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Increase in efficiency of separating pollution from sewage sludge through the pressure filtration process

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ABSTRACT

The article discusses the issue of dewatering sludge from municipal wastewater. Separating solids from sewage sludge constitutes one of the initial steps in managing sewage sludge for further use or processing. The process of removing water from sewage sludge is particularly significant due to its high content in the raw sludge. This translates into problems with transporting and storing sludge. Additionally, the high water content relates to a reduction in the calorific value of the sludge. This paper focuses on the effect of adding polyelectrolytes and solid mineral substances on increasing the efficiency of the sludge dewatering process and eliminating total carbon from the oversedimentary water. The technical aspects of preparing sludge prior to dewatering are described on the basis of studies conducted on municipal sewage sludge. This research focused on conditioning and separating solids from wastewater coming from a selected treatment plant in terms of achieving the lowest final hydration and lowering the amount of total organic carbon in the leachate. The change in sludge compressibility after conditioning, the efficiency and speed of the filtration process were also analysed to reveal the mechanisms involved in the dewatering process.

Keywords: Sludge dewatering; Sludge conditioning; Total organic carbon

1. Introduction

Along with urban development, the length of sewerage systems and the number of necessary wastewater treatment infrastructure facilities are constantly increasing. There is, of course, the need to maintain hygienic standards, which is inextricably related to the problem of increasing the amount of sludge generated from wastewater. These sludges can be treated both as waste as well as a valuable raw material for further processing. Managing sludge is also partly enforced by searching for alternative energy sources and the necessity to reduce consumption of natural resources. The fact that sludge volumes are steadily increasing also works in favour of continuous use and processing of sewage sludge [1].

Sludge is formed during various stages of wastewater treatment and constitutes a compact suspension in a domestic wastewater mixture. Its physical and chemical characteristics depend on the type and technical condition of the sewerage system, the treatment technology, and the standard of living of the area's inhabitants. At the same time, there is no uniform characteristic of sewage sludge which means that its properties can vary depending on where the wastewater is treated. Additionally, it can also vary in annual, monthly, and even daily cycles. The high efficiency of modern wastewater treatment technologies makes it possible to assume that virtually the entire amount of pollutants carried in wastewater is accumulated in biomass in the form of sludge. Each wastewater treatment plant is forced to include the mass of the pollutant load at the inlet and the sludge at the outlet in its balance sheet. This makes it necessary to properly manage the generated sludge. The possibilities of

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managing sludge are mainly determined by the technologies used at a particular facility. For facilities that are being built or upgraded, it is necessary to determine the direction of managing the generated sludge before the work begins. The high degree of hydration translates into technical problems for further transformation [2–4]. Thus, in order to be able to incinerate or process sewage sludge, it is necessary to deprive it of as much water as possible before further processing. Water in sewage sludge exists in four "states":

- free water, unbound with sewage sludge solids;
- colloidal water stored inside the floc structure;
- capillary water, bound mainly by adhesive forces;
- hydration water, that is, water that is biologically bound by organisms living in the sludge.

Mechanical dewatering is a traditional technique used in managing sludge, while its effectiveness is limited due to the hydrophilicity of extracellular polymeric substances [5–7]. Traditional mechanical dewatering is ineffective in reducing the amount of sludge water present in colloidal and bound form in sludge. Therefore, it is necessary to take advantage of sludge conditioning prior to mechanical dewatering in order to improve the efficiency of the process [5,8]. Various methods of sludge enrichment prior to dewatering are being tested, such as oxidation, acid–base treatment, thermolysis, and chemical pretreatment [9]. It is still practical and effective to use coagulation. The process is popular due to its high efficiency and relatively low cost [5,10]. The effectiveness of coagulation depends largely on the selected coagulant. Traditional inorganic and organic coagulants, such as aluminium salts, iron salts, and polyacrylamide, are widely used in wastewater treatment as well as sludge conditioning [11]. However, certain deficiencies of using coagulants are becoming apparent, such as high doses of inorganic salts, the high cost of polyacrylamides, and the toxicity of residual aluminium ions and polymer monomers [5]. Therefore, it is significant and necessary to search for high-performance, low-cost and environmentally friendly coagulants.

An example consists in using polysilicate for sludge coagulation, which possesses excellent charge neutralisation and adsorption properties as well as bridging capacity. It is a promising sludge dewatering agent that can act as a skeletal material and form hydrophobic channels to improve sludge dewatering performance [5,10]. Currently, polysilicate salts have shown satisfactory performance in wastewater treatment. It has also been shown that the combination of Na_2SiO_3 (sodium metasilicate) and $FeCl_3$ (ferric chloride) may improve the efficiency of dewatering sludge [2]. Na_2SiO_3 with $FeCl_3$ has been used as a conditioner by adding it to communal waste in order to decrease the water content. Experimental observations showed that Na_2SiO_3 can optimise the effect of $FeCl_3$ during sludge dewatering resulting in a reduction in sludge hydration of about 3.3%. Then 1.67% by weight of fly ash was added, the moisture content of the filter cakes dropped to about 45%. The strong charge neutrality of $FeCl_3$ and the bridging function of Na_2SiO_3, led to destroying the original sludge structure and forming a new network structure. The new network structure made the sludge flocs stronger and reduced sludge compression, thus improving their dewaterability [2].

An innovative study has also been carried out using the thermal hydrolysis process (THP) and the conditioner sodium persulphate (SPS) to improve the dewaterability of sludge [12]. The results indicated that the sludge was characterized by better dewaterability after conditioning. The specific filtration resistance under the best conditions was 0.51×10^{11} m/kg, which means a decrease of 91.65% compared to raw sludge (6.11×10^{11} m/kg). The mechanism can be explained as follows: (1) the hydrophobicity of sludge increased after treatment; (2) the sludge flocs were re-flocculated by neutralising the charge, resulting in a loose and porous structure; (3) the structure of the extracellular polymeric substances and cells was destroyed and the bound water was released. It was found that conditioning by a combination of THP and SPS was an effective way to improve the dewaterability of sludge [12].

