Utilization of Electrohydrodynamic Cavitation in Primary Sludge Conditioning

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This paper presents a brief characterization of the method of electrochemical conditioning of sludge, using the effect of low-temperature plasma. Primary sludge from the municipal wastewater treatment plant in Gorzów was analysed. The sludge was conditioned electrochemically, chemically with calcium hydroxide and dihydrogen dioxide, and using a combined method – electrochemical and chemical. For each conditioned sludge its settlement characteristics, hydration, dry mass content, organic and mineral substances, calculated and measured specific filtration resistance, effectiveness of filtration, iron content in ash, as well as energy-consumption in the process were determined. For the electrochemical, chemical and combined processes of primary sludge conditioning, their courses were compared. It was proved that (1) processes of conditioning cause changes in properties of primary sludge; (2) electrochemical conditioning causes mineralization and stabilization; (3) dewaterability of sludge is improved; (4) the process can be supported using additionally calcium hydroxide and dihydrogen dioxide; (5) optimization of the process can be performed only by improving the effectiveness of selected process parameters.

Key words:
Electrochemical conditioning, chemical conditioning, specific resistance of filtration, effectiveness of filtration, power consumption, optimization

Introduction

Sewage sludge management is a problem that is currently under investigation. New technologies based on anoxic-steam gasification are being tested. Cheap thermal and electrical energy produced in thermal processes of waste treatment can be utilized for sewage sludge conditioning in order to transform such material into fuel adapted for further treatment in anoxic-steam gasification processes.[1]

In 2001, the amount of sewage sludge generated in the Polish municipal wastewater treatment plants was 397 200 t (dry mass).[2,3] The municipal sewage sludge generated in Poland in 2004 was managed as follows: for agricultural use 17 %, for land reclamation use 28 %, for the cultivation of compostable plants approximately 8 %, for deposit over 41 %, for storage approximately 6 %, and for thermal treatment 0.3 %.[3] According to predictions of KPOŚK (National Programme for Municipal Wastewater Treatment) the amount of dry mass in stabilized sewage sludge to be generated in municipal wastewater treatment plants in 2015 will amount to 642 400 t. It is anticipated that in 2015 about 58 % of overall sludge produced in Poland will be generated in agglomerations of EPN (equivalent population number) above 100 000. In other ranges these amounts will run at, respectively, about 29 % for agglomerations with EPN of 15 000 – 100 000 and about 13 % for agglomerations with EPN of 2 000 – 15 000. Because of these assumptions and demographic prognoses, the amounts of sewage sludge to be generated in Poland by the year 2018 are estimated as follows:

- 2010 – 612 800 t dry solids,
- 2015 – 642 400 t dry solids,
- 2018 – 706 600 t dry solids.[2]

Some authors claim that the process of treatment and disposal of sewage sludge consumes as much as 50 % – and in some cases even as much as 60 % – of the total cost of wastewater treatment.[4–6]

Many different techniques for conditioning, dewatering, and pretreating sludge are currently in use.

Techniques for municipal sewage sludge treatment

Taking further processes of sludge treatment into account, conditioning techniques can be divided into two general types:

A. Techniques supporting processes of mechanical dewatering, utilizing effects of the following factors:

- polyelectrolytes;
- ultrasounds;

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– electrical field;

– electromagnetic field (including microwaves);

– magnetic field;

– chemical treatment;

– simultaneous action of polyelectrolytes together with processes mentioned above.

B. Techniques supporting processes of biodegradation, disintegration or preparing sludge for further treatment, which are classified as follows:

– thermal processes;

– biological and biochemical processes (enzymatic, lysis – latent growth, disordered and supportive metabolism, heterotrophic preying);

– oxidation processes (ozonation, chlorination and advanced oxidizing processes);

– acidification;

– alkalinization;

– high-pressure processes;

– disintegration (mechanical, ultrasonic);

– integrated processes (alkalinization or acidification and ultrasonic treatment, thermal processing and acidification or alkalinization).

Research work being currently carried out in many centres worldwide is directed at reducing the amount of sludge generated and increasing the profitability of treatment, as well as reducing the difficulties of thermal and chemical treatment techniques.

Many authors have been trying to implement individual solutions, such as:

– mechanical disintegration in high-pressure mixers or ball mixers;[6,7]

– ultrasonic treatment;[8–10]

– chemical treatment using ozone,[11] acids or bases;[12,13]

– thermal hydrolysis;[14,15]

– combined thermal and chemical methods of treatment, such as Protox, Syntox, Krepro;[16] and

– processes utilizing the effects of ultrasonic and electrical fields,[17] and a microwave field.[18]

The following are the most important obstacles in the full-scale implementation of these processes:

– high specific consumption of electrical energy and relatively low effectiveness, in the case of mechanical disintegration;

– problems in enlarging the scale of the process; including significant consumption of electrical energy, low durability, and high cost of equipment for ultrasonic treatment;

– considerable capital costs for equipment resistant to the highly corrosive environment, as well as emissions of noxious gases in the chemical treatment processes;

– high environmental load and the need to recirculate a considerable part of the chemical load from thermal hydrolysis to wastewater plants; and

– significant capital costs and high recurrent costs associated with the chemical reagents used in heating the sludge, as well as the marketing problems for the products generated in the combined thermo-chemical processes.

