses determined based on specific resistance were significantly higher than those determined based on CST. Many scientists [9-12] have emphasized that during conditioning of sewage sludge with polyelectrolytes, optimal values of polymer doses should be chosen based on the capillary suction test (CST). For most cases of sewage sludge, doses of polyelectrolytes are small and generally do not exceed 15 mg/g d.m. of sludge [1]. Overdosing leads to a remarkable deterioration of the effects of sludge dewatering. Application of small doses of polyelectrolytes during conditioning does not increase sewage sludge mass, which represents an advantage of these reagents in relation to traditional coagulants, mainly hydrolysing aluminium and iron salts and lime [13]. Reagents dosed into sewage sludge must be well mixed with the sludge. The polymers used for sludge conditioning are water soluble high molecular weight synthetic or natural compounds. Their very good coagulation or flocculation efficiency results mainly from their structure, high molecular weight (up to several million), the presence of functional groups (e.g.: -OH, -COOH, $-NH_2$, $-SO_3H$) and adsorption activity. Polyelectrolytes are generally more effective coagulants and flocculants compared to non-ionic polymers and, depending on the electric charge, they are divided into cationic (polycation, e.g. vinylpyridine), anionic (polyamide, e.g. sodium polyacrylate) and cation-anionic polyelectrolytes, which, during dissociation, form both acid and base groups (e.g. polyacrylonitrile and polyacrylamide) [14].

Sludge conditioning can be also conducted using structure-forming substances such as ashes, coal or diatomaceous earth preparations. Addition of these substances, forming a specific scaffold in the sludge, significantly improves susceptibility of sludge to dewatering. Studies conducted in Poland and abroad have demonstrated that the use of polyelectrolytes, ashes or gypsum in sludge conditioning improves filtration properties, thus causing changes in sludge structure [1, 15-17]. Significant improvements in terms of sludge dewatering were achieved by using coal suspensions for sludge preparation. This is related to a higher density of carbon particles, which ensures higher resistance to shear and compression during mechanical dewatering in filtration presses. Sander et al. [18], Broeckel et al. [19] and Thapa et al. [20] have used carbon dust with polyelectrolytes in order to improve the efficiency of the process of sewage sludge dewatering. Furthermore, Smollen and Kafaar [21] used powder carbon for the methods combined with polyelectrolytes in order to improve dewatering of sewage sludge. They found, that adding powder carbon to loose sludge flocs that were formed during flocculation results in formation of porous, permeable and rigid structure of the net. Volatile ashes, cement dust and other materials have also been used as 'skeleton-forming' materials [22-24]. It is believed that these substances form a permeable and rigid structure of a net, which is likely to remain porous during mechanical dewatering in filtration process. This intensifies the effect of sludge dewatering. In order to improve the effect of dewatering, Zhao [25] and Bień et al. [26] used 'skeleton-forming' gypsum connected with polyelectrolytes. Furthermore, addition of brown coal to sewage sludge [27] leads to an increase in calorific value of sewage sludge, which, after dewatering, can be combusted without supplying additional fuel. Sludge susceptibility to dewatering due to thi type of conditioning and the amount of conditioning agents to be used are determined in an experimental manner. Sludge dewatering is assessed after adding scaffold-building substances, using a filtration resistance test. Good dewatering effects are typically observed when specific filtration resistance does not exceed the level of from 2 to $3 \cdot 10^{12}$ m/kg. Filtration resistance decreases with the higher doses of addition substance. Sometimes sludge conditioning with these methods do not produce the expected effects or high amounts of substance are needed. Combined methods of previous addition of conditioning chemicals are recommended in such cases [1, 28]. The aim of the present study was to examine the interaction between flocs contained in sewage sludge destabilized with chemical conditioning and addition of mineral substances to maintain a certain efficiency and rate of the filtration process, which also resulted in an increase in the effects of sludge dewatering.