Reducing the water content of sludge constitutes the most effective strategy to reduce the costs of sludge treatment and management [13]. Therefore, research concerning the conditioning and mechanical dewatering of sewage sludge is of great importance and has a fundamental impact on subsequent sludge treatment processes.

This article provides new insights concerning the applications of engineering conditioning methods and mechanical sludge dewatering technology in the process of pressure filtration. Polyelectrolytes, gypsum, and ashes were used as conditioning agents, and changes in the total organic carbon content of the leachate were checked, bearing in mind the load returned to the wastewater treatment process line.

The scope of the work was to conduct a study of the interactions between the destabilized flocs contained in the sewage sludge by chemical conditioning and the addition of mineral substances on the reduction of the compressibility coefficient and final hydration, as well as the maintenance of a certain efficiency and speed of the filtration process.

2. Materials and methods

The research took advantage of preliminary and digested sewage sludge from a municipal wastewater treatment plant. This is a classic mechanical–biological treatment plant, where wastewater is strained on mechanical screens, sand removal in a horizontal sand trap, grease removal in an aerated skimmer, removal of perishable suspended solids in radial pre-settlers. Wastewater treatment by activated sludge method in multifunctional biological reactors (oxidation of organic compounds, nitrification, denitrification and biological defosfation), simultaneous precipitation of phosphates with iron compounds is applied. Sedimentation and thickening of suspended activated sludge takes place in secondary settling tanks, and then the treated wastewater is discharged to the receiving water body. The sewage sludge (primary and surplus) and the separated grease fraction is discharged directly to separate digesters (WKF). Table 1 presents the characteristics of the sludge.

The undertaken research intended to demonstrate the effect of changing the compressibility factor of sludge conditioned with polyelectrolytes as well as mineral substances (gypsum, ash) on its dewatering efficiency in the process of pressure filtration. The filtration process was carried out in accordance with the research model in Fig. 1.

Table 1
Characteristics of the tested sludge

	Primary sludge	Digested sludge
Initial hydration, %	97.1 – 98.4 ± 0.19	98.2 – 98.5 ± 0.17
Dry mass of sludge, g/L	29.0 – 16.0 ± 0.2	18.0 – 15.0 ± 0.22
Content of organic substances, g/L	18.5 – 10.2 ± 0.16	9.0 – 7.8 ± 0.17
Content of mineral substances, g/L	10.5 – 5.8 ± 0.13	9.0 – 7.2 ± 0.14
pH	6.8 – 7.1 ± 0.10	6.8 – 7.1 ± 0.10
CST, s	112 – 128 ± 8.0	786 – 865 ± 34.0

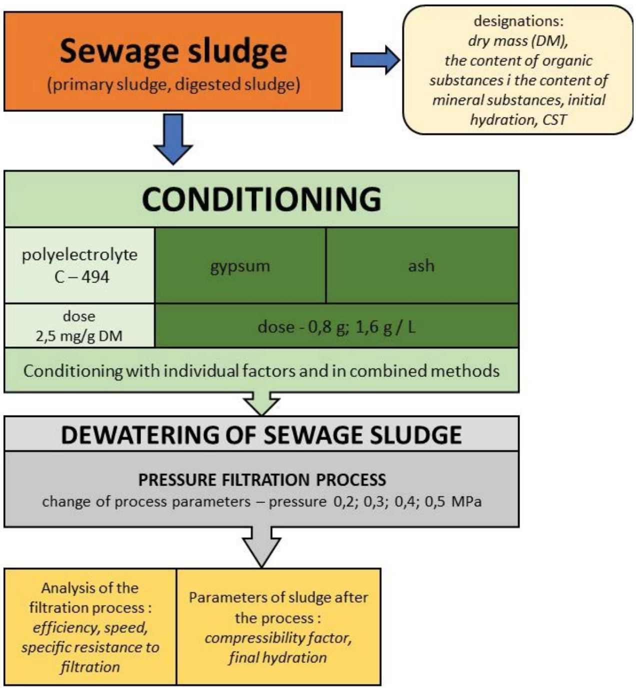

Fig. 1. Research model.

Before initiating the conditioning, the following were determined:

- doses of mineral substances, that is, gypsum and ash, as well as polyelectrolytes;
- parameters of the pressure filtration process – variable pressure,
  Used conditioning substances:
- *polyelectrolyte* – for chemical sludge preparation, the Kemira Superfloc® C-series polyelectrolyte was used: weak cationic C-494. The effect of the gel consists in exchanging the charge between the polyelectrolyte chain and the suspension. As a result of such an action, the suspension loses stability and becomes capable of coagulation or flocculation. In order to improve the properties and dewatering capabilities, a polyelectrolyte at a dose of 2.5 mg/g d.m.o. was added to the tested sludge, irrespective of the type of sludge.

Fig. 2. Pressure filtration station.

- *gypsum* – constitutes hydrated calcium sulphate which, when heated, loses some of its water and turns into burnt gypsum at a temperature of 120°C–130°C. In this form, it easily absorbs water and hardens, which is why it is used as a mortar material. Doses of 0.8 and 1.6 g/1 dm^3 of sewage sludge were used during the research.
- *ash* – it constitutes a solid residue obtained as a result of high temperatures on organic substances such as coal – it is a secondary product of combustion. Doses of 0.8 and 1.6 g/1 dm^3 of sewage sludge were used in the research.