Synergy in processes of municipal sewage sludge treatment

The usual solutions utilize mainly one of the selected effects: mechanical, thermal, chemical and ultrasonic. Simultaneous actions of multiple factors, such as thermochemical, electroacoustic, chemical-electrical methods, are less often utilized.

From the literature information quoted earlier, it turns out that the main factors in sludge treatment processes are as follows:

– heat energy effect;

– mechanical effect – mechanical disintegration in mills or homogenizers;

– action of electric and magnetic fields;

– action of ultrasonic field, together with accompanying phenomena – cavitation, sonoluminescence, thermal phenomena, etc.;

– chemical effects, including advanced oxidation techniques (AOT);

– physicochemical effect of low-temperature plasma;

– other physicochemical effects, such as UV, microwave and ionizing radiation.

A sludge-treating device may combine multiple actions. The effect that should be utilized is synergy, i.e. mutual influence of particular process components. Such an effect can be described as follows:

$$[A + B + C + D] > [A] + [B] + [C] + [D] \quad (1)$$

From the equation above, it turns out that the summaric effect of all actions is greater than the sum of single effects of each component.

The synergy phenomenon is utilized mainly in medicine and in processes of adsorption, catalysis and inhibition.

The main processes affecting treatment of sludge, intended for utilization, are as follows:

[A] – intensified processes of heat and mass exchange;

[B] – processes of high-energy decomposition in low-temperature plasma;

[C] – AOT reactions;

[D] – effects of high-power sounds and secondary reactions.

Devices intensifying processes of heat and mass exchange using electric field have been known in the chemical industry for a long time.[19] In liquids, adsorption processes and oxygen desorption may be intensified by 40–50 %. In case of rectification, the mass transfer coefficient may increase by 2–2.5 times. In turn, in conditions of barbotage the maximum threefold increase of mass exchange coefficient was reported.

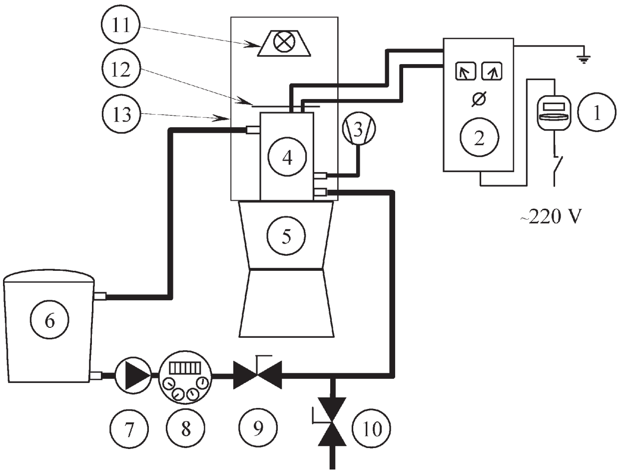
Research on treating bioresistant organic compounds in low-temperature plasma channels was performed by Sugirato *et al.,*[20] Willberg *et al.,*[21] Clement *et al.*[22] and other authors. They showed that multiple high-energy phenomena occur in plasma channels: thermolysis, photolysis, electrohydraulical cavitation. As a result of these reactions, active particles emerge, such as: $OH^\bullet$, $O^\bullet$, $H^\bullet$, O_3.

The influence of ultrasound on sludge was analysed by Bień *et al.,*[8] Chu *et al.,*[23] Yoon *et al.*[24] It was stated that the ultrasonic treatment method consumed significant amounts of energy, but at the same time it had significant potential for development. Hopes are placed on the implementation of "weak" ultrasonic conditioning techniques.[23]

Research methodology and scope

Fluidized bed disintegrator

In order to examine the process of combined treatment, such as heat and mass exchange processes, decomposition in plasma using advanced oxygenation techniques and high-power sound energy, a modified reactor for heat and mass exchange in barbotage conditions was proposed. Such a configuration (Fig. 1) consists of an insulating case, two feed electrodes, a fluidized bed, and a system for delivering a reactive gas (in this instance, air).