1. Research methodology

The research was conducted for samples of fermented sludge obtained from the municipal sewage treatment plant "Warta" S.A. in Częstochowa, Poland. The sludge was initially subjected to physico-chemical tests in order to determine its properties (Table 1). The volume of the sludge sample was 100 mL. The samples were conditioned with polyelectrolytes and/or cement and ash were added. Sludge conditioning was followed by mechanical dewatering by means of pressure filtration for two different pressures (0.4 and 0.8 MPa). The pressure of 0.4 MPa was used to reflect the pressure at which membrane presses are operated in sewage treatment plants, while the double value of the pressure (0.8 MPa) was supposed to verify whether the increase in operating pressure improves dewatering efficiency. Ash and cement were added in doses of 0.7 and 1.4 g/100 mL of sewage sludge (doses chosen based on tests performed prior to the examination).

Table 1. **Physico-chemical properties of raw sludge (mean values from 5 repetitions)**

Parameter	Unit	Value
Water content in raw sludge	%	97.6 ±0.06
Content of mineral substances	%	42.0 ±0.2
Content of organic substances	%	58.0 ±0.2
pH		7.1 ±0.15

Physical parameters of sewage sludge were determined: water content of sewage sludge, dry matter in the sludge, residue on ignition, loss on ignition, and sludge pH. These examinations were performed with consideration for:

– water content, dry matter of sewage sludge according to PN-EN 12880 standard,
– residue on ignition, loss on ignition according to EN 12879,
– pH using a pH meter (Cole Palmer 59002 - 00).

The next step was to perform capillary suction time (CST) tests. This test was used in the measurements performed for raw sludge. Several different doses of polyelectrolytes were applied after obtaining CST results for raw sewage sludge. The main examinations were performed for the most favourable doses of polyelectrolytes C496 and PRAESTOL 863BC, with 4.5 and 6 mg/g d.o.m., respectively. The following definitions of polyelectrolytes were used for the description of the obtained results:

- polyelectrolyte 1 d1: polyelectrolyte C496 with the dose of 4.5 mg/g d.o.m.,
- polyelectrolyte 1 d2: polyelectrolyte C496 with the dose of 6 mg/g d.o.m.,

- polyelectrolyte 2 d1: polyelectrolyte PRAESTOL 863 BC with the dose of 4.5 mg/g d.o.m.,
- polyelectrolyte 2 d2: polyelectrolyte PRAESTOL 863 BC with the dose of 6 mg/g d.o.m.

Several combinations of sludge conditioning were used in the studies:

- polyelectrolyte dosage,
- addition of ash,
- addition of cement,
- combined method: polyelectrolyte and cement,
- combined method: polyelectrolyte and ash.

The examinations allowed for the determination of the following parameters of the pressure filtration process: filtration rate, filtration efficiency, specific filtration resistance.

Filtration rate was computed from the formula:

$$\nu = \frac{V}{t},\ \mathrm{cm^3/s} \tag{1}$$

where:
ν - filtration rate, cm^3/s,
V - volume of filtrate after completion of filtration at time t, cm^3,
t - total filtration time (until the moment of pressure drop on the pressure gauge), s.

Filtration efficiency was computed from the formula:

$$Q = \frac{Mmo}{F \cdot t},\ \mathrm{kg/m^2h} \tag{2}$$

where:
Q - filtration efficiency, kg/m^2h,
Mmo - mass of sludge cake after dewatering (before drying), kg,
F - filtration area (equal to the surface area of the circle of the inner part of the filter), m^2,
T - total filtration time (until the moment of pressure drop on the pressure gauge), h.

Specific filtration resistance (according to PN-EN 14701-2) was computed from the formula:

$$r = \frac{2\Delta P \cdot F_f^2 \cdot b}{\mu \cdot c},\ \mathrm{m/kg} \tag{3}$$

where:
r - apparent mass filtration resistance, m/kg,
ΔP - filtration pressure, N/m^2,
F_f - filtration area, m^2,

b - directional coefficient of a straight line which is a function of $t_f/V_f = f(V)$, s/m^3,
t_f - filtration time, s,
V_f - filtration volume, m^3,
μ - filtrate viscosity, $N \cdot s/m^2$,
c - particulate mass per liquid volume unit in sewage sludge, kg/m^3.

2. Results

Examinations of sewage sludge dewatering were performed for a number of selected sewage sludge conditioning combinations. The focus was on filtration efficiency and filtration resistance (which is directly related to filtration efficiency) and the expected sludge dewatering effects. The following diagrams illustrating the results show the most favourable values achieved for individual combinations of sludge conditioning.