Pressure filtration was carried out on a laboratory pressure filtration unit (Fig. 2). This device consists of a pressure filter, a compressed air cylinder, a control valve to cut off the air supply, a measuring cylinder to collect the filtrate, a filter fabric placed inside the filter, a manometer, and a stopwatch. A specific amount of sludge was measured with a measuring cylinder and poured into the filter pressure vessel onto the filter fabric placed in it beforehand. The air shut-off valve to the filter was then opened. This initiated the pressure filtration process. The volume of filtrate accumulating in the measuring cylinder at specific intervals was recorded. The test was carried out until characteristic air bubbles appeared with a simultaneous drop in pressure observed on the manometer. At that point, the air supply to the filter was cut off. After disassembling the filter, the filter fabric was removed with a sludge cake and placed in an evaporator preweighed on a laboratory scale and labelled. The evaporator and its contents were weighed and then placed in a dryer at 105°C for drying and subsequently determining the dehydration parameters.

Sewage sludge is a material that is compressible. Specific resistance usually increases with an increase in the pressure during the filtration process. The solid phase, or rather its particles, undergo deformation, varying according to the set pressure, which results in filling in the pores inside the resulting cake. Such a relationship can be expressed by Eq. (1):

$$r = r_0 \cdot p^s \tag{1}$$

where r – specific resistance of the sludge at pressure p, r_0 – a constant representing the specific resistance of incompressible sludge cake, p – filtration pressure, s – compressibility factor.

The compressibility factor is determined on the basis of a specific resistance to filtration test, according to several tests carried out on the same sample but at different pressures. Carrying out a chart of the specific resistance of filtration as a function of pressure (logarithmic coordinate system), we obtain the relationship log $r = f(\log p)$, which will be a straight line. The value of the compressibility factor was determined from the equation below, taking advantage of the analytical-graphic method. The value of the compressibility factor of the sludge will be expressed by the tangent of the angle of inclination of the straight line, as can be seen from Eq. (2) and Fig. 3.

$$S = t_g\alpha = \frac{\log r_2 - \log r_1}{\log P_2 - \log P_1} \tag{2}$$

where S – compressibility factor, r_1 – specific resistance at pressure p_1, r_2 – specific resistance at pressure p_2.

3. Results

Using sludge conditioning aims to change the physically and chemically bound water in sludge into gravity-free water, which is most easily removed from the sludge. Conditioning sludge with mineral substances (e.g., ash, gypsum) consists in adding them in given proportions to reduce the compressibility of the sludge. Whereas, excessively high compressibility of sludge results in inhibiting the dewatering process, so it is advisable to condition the sludge before dewatering. Fig. 4 presents the results obtained after pressure filtration of preliminary sludge with the addition of C-494 polyelectrolyte and ash at 0.8 g and 1.6 g per 1 dm^3 sample.

The addition of the ash + polyelectrolyte C-494 complex significantly reduced the value of the sludge compressibility factor for all considered filtration process pressures. A decrease in the compressibility factor was noticeable for both ash doses. It was also found that the higher ash dosage and polyelectrolyte dosage used translated into a lower compressibility factor value. The difference in the value of the discussed parameter between the raw sludge and the sludge with the addition of 1.6 g of ash and polyelectrolyte at the highest applied process pressure was 0.33 (Fig. 4.) The value of the sludge compressibility factor decreased with increasing pressure. The addition of ash and polyelectrolyte C-494 translated into a significant decrease in the hydration of the final sludge when compared to the non-conditioned sludge sample. A decrease in the water content of the sludge occurred for both ash and polyelectrolyte doses. The best sludge dewatering results were obtained at the highest applied pressure of 0.5 MPa and a higher ash dose in the combined polyelectrolyte method and reached 75.5% (Fig. 5).

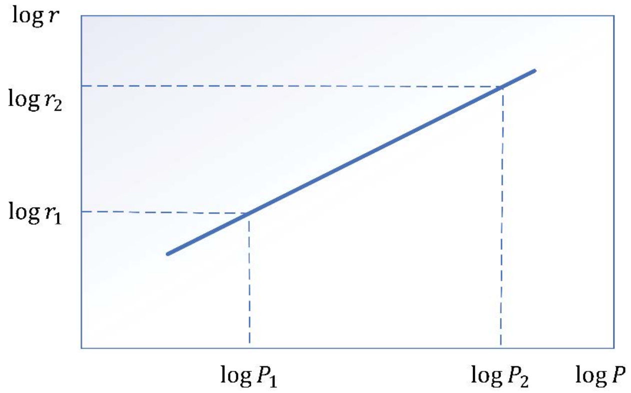

Fig. 3. Determining the sludge compressibility factor.

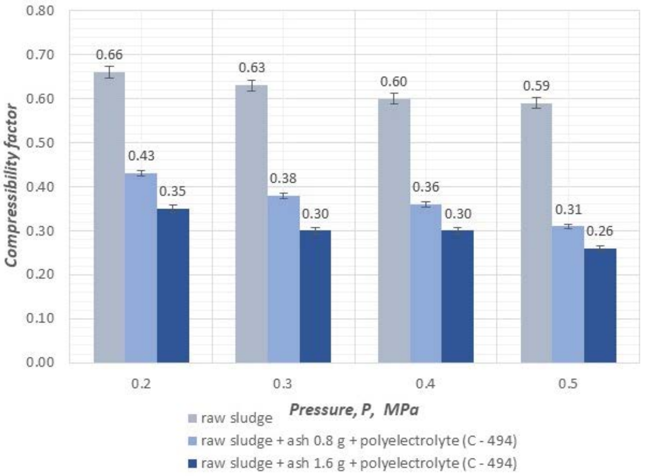

Fig. 4. Change in the compressibility factor of preliminary sludge and preliminary sludge with the addition of ash and polyelectrolyte C-494.