F i g. 1 – *Schematic diagram of experimental stand for investigation of the sludge conditioning process.*[1] *Described in the text.*

Sludge of the volume of 10 dm^3 is introduced batchwise into the tank (6). Then it is pressed by the circulating pump (7) into the reactor (4). The pressure hose is equipped with flow rate meter (8) and poppet valve (9), acting as controller of the flow. Sludge pressed by the circulating pump flows into the reactor (4). The reactor is placed in the plastic bath (5), located 0.6 m from the bottom of the sludge tank (6). Such a location enables gravitational return of the sludge into the tank. The bath (5) also prevents the sludge from escaping outside the research stand, even in the case of leakage from the reactor. The air pump (3) blows through the sludge in the reactor. After leaving the reactor (4), the sludge streams down gravitationally to the sludge tank (6). Sludge samples are taken through the drain valve (10) located on the pressure hose.

The electrodes of the reactor are connected to the electric field generator (2). The electric energy consumed by the generator is measured by a single-phase meter (1).

The protective case (13) is put onto the reactor. It comprises a source of UV radiation (11). The air-stream leaving the reactor, potentially containing harmful aerosols, is subject to the effect of ultraviolet radiation. The sludge is protected from the UV radiation by the aluminium plate (12) located a few centimeters above its surface. The staff operating the reactor is protected by the protective plate (13) from harmful effects of UV radiation.

An electrical discharge is used in the reactor, which simultaneously utilizes a number of other approaches. These include mechanical, chemical, acoustic, electro-hydraulic cavitation, sono-luminescence, plasma, and UV radiation, as well as microwave and electromagnetic radiation.

As a result of the electric field applied to the electrodes, through the fluidized bed submerged in a layer of sludge, the electric current occurs in the form of violent discharges in sludge liquid. As an effect of these discharges, plasma and electrohydraulic cavitation come into existence, locally increasing the temperature and the pressure. A shock wave generated causes violent dispersion and quenching of thrown (knocked-out) cloud of ionized atoms. As a result of the events described above, conditions for the synthesis of new chemical compounds arise. The shock wave induces an oscillating movement of particles in the fluidized bed. During this mutual friction, particles of sludge mechanically disintegrate.

Presumable progression of these phenomena is presented in Fig. 2. The course of the process is confirmed by the results of research performed by Schumacher.[25]

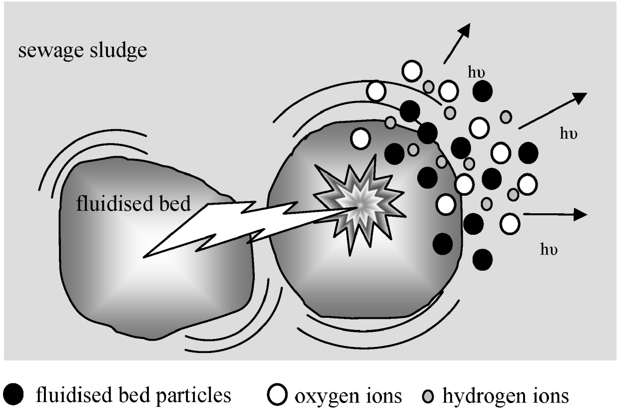


Fig. 2 – *Presumable progression of electrochemical impact on sludge*[26]

It should be noted that because of the discharges in the sludge liquid, the material of the fluidized bed is worn mechanically, chemically and electrochemically. When a fluidized bed containing more than 95 % pure iron is used, flocculent structures of ferrous hydroxide emerge, and simultaneously iron particles are liberated. It is assumed that, in solutions containing dihydrogen dioxide, some reactions that are part of the Fenton process can occur.

In the process described above, the electric field of 400 V and the frequency of about 300 Hz was used. Its frequency was controlled and tuned to resonant oscillations of the fluidized bed.

Source, sampling point and preparation of sludge for research

Primary sludge generated in the municipal wastewater treatment plant (MWWTP) in Gorzów was analyzed. The plant utilizes the activated sludge technology. The load of the plant is 190 000 EPN (equivalent population number), with design load of 160 000 EPN.

Described research was performed in the spring of 2007. Thickened primary sludge was taken from the primary sludge pumping station. A single sample contained about 80 L of sludge. The ambient temperature did not exceed 20 °C. During the next two hours, the sludge was placed in a cooling chamber, at a temperature of 5 °C. Prior to the beginning of the research cycle, the sludge was strained twice, removing the fibrous fraction, then homogenized for 15 minutes, averaging its composition. This sludge was marked as RP (reference primary).