The highest filtration efficiency was obtained for tests with sludge conditioned with polyelectrolyte 1 at a dose of 6 mg/g d.o.m. at filtration pressures of 0.4 and 0.8 MPa, while the lowest efficiency was obtained for the sludge with addition of ash at a dose of 0.7 g (Figs. 1 and 2). In the case of the tests with sludge conditioned with polyelectrolytes and ash or cement at filtration pressure of 0.4 MPa, the highest efficiency was obtained for the test with polyelectrolyte 1 at the dose of 4.5 mg/g d.o.m. and ash at the dose of 1.4 g/100 mL, whereas the lowest efficiency was found for the test with polyelectrolyte 1 at the dose of 4.5 mg/g d.o.m. and cement at the dose of 0.7 g/100 mL. With regards to the tests conducted at the higher pressure, the best efficiency was achieved for the test with polyelectrolyte 2 at the dose of 6 mg/g d.o.m. and ash at the dose of 1.4 g/100 mL, whereas the lowest values were recorded for polyelectrolyte 2 at the dose of 4.5 mg/g d.o.m. and cement at the dose of 0.7 g/100 mL.

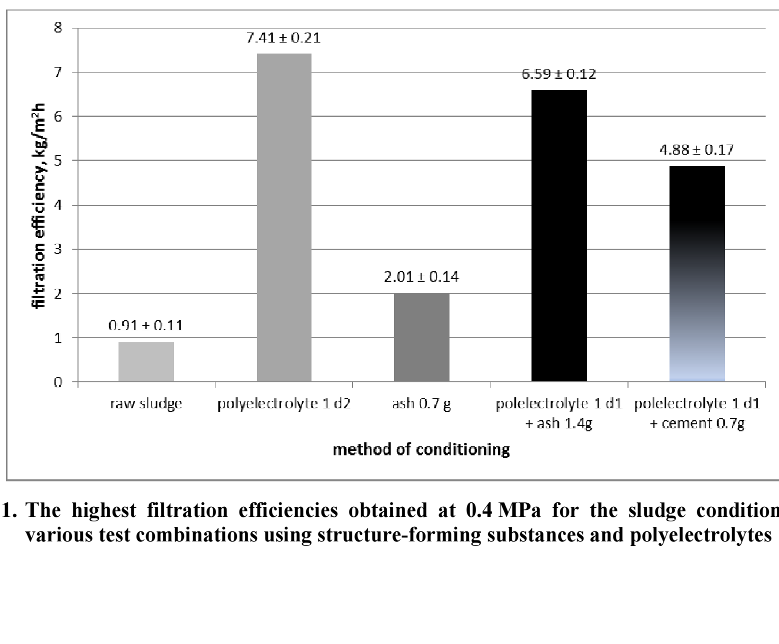

Fig. 1. The highest filtration efficiencies obtained at 0.4 MPa for the sludge conditioned in various test combinations using structure-forming substances and polyelectrolytes

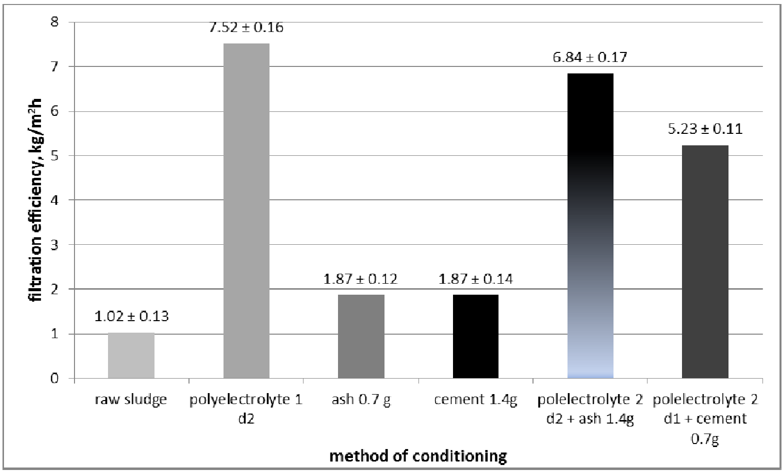

Fig. 2. The highest filtration efficiencies obtained at 0.8 MPa for the sludge conditioned in various test combinations using structure-forming substances and polyelectrolytes