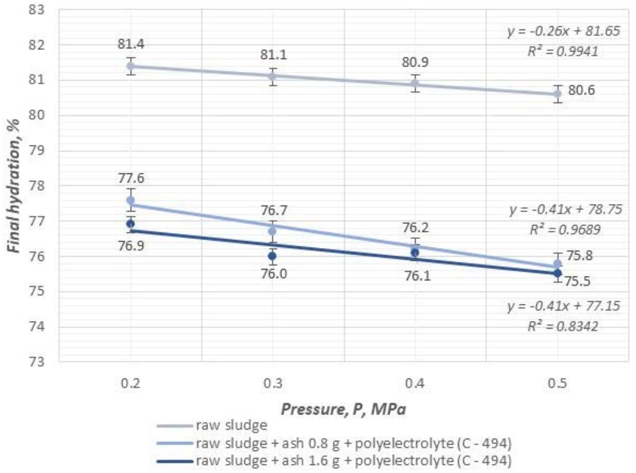

Fig. 5. Change in the final hydration of preliminary sludge and preliminary sludge with the addition of ash and polyelectrolyte C-494.

The addition of gypsum and polyelectrolyte C-494 resulted in reducing the compressibility factor of the sludge regardless of the pressure applied during the filtration process. The lowest value (0.27; Fig. 6) was obtained at 0.5 MPa for sludge conditioned with a dose of gypsum at 1.6 g in combination with the polyelectrolyte. A decrease in the value of the compressibility factor was noticeable for both gypsum doses. The differences in the values of the discussed parameter between the 0.8 g and 1.6 g doses were relatively small, reaching 12% (Fig. 6). Reducing the compressibility factor translated into a decrease in the hydration of the sludge after the filtration process (Fig. 7). The addition of gypsum and polyelectrolyte C-494 to the sludge resulted in reducing the water content of the sludge cake for both doses used and was more effective as the applied pressure increased. A higher dose of gypsum translated into achieving a lower final hydration (74.6%, Fig. 7).

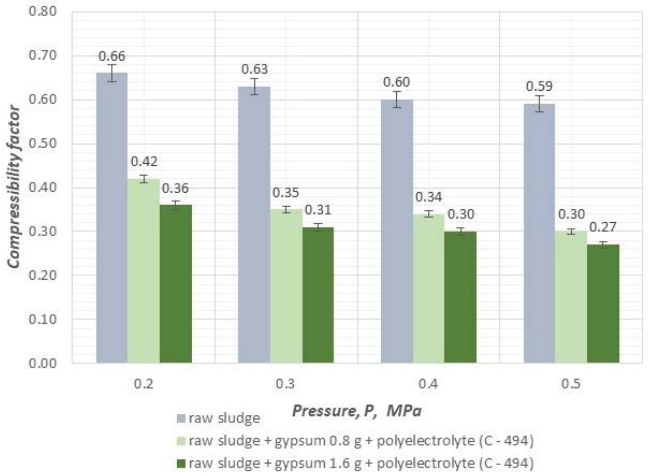

Fig. 6. Change in the compressibility factor of preliminary sludge and preliminary sludge with the addition of gypsum and polyelectrolyte C-494.

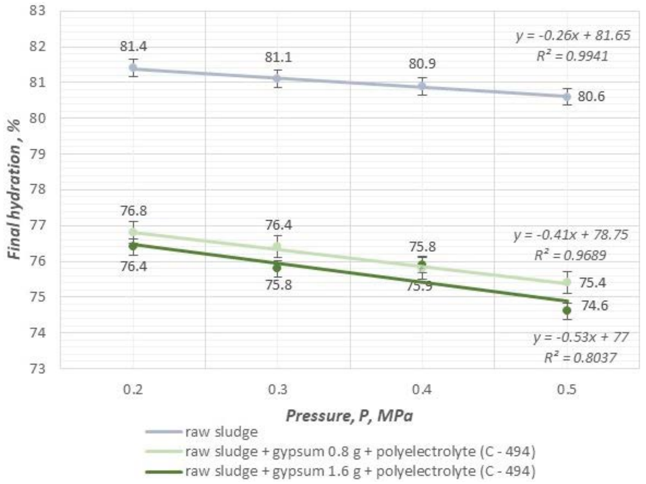

Fig. 7. Change in the final hydration of preliminary sludge and preliminary sludge with the addition of gypsum and polyelectrolyte C-494.

Fig. 8 presents the results obtained from conducting the pressure filtration process for digested sludge. The addition of ash and polyelectrolyte translated into a decrease in the value of the compressibility factor compared to the raw sludge. For an ash dose of 0.8 g, the compressibility factor achieved values of 0.49–0.34. This resulted in a decrease in the compressibility factor value from 0.15 to 0.22, depending on the applied pressure, in relation to the non-conditioned digested sludge (Fig. 8). The percentile difference was between 23.4% and 39.3%. For an ash dose of 1.6 g and polyelectrolyte, the value of the compressibility factor decreased from 0.42 to 0.28. The percentile difference in the factor's values in comparison to sludge without additives ranged from 34.4% to 50.0%. The reduction in the compressibility factor after the addition of ash and polyelectrolyte C-494 related to a significant decrease in the final hydration of the digested sludge. A decrease in water content occurred for both ash doses at each of the applied pressures during filtration. For the 0.8 g ash dose, the final hydration value was 78.4%–76.2%. The decrease in relation to digested sludge without additives was 4.8–6.2 percentile points. A slight improvement in reducing final hydration (77.9%–76.2%; Fig. 9) was obtained using the ash dose of 1.6 g.