The RP sludge was conditioned electrochemically for 10 minutes and labelled as PEC10 (primary (P), electrochemically conditioned (EC), time = 10 minutes (10)). A second sludge was conditioned electrochemically for 30 minutes and labelled PEC30. Then the RP sludge was chemically conditioned with calcium hydroxide in a dose of 10 g dm^{-3} (as CaO) and labelled P + 10 g CaO dm^{-3}. The same sludge was then electrochemically conditioned for 30 minutes and labelled P + 10 g CaO dm^{-3} + EC30. The next sludge was the electrochemically conditioned sludge (EC) additionally conditioned chemically for 30 minutes with reduced dose of 6.5 g calcium hydroxide (as CaO) dm^{-3} – this sludge was labelled PEC30 + 6.5 g CaO dm^{-3}. The next one was the primary sludge conditioned with 30 % dihydrogen dioxide at a dose of 1.4 g dm^{-3}. It was labelled P + 1.4 g H_2O_2 dm^{-3}. The last sample was the sludge conditioned with 30 % dihydrogen dioxide at a dose of 1.4 g dm^{-3}, next conditioned electrochemically for 30 minutes. This material was labelled P + 1.4 g H_2O_2 dm^{-3} + EC30.

All tests on electrochemically conditioned sludges were performed in barbotage conditions.

Between the processes of electrochemical and chemical conditioning, as well as before measurements, the sludges were seasoned for about 48 hours.

Table 1 presents labelling of the samples and their descriptions.

The following parameters were measured: hydration of sludge, dry mass content, ash and organic substance content, capillary suction time (CST), specific resistance of filtration, effectiveness of filtration, thickening after 24 hours. All measurements were performed according to the directives described in literature.[27]

Hydration (X) of the sludge cake was determined according to the eq. (2)

$$X = \frac{y - z}{y - p - b} \cdot 100\ \% \tag{2}$$

where

X – moisture content in sludge cake, %
p – mass of evaporating dish, g
b – mass of filtering paper, g
y – mass of evaporating dish + filtering paper + moist sludge, g
z – mass of evaporating dish + filtering paper + dry sludge (105 °C), g

Iron content in the ash was determined after mineralization of samples in a mixture of concentrated acids HNO_3 and $HClO_4$, using the method of mass spectrometry in the AAS1 apparatus.

For electrochemically conditioned sludges, the electric energy consumption per volume unit and per kg of dry mass was determined, according to the formulas below:

Table 1 – *Listing of numbers, markings and descriptions of samples*

Sample No.	Label	Description
0	RP	Primary (P) sludge of reference (R)
1	PEC10	Primary (P) sludge conditioned electrochemically (EC) for 10 minutes (10)
2	PEC30	Primary (P) sludge conditioned electrochemically (EC) for 30 minutes (30)
3	P + 10 g CaO dm^{-3}	Primary (P) sludge conditioned with 10 g calcium hydroxide (as CaO) per 1 dm^3
4	P + 10 g CaO dm^{-3} + EC30	Primary (P) sludge conditioned with 10 g calcium hydroxide (as CaO) per 1 dm^3, and then conditioned electrochemically (EC) for 30 minutes
5	PEC30 + 6.5 g CaO dm^{-3}	Primary (P) sludge conditioned electrochemically (EC) for 30 minutes and then chemically with decreased dose of calcium hydroxide (as CaO) 6.5 g per 1 dm^3
6	P + 1.4 g H_2O_2 dm^{-3}	Primary (P) sludge conditioned with 1.4 g 30 % dihydrogen dioxide (H_2O_2) per 1 dm^3
7	P + 1.4 g H_2O_2 dm^{-3} + EC30	Primary (P) sludge conditioned with 1.4 g 30 % dihydrogen dioxide (H_2O_2) per 1 dm^3 and then conditioned electrochemically (EC) for 30 minutes

Electric energy consumption E_v per unit volume of sludge:

$$E_v = \frac{E}{V} \text{ [kWh m}^{-3}\text{]}, \qquad (3)$$

where

E – quantity of electric energy consumed, as a difference in readings of watt-hour meter, kWh;

V – volume of processed sludge – here: 0.01 m^3.

Electric energy consumption E_{ds} per unit volume of sludge:

$$E_{ds} = \frac{E}{V \cdot ds} \text{ [kWh kg}^{-1} \text{ dry solids]}, \qquad (4)$$

where

E – quantity of electric energy consumed, as a difference in readings of watt-hour meter, kWh;

V – volume of processed sludge – here: 0.01 m^3;

ds – dry solids content in sludge, g dm^{-3}.

For comparison, in order to convert the consumed electric energy from Wh to J, the following conversion rate was used:

$$1 \text{ kWh} = 3.6 \text{ MJ} \qquad (5)$$

Results and discussion

The following parameters of the examined sludges were measured: hydration of sludge, dry mass content, ash and organic substance content, capillary suction time (CST), specific resistance of filtration, effectiveness of filtration, thickening after 24 hours. All measurements were performed according to the directives described in literature.[27] The results for the reference sludge, as well as conditioned sludges, are summarized in Table 2 and presented graphically in Figs. 3, 4, 5 and 6.

