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Effects of changes in sewage sludge compressibility in the context of micro-contamination immobilization

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ABSTRACT

Due to a highly compressible character of solids contained in sewage sludge, mechanical process of sludge dewatering is often difficult since dewatering leads to deformation and clogging of pores and micropores in the filter cake. The study attempts to increase the strength and permeability of sedimentary cake during compression that resulted in increased productivity and process rate. The sludge conditioning was performed by addition of 5 mg g^{-1} dm highly cationic polyelectrolyte, Praestol 658 BC, cement or ash (in an amount of 0.6 or 1.2 g g^{-1} dm). The pressure filtration process was carried out at a variable pressure of 0.2, 0.4, 0.6 and 0.8 MPa. Compressibility factor values of the examined sludge changed with pressure change in the filtration process. For raw sludge and the sludge conditioned only with structural additions or with polyelectrolyte, this factor adopted lower values at the increasing filtration pressure. The lowest value of the compressibility factor of 0.1 does not correspond to the best dewatering effects. Substantially better results were obtained for the compressibility factor of 0.2–0.4.

Keywords: Sewage sludge; Sludge dewatering; Filtration; Conditioning; Micro-contamination immobilization

1. Introduction

Sludge composition, and the method it is treated and the relative processes have an effect on the character of the sludge. Water is a component of sewage sludge. Sludge hydration is defined by the amount of water contained [1,2]. The sludge generated during sewage treatment is usually characterized by a low content of dry matter [3]. Sludge properties determine the effectiveness of individual treatment methods [4,5]. The principal aim of sewage sludge processing is to achieve the product that does not threaten natural environment and human health. Sewage sludge should be managed in a safe manner and finally treated [1]. Its high water content has an effect on further processing, transport and management and makes those processes uneconomical without previous removal of water. Dewatering often represents the main process in sludge management systems in sewage treatment plants [6].

1.1. Filtration

In a technological system of sludge management, the basic method to separate phases is the filtration. During this process, the separated fluid flows through the sludge cake and filtration partition wall and has to overcome the resistance. This is achieved by applying an adequate level of pressure [7]. Fluid flow through the filtration partition wall is possible through differences in pressures from both sides [8]. If filtration is carried out at a constant pressure and the sludge formed is not compressible, the specific resistance of the sludge is not constant, whereas filtrate flow intensity decreases with the increase in sludge layer. Changes in the value of pressure difference at both sides of the partition wall during the filtration process are directly linked to the method used.

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In practice, three methods are applied [9]:

- filtration at constant pressure difference (isobaric) – in this case, the thickness of sludge on the filter (and consequently its resistance) increases with time, while filtration efficiency decreases,
- filtration at constant filtrate efficiency – with time, the value of pressure difference increases proportionally to the increase in sludge layer resistance,
- two-step filtration – during the first stage, the process occurs at constant insignificant filtrate efficiency (low ΔP). After a sludge layer with desired filtration properties is formed on the filtration partition wall, the second stage begins: filtration at constant pressure (high ΔP).

The factors that affect filtration rate are:

- partition wall properties,
- sludge type,
- sludge layer thickness,
- type of conditioning,
- temperature,
- pressure.

Pressure filtration is a process used if the need arises for maximal dewatering of sewage sludge. Basic parameters that measure sludge dewatering capacity include [8,10]:

- specific filtration resistance,
- compressibility factor,
- capillary suction time (CST).

Specific filtration resistance is a parameter that is most frequently used to evaluate relative dewatering capacity using the filtration process. The lower the value of specific filtration resistance the more efficiently water is removed during the dewatering process [8,10]. Sewage sludge should be resistant to compression. Sewage sludge represents a compressible medium. Its specific resistance increases with the increase in filtration pressure. During filtration, solid particles of sewage sludge, depending on the pressure used, are deformed and fill the pores in the filtration cake [8,9]. The measurement of compressibility is performed in order to determine the best range of pressure that will be used during filtration. In the case of very compressible sludge, the sludge with low porosity (low permeability) is formed very quickly. This leads to a decline in filtration rate, thus reducing the cycle efficiency. This phenomenon can be prevented by mechanical conditioning. A structure that prevents sludge compression is formed in the sludge, leading to the increase in filtration efficiency. Capillary suction time is approached as an alternative to determination of specific filtration resistance. More favourable are lower values of CST.

1.1.1. Specific filtration resistance

Relative sludge dewatering during filtration can be described by specific resistance, expressed as a pressure difference that is required for the flow per unit viscosity and mass of the filtration cake. The equation that can be used to determine specific filtration resistance was derived by Heidrich [1] and Coackley [11]:

$$r = \frac{2p \cdot F^2 \cdot b}{\mu \cdot c}\left(\frac{\mathrm{m}}{\mathrm{kg}}\right) \tag{1}$$

where r – specific filtration resistance (m·kg^{-1}); p – filtration pressure (Pa); F – filtration area (m^2); μ – filtrate viscosity (Pa·s); c – solid particle mass per unit of volume of fluid in the sludge (kg·m^{-3}).