By changing the conditioning agent of the digested sludge to gypsum and adding it in combination with the polyelectrolyte, a decrease in the value of the compressibility factor was also obtained. This decrease occurred for both gypsum doses (0.8 and 1.6 g) and for each of the filtration pressures used during the laboratory tests. For the gypsum dose of 0.8 g, the compressibility factor took on a value between 0.45 and 0.34 (Fig. 10). Compared to non-conditioned digested sludge, the decrease reached between 0.17 and 0.22. For the gypsum dose of 1.6 g, the value of the sludge compressibility factor ranged from 0.40 to 0.34, and as it can be observed this did not constitute a significant difference when compared to using the gypsum dose of 0.8 g. As the compressibility factor decreased, there was a decrease in the moisture content of the digested sludge after the filtration process. A decrease in final hydration occurred for both used gypsum doses and each filtration pressure value used in the experiment. For the gypsum dose of 0.8 g, the final hydration of the sludge ranged from 77.9%–75.9%

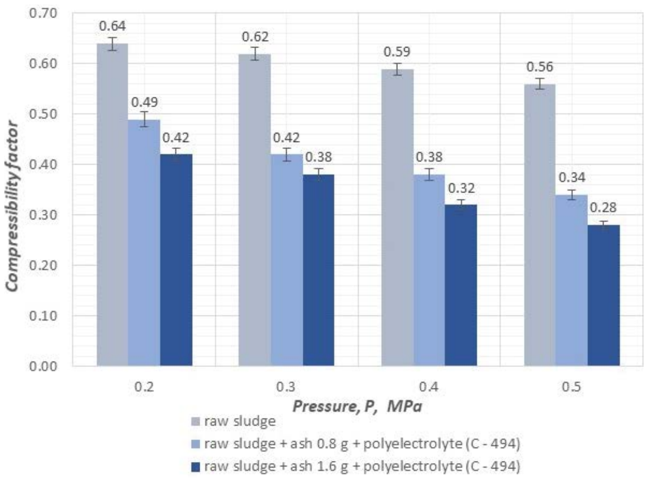

Fig. 8. The compressibility factor of digested sludge and digested sludge with the addition of ash and polyelectrolyte C-494.

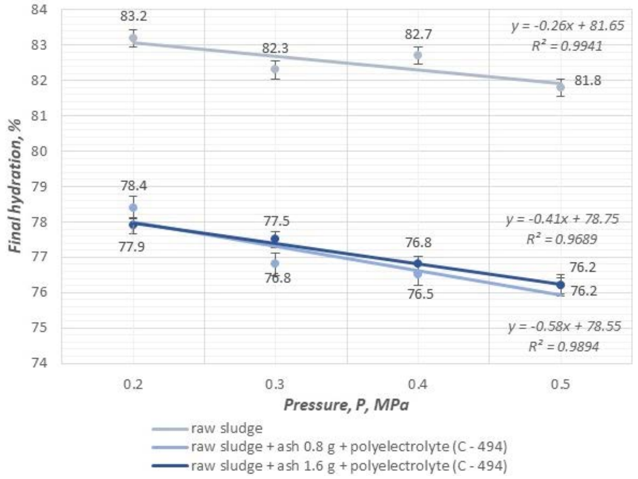

Fig. 9. The final hydration of digested sludge and digested sludge with the addition of ash and polyelectrolyte C-494.

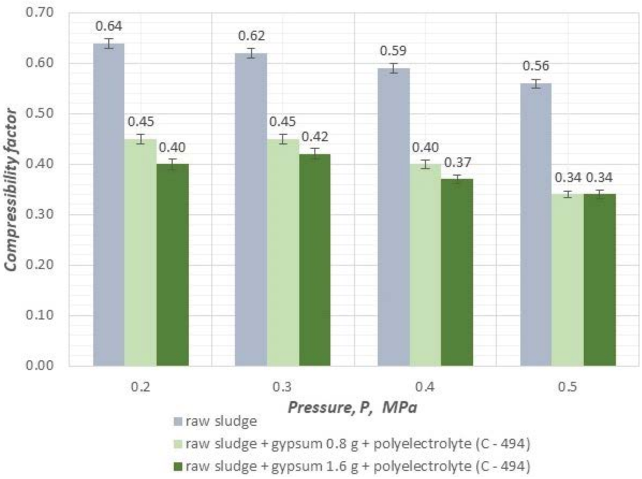

Fig. 10. The compressibility factor of digested sludge and digested sludge with the addition of gypsum and polyelectrolyte C-494.

(Fig. 11). Compared to digested sludge without additives, the decrease in hydration achieved 4.9–6.2 percentile points. At the dose of 1.6 g of the conditioning agent in question, the final hydration of the sludge decreased from 77.2% to 75.4%.

Other parameters of the filtration process – filtration efficiency and speed, as well as filtration resistance – were analysed (Table 2). For both preliminary sludge and digested sludge conditioned with ash and polyelectrolyte, an increase in the efficiency and speed of filtration were recorded. The best results were obtained when using a higher dose of ash and higher pressure during filtration of 0.5 MPa. Efficiency of 11.54 kg/m^2·h (for preliminary sludge) and 10.26 kg/m^2·h (for digested sludge) were obtained. Comparing to raw sludge, these were values higher at 8 kg/m^2·h (preliminary) and 7.19 kg/m^2·h (digested). The filtration speed also increased from 0.26 to 0.48 cm^3/s (preliminary sludge) and from 0.22 to 0.50 cm^3/s (digested sludge) (Table 2). A decrease in the filtration resistance of sludge conditioned by the combined ash and polyelectrolyte method was observed compared to raw sludge. The best results (58% reduction for preliminary sludge, 59% for digested sludge) were obtained when the sludge was conditioned with 0.8g ash and polyelectrolyte and a process pressure of 0.2 MPa (Table 2). Very similar results were obtained by changing the conditioning agent to gypsum (Table 3). Taking advantage of the same conditioning combination, a significant increase in filtration efficiency and speed was observed reaching 11.24 kg/m^2·h and 0.52 cm^3/s, respectively, at the highest conditioning and process parameters. The lowest reduction in filtration resistance was up to 58%.