Chemical and electrochemical conditioning only slightly affected the parameter of initial hydration of sludge (Fig. 3). A decrease in hydration was demonstrated in reference to the sludges conditioned with calcium hydroxide (P + 10 g CaO dm^{-3}), and sludges conditioned both with calcium hydroxide and electrochemically (P + 10 g CaO dm^{-3} + EC30, PEC30 + 6.5 g CaO dm^{-3}). Decrease in the hydration level of the sludge conditioned with calcium hydroxide is bound up mainly with addition of dry mass in the form of calcium oxide (CaO).

Chemical and electrochemical conditioning (PEC30, P + 10 g CaO dm^{-3} + EC30, P + 1.4 g H_2O_2 dm^{-3}) caused no visible decrease in hydration of the sludge cake compared with the reference sludge (Fig. 3), whereas the conditioning process often caused an (sometimes significant) increase in the level of hydration, as in the case of the

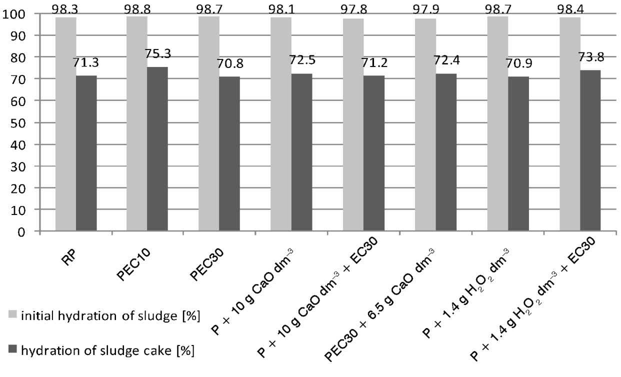


Fig 3 – *Changes in hydration of the sludges and in moistness of the sludge cakes*

Table 2 – *Results of primary sludge conditioning*

Parameter	Unit	RP Reference (primary sludge)	PEC10	PEC30	P + CaO 10 g dm^{-3}	P + CaO 10 g dm^{-3} + EC30	PEC30 + CaO 3.5 g dm^{-3}	P + H_2O_2 1.4 g dm^{-3}	P + H_2O_2 1.4 g dm^{-3} + EC30
Sludge Sample No.		0	1	2	3	4	5	6	7
initial hydration of the sludge	%	98.3	98.8	98.7	98.1	97.8	97.9	98.7	98.4
hydration of sludge cake	%	71.3	75.3	70.8	72.5	71.2	72.4	70.9	73.8
dry mass in the sludge	g dm^{-3}	16.6	12.4	12.6	19.1	21.8	20.6	12.8	15.8
ash content	g dm^{-3}	5.0	4.3	5.1	12.0	15.7	14.5	4.1	5.0
	% dry solids	30	35	40	63	72	70	32	32
organic substances content	g dm^{-3}	11.6	8.1	7.5	7.1	6.1	6.1	8.7	10.8
	% dry solids	70	65	60	37	28	30	68	68
CST	s	60.6	42.9	39.2	12.1	14.0	9.2	40.7	16.3
specific resistance of filtration	· 10^{10} m kg^{-1}	35	43	19	0.8	0.6	0.4	20	3.4
effectiveness of filtration	kg m^{-2} h^{-1}	1.1	1	2.4	41.8	58.5	83.1	1.7	8.2
thickness after 24 hours	cm^3 dm^{-3}	972	990	830	330	320	310	210	280
iron content in ash	g kg^{-1}	37.9	109	168	16.2	30.9	101	34.6	222
energy consumption per m^3 sludge	–	12.8	50.4	–	612	50.4	–	75.6	75.6
kg dry solids	–	0.32	4.01	–	28.1	2.18	–	4.8	4.8

sludge electrochemically conditioned (PEC10) and conditioned both with dihydrogen dioxide and electrochemically (P + 1.4 g H_2O_2 dm^{-3} + EC30).

Electrochemical conditioning of primary sludges for 10 or 30 minutes (PEC10 and PEC30) caused a decrease in the dry mass content (Fig. 4). It is presumed that this could be associated with strong chemical reactions and decomposition of organic compounds. In the case of sludge conditioned with calcium hydroxide together with electrochemical conditioning, an increase in the dry mass content was observed, as a result of reagent addition. A decrease in the dry mass content in comparison with the sludge conditioned with dihydrogen dioxide (P + 1.4 g H_2O_2 dm^{-3}) was demonstrated, as a result of strong chemical effect of reagent – close to electrochemical effect (PEC10 and PEC30). An increase in the dry mass content in the sludge conditioned with dihydrogen dioxide and electrochemically conditioned (P + 1.4 g H_2O_2 dm^{-3} + EC30) was associated with some amount of iron that was transferred to sludge as a result of electrochemical conditioning.