The value of filtration resistance r expressed in (m·kg^{-1}) is usually given as a product of the result number and the power of the number greater than 10, for example, 7.4×10^{12} [1].

Sewage sludge is a compressible material. Specific resistance is usually increased with the increase in pressure during the filtration process. The solid phase, or, more specifically, its particles, are deformed depending on the pressure applied, which leads to filling the pores inside the cake. This relationship can be expressed by Eq. [1]:

$$r = r_0 \cdot p^s \tag{2}$$

where r_0 – constant that represents specific resistance of the cake of incompressible sludge (m·kg^{-1}); s – compressibility factor.

1.1.2. Compressibility factor

Compressibility factor is determined based on the test of specific filtration resistance according to several examinations performed for the same specimen at different pressure values. In the chart of the specific filtration resistance vs. pressure (logarithmic coordinate system), the $\log r = f(\log p)$ relationship is obtained (straight line). The value of the compressibility factor for the sewage sludge is expressed by the tangent of the inclination line, which can be observed in Fig. 1 [1].

$$s = tg(\alpha) = \frac{\log r_2 - \log r_1}{\log P_2 - \log P_1} \tag{3}$$

where r_2 – specific filtration resistance at pressure p_2, (m·kg^{-1}); r_1 – specific filtration resistance at pressure p_1, (m·kg^{-1}).

Compressibility factor for sewage sludge ranges in the literature from 0.2 to 1. It is also possible to find coefficients values lower than 0, but they are characteristic for hydrophobic sludge (heavy metal hydrocarbons) whereas the values of 0 – for sand. The increase in the degree of flocculation leads

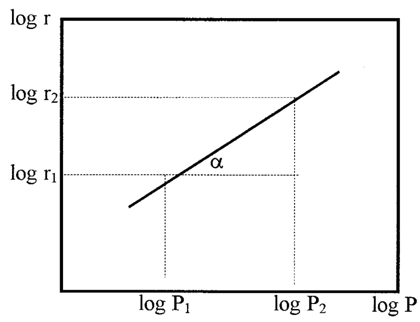

Fig. 1. Determination of sludge compressibility factor [1].

to the increase in compressibility, whereas it is avoided to use sudden high pressure for the separation of water from the sludge sampled from the municipal sewage treatment plants since this can lead to clogging pores (siltation) in the filtration partition wall. This observation is justified and worth respecting during laboratory examinations. In pressure filtration presses, the increase in pressure is slow and gradual in order to increase the content of sludge dry matter [1].

Broad theoretical explorations have also been conducted to examine the filtration process for the mixtures that form compressible sludge on the filtration mesh [12].

It is also possible to calculate values of specific filtration resistance based on the compressibility factor using Eq. (1):

$$r_1 = r_2\left(\frac{p_2}{p_1}\right)^s \tag{4}$$

2. Methodology

Laboratory examinations concerned pressure filtration of mixed sludge (initial sludge and excess sludge) using the filtration press at various pressure of 0.2, 0.4, 0.6 and 0.8 MPa. The filtration cloth of with the symbol PP25 (cotton cloth) was used for the examinations. The sludge was conditioned by addition of polyelectrolyte, cement and ash (with the amount of 0.6 or 1.2 g g^{-1} dm) from combustion of hard coal. The polyelectrolyte dose was chosen at 5 mg g^{-1} dm of the sludge. Strong cation polyelectrolyte (Praestol 658 BC) was used. Table 1 presents a characterization of the raw sludge.

3. Results

Analysis of the results obtained for the dependence of the value of compressibility factor on the process pressure for raw sludge at the increase in pressure from 0.2 to 0.8 MPa revealed a reduction in the compressibility factor by five times. Similar relationships were observed after addition of cement and ash with the dose of 0.6 g g^{-1} dm. Those additions do not substantially change the value of compressibility factor and, at the pressure of 0.8 MPa, it is twice greater than for raw sludge. The opposite relationship is observed when polyelectrolyte is used (Fig. 2), with the increase in pressure leading to the increase in the value of compressibility factor whereas no such dependency was observed for structural additions and sewage sludge. Sludge conditioning leads to the immediate separation of a large amount of water from solids contained in the sludge. This results in the increase in filtration process efficiency and its rate.