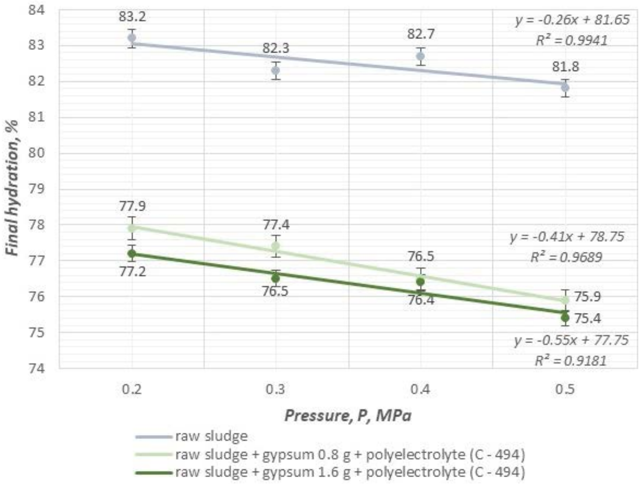

Fig. 11. The final hydration of digested sludge and digested sludge with the addition of gypsum and polyelectrolyte C-494.

The research was complemented by measurements of the change in total organic carbon in the leachate after the filtration process to verify whether mineral substances added to the sludge could act as adsorbents for organic carbon. For the preliminary sludge, the addition of ash together with the polyelectrolyte C-494 translated into a significant increase in the organic carbon content of the leachate compared to the sludge without additives at a filtration pressure of 0.2 MPa, (Fig. 12). For both ash doses, a decrease in total organic carbon content was observed when pressures of 0.3 MPa and above were applied during filtration. However, this was not a large reduction in carbon content, reaching 20%. For digested sludge, a small and irregular decrease in total carbon content at average 15% was noted for sludge conditioned with 0.8 g ash and polyelectrolyte. At a higher dose of ash, in several cases there was an increase in total organic carbon (Fig. 12).

The addition of gypsum at a dose of 1.6 g and polyelectrolyte C-494 at pressures of 0.3 MPa and higher translated into reducing organic carbon content compared to the raw preliminary sludge. The decrease was irregular and no trend of change in organic carbon content was observed. When gypsum was dosed at 0.8 g, there was a slight increase in the organic carbon content of the leachate in almost every case. Similar relations of changes in organic carbon content were observed when conducting filtration of digested sludge. Regardless of the gypsum dose and the process

Table 2
Change of selected filtration process parameters of preliminary sludge and digested sludge with the addition of ash and polyelectrolyte C-494

Conditioning method	Pressure (MPa)	Primary sludge			Digested sludge		
		Efficiency (kg/m^2·h)	Speed (cm^3/s)	Specific resistance to filtration, (m/kg × 10^{13})	Efficiency (kg/m^2·h)	Speed (cm^3/s)	Specific resistance to filtration, (m/kg × 10^{13})
Raw sludge	0.2	2.09 ± 0.015	0.15 ± 0.009	4.71 ± 0.06	1.89 ± 0.013	0.13 ± 0.008	6.17 ± 0.08
	0.3	2.45 ± 0.010	0.17 ± 0.007	4.36 ± 0.08	2.25 ± 0.012	0.12 ± 0.006	6.30 ± 0.09
	0.4	2.86 ± 0.017	0.19 ± 0.003	4.56 ± 0.08	2.76 ± 0.015	0.16 ± 0.009	5.60 ± 0.08
	0.5	3.54 ± 0.014	0.26 ± 0.010	5.06 ± 0.04	3.07 ± 0.019	0.22 ± 0.011	5.78 ± 0.07
Raw sludge + ash 0.8 g + polyelectrolyte (C-494)	0.2	8.92 ± 0.033	0.38 ± 0.018	1.97 ± 0.02	7.38 ± 0.022	0.35 ± 0.014	2.56 ± 0.021
	0.3	9.56 ± 0.039	0.42 ± 0.021	2.18 ± 0.04	8.75 ± 0.023	0.38 ± 0.015	2.14 ± 0.025
	0.4	9.07 ± 0.033	0.39 ± 0.019	2.26 ± 0.04	8.89 ± 0.023	0.42 ± 0.019	2.89 ± 0.019
	0.5	10.6 ± 0.042	0.47 ± 0.021	2.64 ± 0.04	9.09 ± 0.026	0.41 ± 0.019	3.35 ± 0.021
Raw sludge + ash 1.6 g + polyelectrolyte (C-494)	0.2	9.17 ± 0.036	0.39 ± 0.019	2.56 ± 0.04	7.93 ± 0.033	0.43 ± 0.020	2.58 ± 0.02
	0.3	9.85 ± 0.040	0.42 ± 0.022	2.17 ± 0.04	8.59 ± 0.030	0.44 ± 0.022	3.78 ± 0.04
	0.4	10.6 ± 0.043	0.41 ± 0.022	2.64 ± 0.05	9.78 ± 0.037	0.46 ± 0.023	3.65 ± 0.03
	0.5	11.5 ± 0.046	0.48 ± 0.024	3.87 ± 0.05	10.2 ± 0.039	0.50 ± 0.025	3.46 ± 0.04

Table 3
Change in selected filtration process parameters of preliminary sludge and digested sludge with the addition of gypsum and polyelectrolyte C-494