Electrochemical conditioning of the primary sludges (PEC10 and PEC30) had no significant effect on its ash content (Fig. 4). A significant change in the ash content was observed in case of the sludge conditioned with calcium hydroxide (P + 10 g CaO dm^{-3}) and conditioned both with calcium hydroxide and electrochemically (P + 10 g CaO dm^{-3} + EC30 and PEC30 + 6.5 g CaO dm^{-3}).

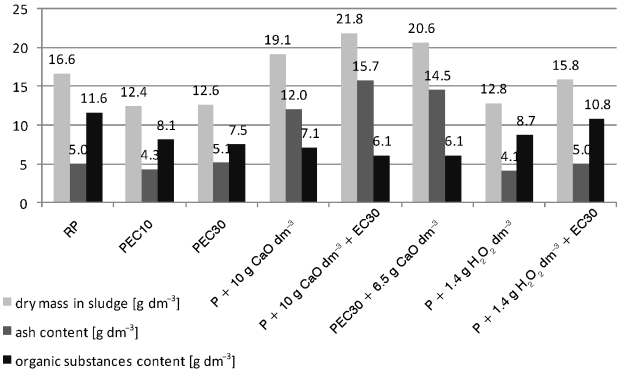


Fig. 4 – *Changes in the dry mass, ash and organic substance content in conditioned and reference sludges*

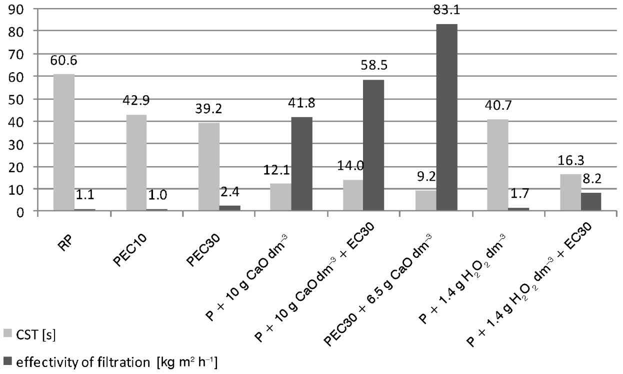
This was associated with the addition of mineral substances in the form of chemical reagents (calcium oxide). The treatment with dihydrogen dioxide (P + 1.4 g H_2O_2 dm^{-3}) and dihydrogen dioxide together with electrochemical conditioning (P + 1.4 g H_2O_2 dm^{-3} + EC30) had no significant effect on the ash. It can be assumed that slight changes in the ash content of sludges conditioned electrochemically (PEC10 and PEC30), as well as sludges conditioned with dihydrogen dioxide (P + 1.4 g H_2O_2 dm^{-3}, P + 1.4 g H_2O_2 dm^{-3} + EC30) might be associated, on the one hand, with oxidation of mineral and organic fractions, and on the other with increased amount of ash due to transferring part of the fluidized-bed material into sludge in the case of sludges conditioned electrochemically (PEC10, PEC30 i P + 1.4 g H_2O_2 dm^{-3} + EC30, PEC30 + 6.5 g CaO dm^{-3}, P + 1.4 g H_2O_2 dm^{-3} + EC30).

At the same time, it was demonstrated that electrochemical conditioning (PEC10 and PEC30) caused a reduction in the organic fraction content (Fig. 4). Similarly, a reduction in the organic fraction occurs during conditioning with calcium hydroxide (P + 10 g CaO dm^{-3}), as well as during conditioning both with calcium hydroxide and electrochemical conditioning (P + 10 g CaO dm^{-3} + EC30 and PEC30 + 6.5 g CaO dm^{-3}). Significantly less reduction in organic substances occurs as a result of conditioning with dihydrogen dioxide, and as a result of conditioning both with dihydrogen dioxide and electrochemically (P + 1.4 g H_2O_2 dm^{-3}, P + 1.4 g H_2O_2 dm^{-3} + EC30). A reduction in the organic fraction is often associated with the mineralization of sludge under the influence of the chemical effects of conditioning with calcium hydroxide and dihydrogen dioxide, as well as physicochemical effects under the influence of electrochemical conditioning.