Table 1
Characterization of the raw sludge

Parameter	Value
Water content, %	96.3
Dry matter of sludge, g/L	37.0
Content of mineral substances, g/L	10.36
Content of organic substances, g/L	26.64
pH	5.2

The diagram in Fig. 3 presents changes in final water content of the sludge subjected to filtration. Final water content in the raw sludge reduces with the increase of the filtration pressure. During the comparison of the curves obtained for conditioned sludge dewatering with the curve for non-conditioned raw sludge dewatering, the first observed difference is inhibition of this process at the level of 82.5% of final water content at preparing the sludge with polyelectrolyte. Water content in this type of sludge is significantly reduced, but only to the pressure of 0.4 MPa. Higher pressure values (0.6 and 0.8 MPa) do not lead to substantial changes in this parameter. Moreover, it is higher than for raw sludge.

A significant reduction in final water content in the sludge was obtained using ash for conditioning, where the value of 75.4% (Fig. 3) was obtained, which was lower by 1.8% than that obtained for the same dewatering parameters for raw sludge (filtration pressure 0.8 MPa).

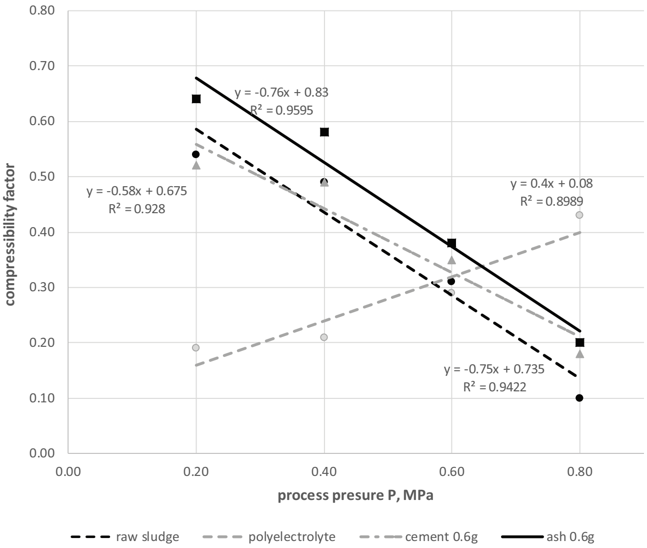

Fig. 2. Changes in compressibility factor during filtration of sewage sludge conditioned with various chemical substances.

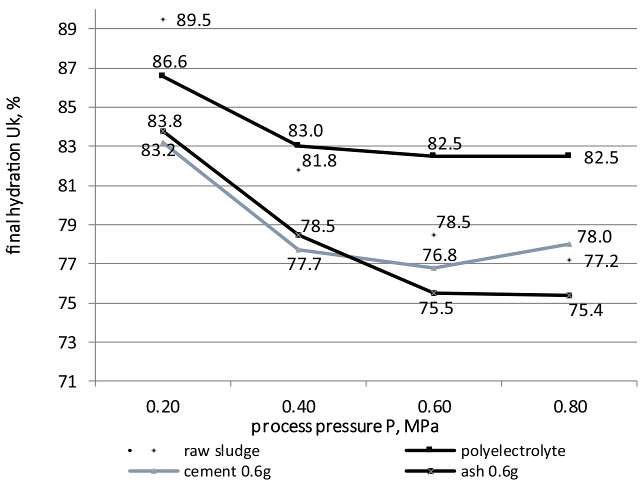

Fig. 3. Changes in final water content after filtration of sewage sludge conditioned with various chemical substances.

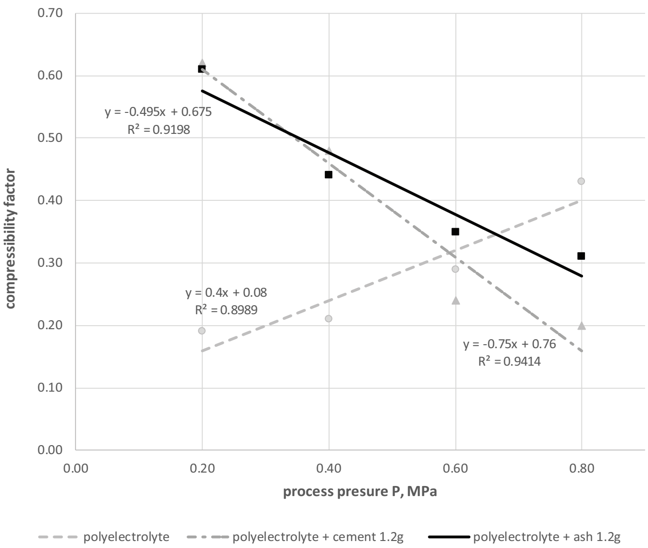

Fig. 4. Changes in compressibility factor during filtration of sewage sludge conditioned by means of the combined method.

The values of the compressibility factor for the sludge with addition of only polyelectrolyte rose noticeably with the increase in process pressure. Addition of cement or ash with the dose of 1.2 g g^{-1} dm to this sludge yielded a reduction in compressibility factor with the increase in the pressure applied during filtration, which is noticeable in the curves presented in Fig. 4.