Conditioning method	Pressure (MPa)	Primary sludge			Digested sludge		
		Efficiency (kg/m^2·h)	Speed (cm^3/s)	Specific resistance to filtration, (m/kg × 10^{13})	Efficiency (kg/m^2·h)	Speed (cm^3/s)	Specific resistance to filtration, (m/kg × 10^{13})
Raw sludge	0.2	2.09 ± 0.015	0.15 ± 0.009	4.71 ± 0.06	1.89 ± 0.013	0.13 ± 0.008	6.17 ± 0.08
	0.3	2.45 ± 0.010	0.17 ± 0.007	4.36 ± 0.08	2.25 ± 0.012	0.12 ± 0.006	6.30 ± 0.09
	0.4	2.86 ± 0.017	0.19 ± 0.003	4.56 ± 0.08	2.76 ± 0.015	0.16 ± 0.009	5.60 ± 0.08
	0.5	3.54 ± 0.014	0.26 ± 0.010	5.06 ± 0.04	3.07 ± 0.019	0.22 ± 0.011	5.78 ± 0.07
Raw sludge + gypsum 0.8 g + polyelectrolyte (C-494)	0.2	9.02 ± 0.033	0.44 ± 0.025	3.01 ± 0.05	8.42 ± 0.032	0.42 ± 0.023	2.68 ± 0.04
	0.3	9.82 ± 0.039	0.49 ± 0.027	2.87 ± 0.04	8.93 ± 0.037	0.46 ± 0.025	2.48 ± 0.04
	0.4	10.4 ± 0.043	0.43 ± 0.025	2.45 ± 0.04	9.89 ± 0.041	0.48 ± 0.028	3.48 ± 0.05
	0.5	11.2 ± 0.046	0.49 ± 0.028	2.94 ± 0.05	11.2 ± 0.046	0.56 ± 0.034	3.47 ± 0.05
Raw sludge + gypsum 1.6 g + polyelectrolyte (C-494)	0.2	9.78 ± 0.036	0.42 ± 0.021	2.45 ± 0.04	8.87 ± 0.035	0.43 ± 0.021	2.49 ± 0.04
	0.3	10.4 ± 0.040	0.48 ± 0.027	3.07 ± 0.05	8.65 ± 0.034	0.44 ± 0.025	2.41 ± 0.04
	0.4	10.2 ± 0.043	0.51 ± 0.030	3.18 ± 0.05	10.2 ± 0.043	0.49 ± 0.029	2.78 ± 0.04
	0.5	11.2 ± 0.046	0.52 ± 0.032	2.95 ± 0.04	10.8 ± 0.046	0.52 ± 0.032	2.56 ± 0.04

pressure used, there were irregular changes in the organic carbon content of the leachate. Depending on the filtration pressure, there was an increase or decrease in the discussed parameter (Fig. 13).

4. Discussion

Pressure is an important parameter during dewatering in the pressure filtration process. The use of high pressure does not always increase filtration efficiency. Laheij et al. [14], in their study, found that a high dry matter content of 35%–40% by weight in dewatered sludge can be achieved by using a pressure of 0.3–0.4 MPa for filtration, but 60% dry matter content can be achieved at 6–10 MPa. Using variable pressure in the pressure filtration process, a fundamental difference in final hydration was achieved already at the stage of dewatering raw sludge. Between the lowest pressure applied (0.2 MPa) and the highest (0.5 MPa), a difference of up to 1% in hydration was obtained (81.4% – 0.2 MPa pressure and 80.6% – 0.5 MPa pressure). It was also noted that with increasing pressure the filtration resistance decreased slightly from 6.17 × 10^{13} m/kg (0.2 MPa) to 5.78 × 10^{13} m/kg (0.5 MPa). Confirmation of the results obtained can be found in the results presented by Zhao and Bache [15]. They conducted a study on the pressure filtration process taking into account the pressure and filtration time and polymer dosage to investigate the integrated effect on the dewatering of aluminous sludge. The results

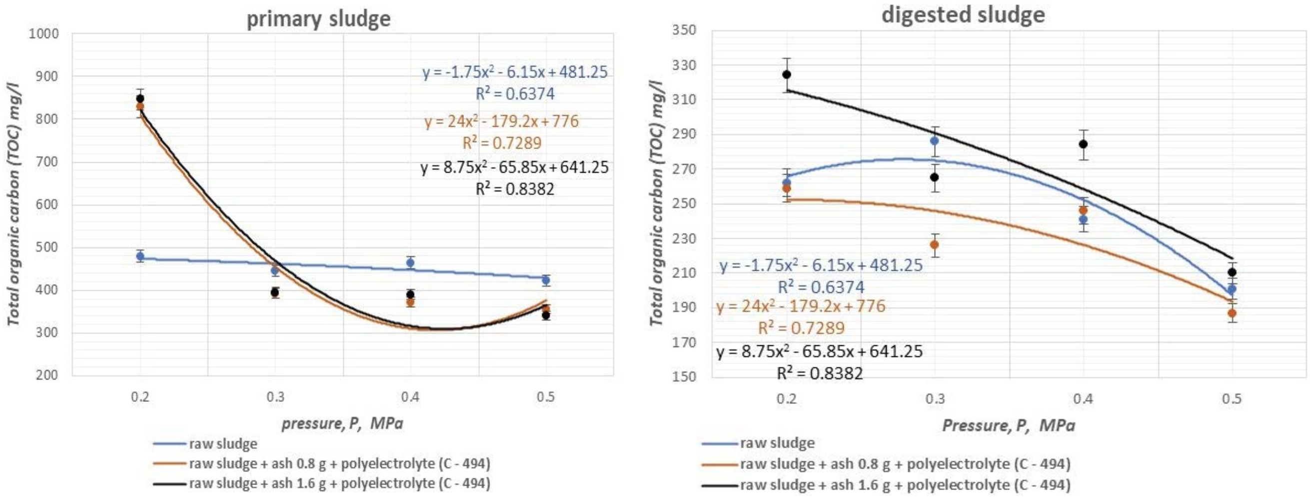

Fig. 12. Change in organic carbon content of over sedimentary water after filtration of preliminary and digested sludge conditioned with polyelectrolyte and ash.