Among the results obtained at pressure 0.4 MPa, the highest water content of 92.6% was obtained for dewatering of raw sewage sludge (Fig. 3). By increasing the process pressure to 0.8 MPa, an insignificant change in final water content (91.4%) was obtained. Using polyelectrolytes for conditioning as the only conditioning factor at the highest applied pressure, final water content was 88.1%. Significantly better effects were obtained after conditioning of sludge with ash. Water content of 82.4%, compared to water content in raw sludge (91.4%), decreased by 9 percentage points. The lowest final water content of 75% was found for the dewatering of sludge conditioned with a combined method using polyelectrolyte 2 at a dose of 6 mg/g d.o.m. and ash at a dose of 1.4 g/100 mL (Fig. 4).

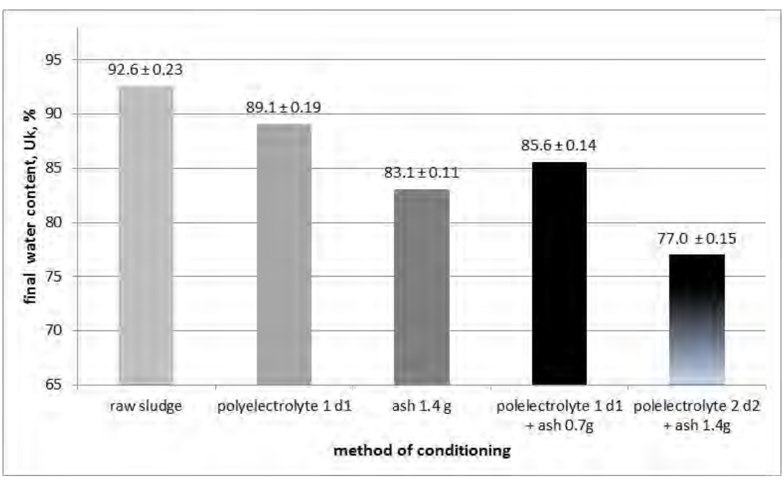

Fig. 3. The highest final water content values after filtration conducted at 0.4 MPa for the sludge conditioned with various test combinations using structure-forming substances and polyelectrolytes

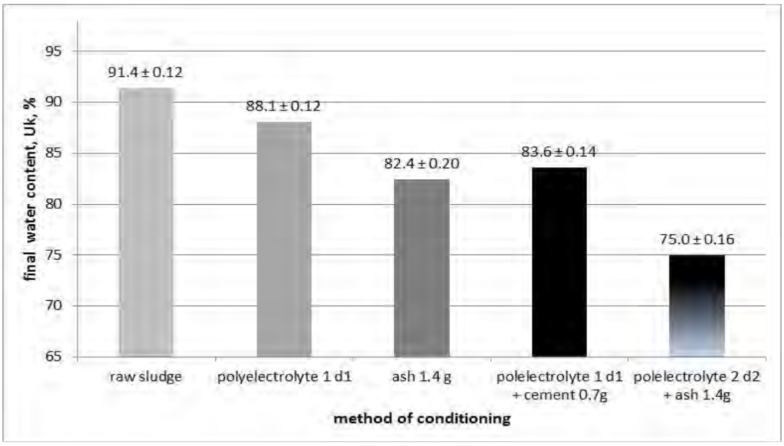

Fig. 4. The highest final water content values after filtration conducted at 0.8 MPa for the sludge conditioned with various test combinations using structure-forming substances and polyelectrolytes

With regard to the results of filtration resistance at 0.4 MPa, its value for raw sludge was $1.98\cdot10^{13}$ m/kg, whereas at 0.8 MPa, this was $1.17\cdot10^{13}$ m/kg. After addition of polyelectrolytes to the sludge and filtration at 0.4 MPa, filtration resistance declined to $0.76\cdot10^{13}$ m/kg, whereas at 0.8 MPa, filtration resistance was $0.54\cdot10^{13}$ m/kg. Addition of structure-forming substances to the sludge did not lead to significant changes in filtration resistance, regardless of the pressure (Fig. 5 and 6). Reduction in resistance was found for the conditioning by means of the methods combined with the use of polyelectrolyte and cement. The value of this parameter at both applied pressures was $0.87\cdot10^{13}$ m/kg. The change in the structure-forming factor from cement into ash did not result in the expected reduction of filtration resistance.