A more stable structure and lower compressibility factor (0.20) was obtained for conditioning the sludge by means of the combined method that used polyelectrolyte and cement with the dose of 1.2 g g^{-1} dm. This value was obtained for the pressure of 0.8 MPa. Doubling the dose of structure-forming substances added to the sludge leads to a reduction in the compressibility factor. A significant difference was observed in final water content after filtration between the sludge conditioned only with polyelectrolyte and the sludge conditioned using the combined methods (polyelectrolyte with cement/ash). The highest differences, reaching ca. 7.5% were obtained using the highest pressure of 0.8 MPa. Similar effects of sludge dewatering were obtained for both substances (cement and ash). The results are shown in Fig. 5.

4. Discussion

Efficiency of mechanical dewatering of sewage sludge mainly depends on sludge properties, for example, the amount of extracellular polymeric substances, water content, size of sludge particles, content of dry mass, etc. Before mechanical dewatering, sludge is subjected to preparation in order to change its properties and, consequently, improve conditions of water release. In practice, chemical conditioning is most often used. The role of the chemical mechanism for sewage sludge conditioning is to destroy the colloidal system of sludge and flocculate sludge by addition of, for example, polyelectrolyte, iron chlorides and other chemical substances. Other solutions are being explored due to the cost of the above substances. In the present paper, the

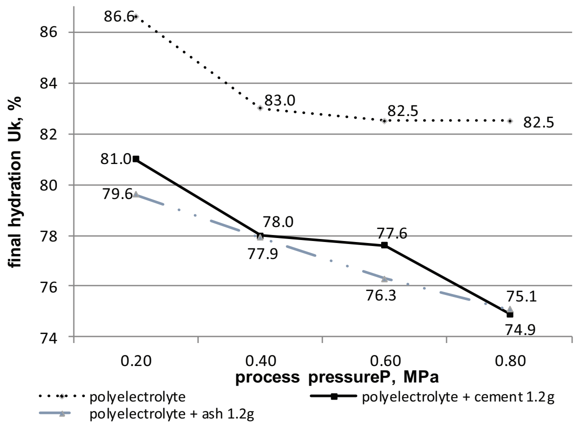

Fig. 5. Changes in final water content after filtration of sewage sludge conditioned by means of the combined method.

requirements were met by such chemical substances as ash or cement. Ash particles from combustion of hard coal have spherical shape and are mostly rough. Large content of SiO_2 and Al_2O_3 in ashes lead to the formation of active spots on the particle surfaces. Substantial specific area of ash particles leads to the adsorption of sludge particles and, consequently, formation of greater aggregates and the increase in the rate and efficiency of sewage sludge dewatering. High amount of negatively charged sludge particles leads to repulsion of particles due to the electrostatic effect and formation of a stable system that impact on low efficiency during dewatering of sewage sludge. Adding ash to sewage sludge with negative electrokinetic potential leads to the increase in the value of 0 mV. A negative charge of sewage sludge is destabilized by positive charges of aluminium, iron or calcium silicates contained in ash. This leads to the destruction of stability of colloidal particles and their approaching to each other. With the intermolecular effect of van der Waals forces, colloidal particles form greater aggregates that improve dewatering capacity of the conditioned sewage sludge [13].

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 the increase of the floc size and bridging the remaining microspheres, leading to the formation of large reinforced aggregates of sludge flocs which were resistant to structure damage caused by high pressure during filtration. Apart from the destabilization of sludge floc systems, conditioning of sewage sludge with chemical substances used in the above examinations leads to the formation of their structure, which forms a permeable and rigid structure that remains porous under high pressure and also changes sludge compressibility. Moreover, the rough surface of ash and cement particles is likely to ensure more microchannels that stop solid particles in sewage sludge and enhance the release of free water, thus enhancing the dewatering effect. The mechanism of sewage sludge conditioning with ash and cement consists in the improvement in flocs formation through destabilization of sludge charges, adsorption of bridge charges and transfer of free water to the parts from the formed skeleton of dewatered sludge [13].

5. Conclusions

The following conclusions were formulated based on the analysis of the results and the discussion of the mechanism of the reduction of sludge compressibility factor:

- Compressibility factor values of the examined sludge changed with the change in the filtration process pressure. For raw sludge and the sludge conditioned only with structural additions or with polyelectrolyte, this factor adopted lower values at the increasing filtration pressure. The lowest value of the compressibility factor of 0.1 was obtained during filtration at the pressure of 0.8 MPa for raw sludge.
- The most favourable effect of structural additions was observed for ash as it helps maintain a constant decline in the compressibility factor and final water content in the sludge with the increase in pressure.
- The lowest value of the compressibility factor of 0.1 does not translate into the best dewatering effects. Substantially better results were obtained for the compressibility factor of 0.2–0.4.

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