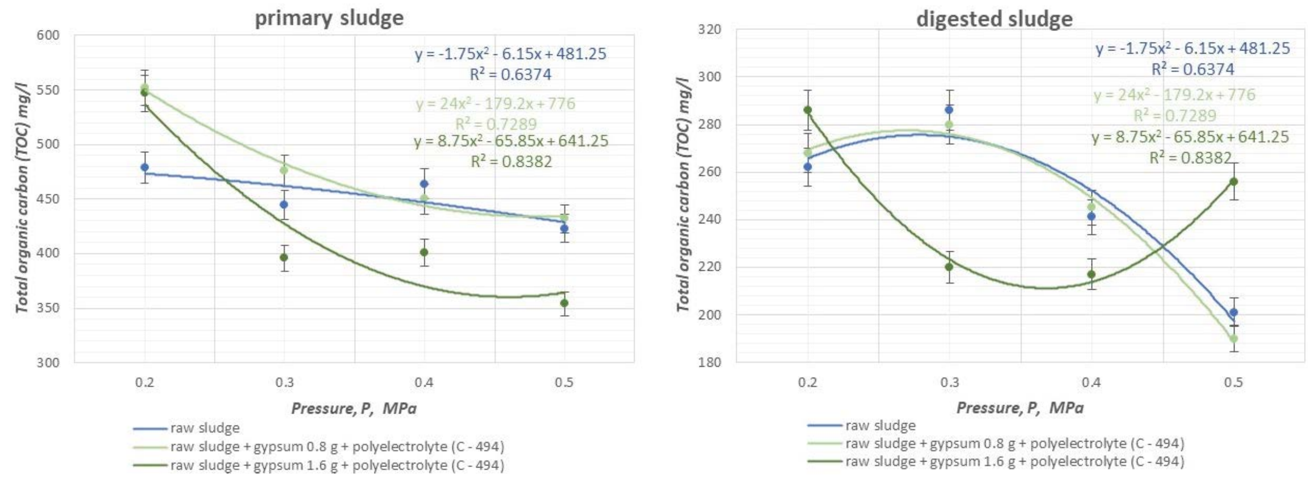

Fig. 13. Change in organic carbon content of over sedimentary water after filtration of preliminary and digested sludge conditioned with polyelectrolyte and gypsum.

showed that dewatering effects can be increased by increasing the pressure and filtration time. After reaching a certain optimum point, further increasing the pressure and lengthening the filtration time brings little improvement. Wu et al. [16] experimentally found that there was a pressure threshold, exceeding which significantly worsened the filtration process. A clear increase in efficiency at any applied pressure, and at the same time a decrease in filtration resistance, was obtained when sludge was prepared with polyelectrolyte followed by the addition of ash. The highest process efficiency of 11.5 kg/m^2·h (0.5 MPa), and filtration resistance of 3.46–1013 m/kg at the same pressure were recorded. Conditioning the sludge with polyelectrolyte and gypsum resulted in the highest concentration of dry matter in the dewatered sludge at 25%, at a pressure of 0.5 MPa. The use of low pressure of 0.2–0.5 MPa in the filtration process for dewatering properly prepared sludge can lead to 22% to 25% dry matter content in dewatered sludge. Confirmation of the presented effects can be found in the previously mentioned study by Laheij et al. [14]. On the other hand, Lee and Liu [17] claims that a much higher pressure of 28 MPa is able to provide about 45% dry matter concentration in the dewatered sample.

The efficiency of mechanical sludge dewatering depends mainly on the properties of the sludge, for example, the amount of extracellular polymeric substances, hydration, sludge particle size, dry matter content, etc. Prior to mechanical dewatering, the sludge is subjected to preparation in order to alter its properties and thus improve the conditions for releasing water. The chemical reactants used for sludge conditioning are expensive and significantly impact the overall cost of sludge management, so an important intention is to find a low-cost and effective way of conditioning. In the presented work, the chemicals used in the study such as fly ash and gypsum meet the requirements. The large specific surface area of fly ash particles leads to the adsorption of sludge particles and thus the formation of larger agglomerates and consequently an increase in sludge dewatering efficiency. The large number of negatively charged sludge particles results in the particles to repel each other due to electrostatic interactions and creates a stable system that affects the low efficiency during sludge dewatering. The negative load of sewage sludge is destabilised by the positive loads of aluminium, iron, or calcium silicate contained in the fly ash. As a result, this leads to destroying the stability of the colloidal particles and bringing them closer together. As a result of intermolecular Van der Vaals forces, colloidal particles combine into larger agglomerates. This reduces the compressibility of the sludge which has a significant impact on improving the dewaterability of the conditioned sludge.

5. Final conclusions

- Using the mineral substances and polyelectrolyte selected in the study to condition the sludge prior to the pressure filtration process reduced the compressibility factor of the sludge and the associated hydraulic resistance of the filter baffle, which translated into an increase in the efficiency and speed of the filtration process.
- The value of the compressibility factor of the sludge decreases with an increase in the pressure during the filtration process and the dosage of mineral substances.
- The conditioning of sludge in combined methods using polyelectrolyte C-494 and mineral substances made it possible to reduce the compressibility factor to 0.25–0.40 and, at the same time, to achieve the best results of sludge dewatering in the filtration process (preliminary sludge – up to 74.6% and digested sludge – up to 75.4%).
- The best results in the form of final hydration, efficiency, and filtration speed were achieved by carrying out the sludge filtration process at 0.5 MPa.
- Changes in total organic carbon content in the oversedimentary water after the filtration process were irregular and no trend related to sludge conditioning was observed.

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