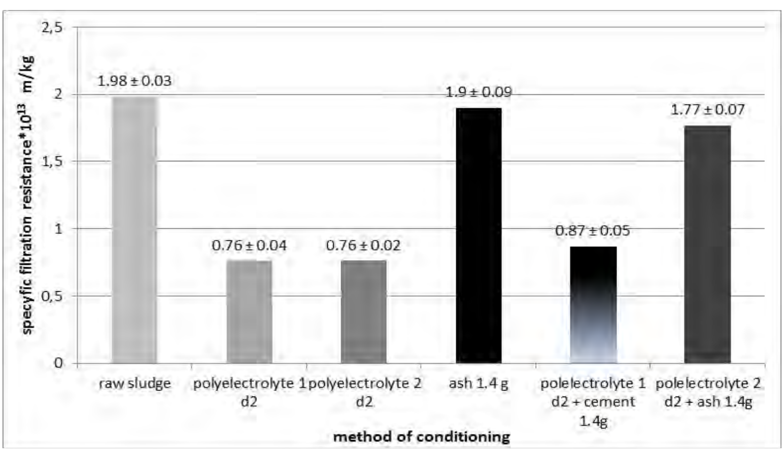

Fig. 5. The lowest filtration resistance values obtained following the process conducted at 0.4 MPa for sludge conditioned with various combinations using structure-forming substances and polyelectrolytes

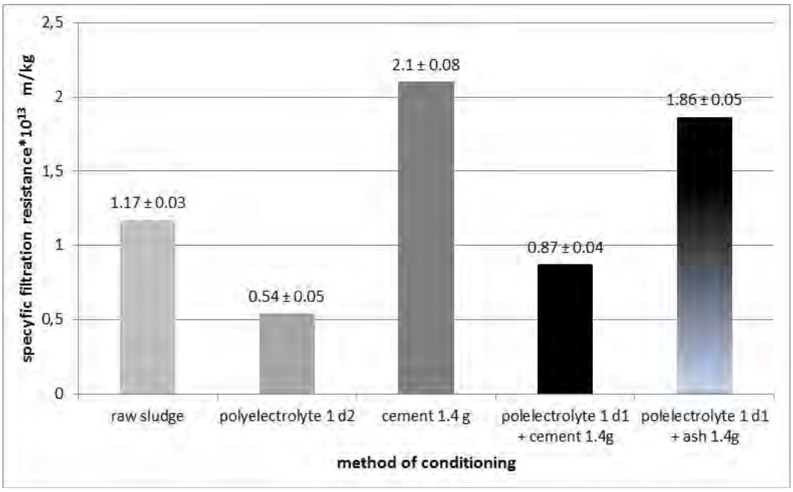

Fig. 6. The lowest filtration resistance values obtained following the process conducted at 0.8 MPa for sludge conditioned with various combinations using structure-forming substances and polyelectrolytes

3. Summary of results

The results obtained in the study show that conditioning of raw sludge with both polyelectrolytes and structure-forming substances leads to an increase in filtration efficiency and a decrease in final water content in the sludge. The filtration resistance was also lower in most cases after the addition of these substances. An increase in filtration pressure resulted in a slight increase in its efficiency and a decrease in final water content. However, in some cases, tests with structure-forming substances at a higher pressure also resulted in an increase in specific filtration resistance. For the obtained results of filtration efficiency, final water content and specific filtration resistance, the highest and lowest values of these parameters were selected for the tests with polyelectrolyte alone and structure-forming substance, and then for the tests with the addition of both polyelectrolyte and structure-forming substances, separately for 0.4 and 0.8 MPa, as presented in the above diagrams (Figs. 1 to 6).