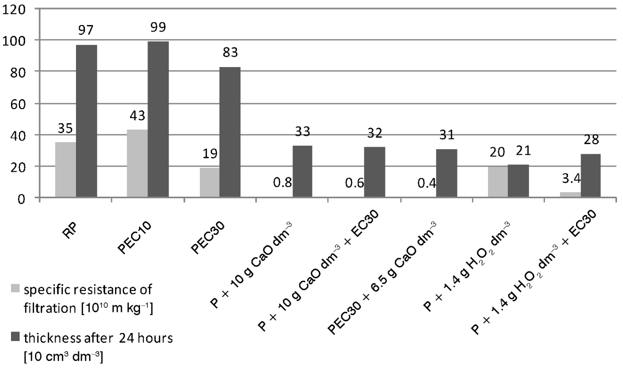
It was also observed that electrochemical conditioning (PEC10 and PEC30) shortened the capillary suction time CST (Fig. 5). This might be associated with the effect of solid iron particles forming a sludge matrix and chemical effects, as well as with coagulation being the result of the presence of iron compounds. Conditioning with calcium hydroxide (P + 10 g CaO dm^{-3}) affected the CST more favourably. The most beneficial effect was observed in the case of electrochemical conditioning together with calcium hydroxide (PEC30 + 6.5 g CaO dm^{-3}). The shorter CST might be associated with the matrix of solid particles in the sludge of calcium hydroxide and iron, thus improving the process of water transport in the sludge layer, as well as chemical effects connected mainly with floccule agglomerations emerging according to the theory of divalent cation bridging (DCB).[28]

Conditioning with dihydrogen dioxide (P + 1.4 g H_2O_2 dm^{-3}) had a significantly worse effect on CST than conditioning with calcium hydroxide (P + 10 g CaO dm^{-3}). This could be improved by electrochemical conditioning of sludge previously treated with dihydrogen dioxide (P + 1.4 g H_2O_2 dm^{-3} + EC30).

A short time of electrochemical conditioning (PEC10) caused an increase, and longer time (PEC30) – a decrease in the specific resistance of filtration (Fig. 6). This might be due to affecting the sludge particles by iron compounds. Short conditioning (PEC10) destroys the structure of the sludge, but the amounts of iron compounds present are too small to improve the dewaterability to a considerable degree. Calcium hydroxide (as CaO) (P + 10 g CaO dm^{-3} + EC30) significantly affects the resistance of filtration, causing its many-fold reduction. This might be caused by the chemical effect connected with emerging floccule agglomerations, according to the theory of divalent cation bridging (DCB), and formation of permeable structure of the sludge matrix. Further improvement might be achieved by electrochemical conditioning combined with a reduced dose of calcium hydroxide (PEC30 + 6.5 g CaO dm^{-3}). Conditioning with dihydrogen dioxide (P + 1.4 g H_2O_2 dm^{-3}) affects



F i g 5 – *Measurements of capillary suction time CST and effectiveness of filtration*



F i g . 6 – *Measurements of specific resistance of filtration and the course of thickening after 24 hours* the specific resistance of filtration similarly as prolonged electrochemical conditioning (PEC30). A decrease in the specific resistance of filtration might be caused by an increase in the degree of sludge mineralization. Further, significant improvement might be achieved by subsequent electrochemical conditioning of this sludge (P + 1.4 g H_2O_2 dm^{-3} + EC30). Such a considerable decrease in the specific resistance of filtration might be connected with the chemical and physical effects of electrochemical conditioning and with the formation of an additional permeable matrix of particles and compounds of iron.

It was also observed that electrochemical conditioning (PEC30) has a beneficial effect on the effectiveness of filtration (Fig. 5), what might be caused by positive changes in the structure of sludge (flocculation and coagulation). However, conditioning sludge with calcium hydroxide (P + 10 g CaO dm^{-3}, P + 10 g CaO dm^{-3} + EC30) causes the increase in the effectiveness by a factor of some tens, and its maximum value is achievable in the case of sludges conditioned chemically with a reduced dose of calcium hydroxide, after the process of electrochemical conditioning (PEC30 + 6.5 g CaO dm^{-3}). As a result of conditioning the primary sludge (RP) with dihydrogen dioxide (P + 1.4 g H_2O_2 dm^{-3}), the effectiveness of filtration increased by about 50 %, but after the process of electrochemical conditioning – almost eightfold (P + 1.4 g H_2O_2 dm^{-3} + EC30). Such an approach of combined treatment with dihydrogen dioxide and electrochemically utilizes the synergic effect of physicochemical process of electrochemical conditioning and chemical effect of the process of conditioning with dihydrogen dioxide.