The task of sewage sludge chemical conditioning mechanisms is to destroy the sludge colloidal system and flocculation of sludge flocs by adding e.g. polyelectrolytes, coagulants and other chemical substances. A high cost of these substances encourages searching for cheaper solutions. As demonstrated by the results, these requirements are met by the ash and cement used in the study. The spherical structure of ash particles and their roughness as well as the content of large amounts of SiO_2 and Al_2O_3 led to the formation of active locations on the surfaces of these particles. The large specific surface area of ash particles leads to the adsorption of sludge particles and, consequently, to the formation of larger agglomerates and an increase in the efficiency and rate of sludge dewatering. A significant amount of negatively charged sludge particles leads to the repulsion of particles due to electrostatic effects and forms a stable system that affects the efficiency of sludge dewatering [14]. Due to the properties of added chemical substances that lead to destabilization of the colloidal systems of sewage sludge, mineral particles act as a core for aggregation of sludge flocs on them. Deformation of raw sludge with high compressibility factor under pressure leads to limitation in the size of microchannels which release water until filtration process is stopped. Adding ashes and cement led to the formation of microzones with sludge flocs concentrated around particles (cores) of the added chemical substances. This resulted in an increase in the size of flocs and the bridging of microspheres, which resulted in large, reinforced agglomerates of sludge flocs. These agglomerates, being resistant to structure damage caused by high filtration pressure, led to the construction of their skeleton, which formed a permeable and rigid structure increasing the efficiency and effectiveness of sludge dewatering [14].

Conclusions

The results obtained in this study and their detailed analysis lead to the following conclusions:

1. The best results for filtration efficiency were obtained when sludge was conditioned before chemical dewatering by adding polyelectrolyte C496 at a dose of 6 mg/g d.o.m. at 0.8 MPa. The filtration efficiency of 7.52 kg/m^2h was obtained in this case. The lowest efficiency was achieved for the sludge conditioned with ash at a dose of 0.7 g/100 mL and cement at a dose of 1.4 g/100 mL, at a filtration pressure of 0.8 MPa. In these tests, filtration efficiency was 1.87 kg/m^2h.
2. The best results in terms of water content results were obtained for samples conditioned with structure-forming substances and polyelectrolytes. Such a combination allows for a much lower final water content than in the case of using only polyelectrolyte or a structure-forming substance. The lowest water content was obtained at 0.8 MPa for the PRAESTOL 863BC polyelectrolyte and ash at a dose of 1.4 g/100 mL. This combination resulted in water content of 75%.
3. The best results for specific resistance to filtration were obtained at filtration pressure of 0.8 MPa for tests with the addition of polyelectrolyte C496 at a dose of 6 mg/g d.o.m. Specific resistance in this test was $0.54\cdot10^{13}$ m/kg. In some cases, the increase in pressure caused the increase in specific resistance to filtration in the case of tests with ash and cement.

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Streszczenie

Jedną z metod odwadniania osadów ściekowych jest filtracja ciśnieniowa. Pozwala ona na uzyskanie osadów o znacznie mniejszym stopniu uwodnienia. Metoda ta wykorzystywana jest głównie dla osadów ciężko odwadniających się. Przebieg samego procesu filtracji ciśnieniowej zależy od rodzaju zastosowanego materiału filtracyjnego, wartości stosowanego ciśnienia, a także od właściwości filtracyjnych samych osadów ściekowych. W celu polepszenia zdolności odwadniania osadów przed procesem filtracji stosuje się proces kondycjonowania. Jako środki kondycjonujące mogą być stosowane substancje organiczne - polielektrolity oraz substancje strukturotwórcze - cement czy popiół. Bardzo ważny jest dobór dawki optymalnej tych substancji, pozwalającej na poprawę właściwości osadów, przede wszystkim łatwość oddawania wody, zmianę lepkości i struktury osadów. Badania prowadzone na osadach przefermentowanych kondycjonowanych substancjami organicznymi, tj. polielektrolitami średnio i silnie kationowymi, oraz substancjami strukturotwórczymi, takimi jak cement i popiół, miały na celu polepszenie zdolności odwadniania osadów przed filtracją. Odpowiednio dobrane dawki poprawiły właściwości osadu, przez co zdolność odwadniania uległa poprawie. Stosowaną metodą odwadniania była filtracja ciśnieniowa dla dwóch różnych ciśnień 0,4 i 0,8 MPa z zastosowaniem tkaniny bawełnianej BT 72/80. Najlepszą wydajność filtracji równą 7,52 kg/m^{2}h uzyskano dla osadów kondycjonowanych przed odwadnianiem metodą chemiczną poprzez dodanie polielektrolitu C496.

Słowa kluczowe: **odwadnianie osadów ściekowych, filtracja ciśnieniowa, kondycjonowanie, wydajność filtracji**