In the case of the primary sludge examined (RP), previous electrochemical conditioning (PEC10) negatively affected the course of the thickening process (Fig. 6), but it must be noted that further conditioning (PEC30) influenced this course positively. It might be connected with the effect on coagulation of iron compounds. Short electrochemical conditioning probably destroys the structure of the sludge, but the amount of iron compounds present is too small to improve the thickening significantly. The course of thickening might be very positively influenced by chemical conditioning with calcium hydroxide (P + 10 g CaO dm^{-3}, P + 10 g CaO dm^{-3} + EC30), which can be associated with the formation of bivalent cation bridges between particles of floccules, together with simultaneous processes of flocculation and coagulation. Thickening may be further improved by initial electrochemical conditioning and subsequent chemical treatment with reduced dose of calcium hydroxide (PEC30 + 6.5 g CaO dm^{-3}). The sludge is initially subjected to electrochemical conditioning and floc particles released from the structure as a result of chemical conditioning with calcium hydroxide flocculate and coagulate – and these phenomena improve their sedimentation. The best results of thickening were achieved in treatment with dihydrogen dioxide (P + 1.4 g H_2O_2 dm^{-3}). This effect deteriorates after the process of electrochemical conditioning, as a result of breaking the flocs structure (P + 1.4 g H_2O_2 dm^{-3} + EC30).

The iron content of the ash (Table 2) was proportional to the time of electrochemical conditioning (PEC10, PEC30). It seems natural, because during the process of electrochemical conditioning a part of iron is being transferred to the sludge. The smallest amounts of iron in the ash were observed in the case of sludges conditioned with calcium hydroxide, because the iron from the sludge was "diluted" in sediments of calcium (P + 10 g CaO dm^{-3}). It is similar to the sludges conditioned chemically with CaO together with electrochemical conditioning (P + 10 g CaO dm^{-3} + EC30, PEC30 + 6.5 g CaO dm^{-3}). The iron remaining in the ash decreased its concentration as a result of "dilution" with calcium compounds. The highest iron content in the ash was observed in the sludges conditioned chemically with dihydrogen dioxide and electrochemically (P + 1.4 g H_2O_2 dm^{-3} + EC30), where the amount of iron in the ash exceeded 20 %.

The amount of electric energy consumed in the process of electrochemical conditioning (Table 2) is proportional to conditioning time and the losses associated with the transfer of energy in sludge liquids. The greatest amounts of energy were consumed for electrochemical conditioning of sludges conditioned earlier with calcium hydroxide (P + 10 g CaO dm^{-3} + EC30). Disproportionately high energy consumption was directly related to good electrical conductivity of the sludge and calcium hydroxide solution.

The amount of the electric energy consumed per unit of dry mass of sludge in electrochemical conditioning (Table 2) is proportional to conditioning time and the dry mass content of the sludge. Apart from the case where a considerable part of energy was dispersed as a result of good conductivity of the sludge (P + 10 g CaO dm^{-3} + EC30), the amounts of electric energy used per unit of dry mass of sludge ranged from 0.3 (PEC10) to 5 MJ kg^{-1} d.m. of sludge (P + 1.4 g H_2O_2 dm^{-3} + EC30). Comparing this data with the information in the literature, it can be stated that the energy recommended by the authors for the partial disintegration of sludge should amount to 200 MJ kg^{-1} dry solids.[24] Other authors claim that the amount of energy for mechanical treatment in ball mills should range at the level of 1 MJ kg^{-1} dry solids.[29] To sum up, we may state that with regard to energy consumption the processes of electrochemical conditioning are more closely related to the processes of mechanical treatment than to ultrasonic treatment.

Conclusions

It was observed that it is impossible to perform the process of primary sludge conditioning in a way that could maximize all the parameters associated with the improvement of dewaterability. The optimization of the process may be performed only by improving the effectiveness of selected parameters affecting the dewaterability of the sludge.

Regarding the primary sludges examined, only electrochemical conditioning caused:

– a decrease in the mass of the sludge;

– an increase in the degree of mineralization; and

– an improvement in dewaterability through a decrease in specific resistance of filtration and an increase in the effectiveness of filtration.

Next, supporting the process with calcium hydroxide may multiply the effectiveness of filtration and significantly reduce the specific resistance of filtration, as well as improve the course of sedimentation, with simultaneous increase in the dry solids content.

The processes of electrochemical conditioning in a disintegrator equipped with a fluidized bed are, with regard to energy consumption, most closely related to the processes of mechanical disintegration, than to the processes of ultrasonic disintegration.

The improvement in the course of sedimentation is achieved also through chemical supporting with dihydrogen dioxide, without causing an increase in dry solids content in the sludge being conditioned.

List of symbols

X – moisture content in sludge cake, %
p – mass of evaporating dish, g
b – mass of filtering paper, g
y – mass of evaporating dish + filtering paper + moist sludge, g
z – mass of evaporating dish + filtering paper + dry sludge (105 °C), g
E – quantity of electric energy consumed, as a difference in readings of watt-hour meter, kWh
V – volume of processed sludge – here: 0.01 m^3
ds – dry solids content in sludge, g dm^{-3}

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