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PRELIMINARY RESEARCH INTO THE DIGESTION OF POST-COAGULATION SLUDGE

An increasingly higher number of water treatment plants are currently searching for a technology which would make it possible to dispose post-coagulation sludge from water treatment processes. Due to the fact that sludge contains a substantial amount of organic compounds, some tests were conducted to see how such sludge can be stabilised in anaerobic conditions. Sludge supplied by two water treatment plants was tested. Sludge 1 was a mixture of sludge from the treatment of filter backwash water and backwash water separated from water after coagulation. Sludge 2 was the product of the treatment of backwash water from carbon and contact filters as well as wastewater produced when primary settling tanks are cleaned. Prior to digestion, post-coagulation sludge was inoculated with the sewage sludge collected from the anaerobic digester of a municipal wastewater treatment plant. To determine the effectiveness of the tests, the sewage sludge used as an inoculate was also digested. The digestion process was conducted for 35 days at a temperature of 37 °C. Compared to sewage sludge, a small amount of the sludge-digestion gas produced by the post-coagulation sludge was observed during the process. For the sewage sludge, the sludge-digestion gas evolution rate per volatile solids (VS) input was 0.19 m^3/kg VS, for post-coagulation sludge 1–0.09 m^3/kg VS and for post-coagulation sludge 2–0.05 m^3/kg VS. The sludge mineralization rate expressed as a percentage loss of dry volatile solids was the highest for the sewage sludge alone and it was 19%, whereas for the post-coagulation sludge it was 11.8% (sludge 1) and 5.8% (sludge 2). The digestion process substantially enhanced the filtration properties of the tested sludge. The post-coagulation sludge produced small volumes of sludge-digestion gas, thus it can be stated that the digestion of this sludge alone would not be technically nor economically profitable. Therefore, research into the digestion of post-coagulation sludge with a considerably higher share of sewage sludge should be done to identify the potential for their co-stabilization. Such a solution would provide a potential opportunity for resolving the problem of post-coagulation sludge through its disposal in wastewater treatment plants.

1. INTRODUCTION

Post-coagulation sludge is generated in the treatment of surface water or filter backwash water. It has an amorphous or formless structure. The amorphous structure

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is mainly built of metal hydroxides that are precipitated from the aluminium and iron coagulants used for coagulation. As a result of dissociation and hydrolysis, coagulants that are dosed into water form numerous hydro-complexes, which combine with coagulated impurities during association and adsorption and flocculate as flocks. The properties of post-coagulation sludge depend on the employed technology and the composition of intake water. Depending on the season of the year, this sludge shows very high hydration levels of 98.7 to 99.8%, and a variable content of organic substances ranging from 45 to 64%. When temperatures are high, post-coagulation sludge tends to putrefy, which involves the emission of unpleasant odours [1], [2], [3], [4]. A vegetable smell which occurs from time to time may suggest a high proportion of phytoplankton in such sludge. This proportion grows significantly when algal blooms occur in the tank [2], [5]. This is why this sludge should be stabilized, just as the sludge from wastewater treatment plant, to prevent the emission of unpleasant odours and reduce the volume of organic substances [6]. Hence, research is required to find effective ways of stabilizing post-coagulation sludge and determining achievable levels of its disposal.

One of the common methods of sewage sludge stabilization is methane digestion, the method widely described in scientific literature [6], [7], [8], [9]. Methane digestion is defined as a set of anaerobic biochemical processes in which high-molecular organic matter (mainly carbohydrates, proteins, fats and their derivatives) are reduced to alcohols or lower organic acids, as well as methane, carbon dioxide and water [10]. In general, methane digestion results in the products of incomplete oxidation of organic compounds, new bacterial cells, energy for the vital processes of microorganisms, and final gaseous products – mostly methane and carbon dioxide (sludge-digestion gas), but also other products, such as hydrogen sulphide, hydrogen and ammonia. The process can be described in a very simplified way using the following formula [11]:

$$\textbf{Organic matter} \xrightarrow[\text{bacteria}]{\text{anaerobic}} \textbf{New cells} + \underset{\text{(thermal and biochemical)}}{\textbf{Energy}} \quad \mathbf{CH_4} + \mathbf{CO_2} + \underset{\text{(e.g. } H_2S \text{ and } NH_3\text{)}}{\textbf{Other products}}$$

Methane digestion is a four-stage process (hydrolysis, acidogenesis, acetogenesis, methanogenesis) supported by many groups of microorganisms, each of which requires its own specific environmental conditions. In addition to the type of the parent substance used, proper fermentation depends on appropriate populations of microorganisms and environmental parameters (pH, temperature, redox potential, alkalinity, contents of volatile fatty acids) as well as the presence of nutrients and toxins [12].

Microorganisms responsible for the development of the digestion process are very sensitive to some chemicals [12] which can be supplied in raw materials to be digested, or be intermediate products of the decomposition process. These toxic substances encompass both mineral (including heavy metals) and organic compounds, including mainly pesticides and surfactants. Methane formation is inhibited by the presence of oxygen, nitrates, sulphates and sulphites. Aluminium and iron ions are among substances that have toxic impact on the digestion process, too. Hence, mineral coagulants, such as aluminium and iron salts that are commonly used in water and wastewater treatment technologies, are not inert during digestion. This was confirmed by the tests, which showed that such coagulants have a negative effect on the activity of anaerobic microorganisms [13].

The purpose of the present research was to determine to what extent it is reasonably practicable to ensure effective stabilization of post-coagulation sludge during methane digestion. Various physicochemical parameters of the post-coagulation sludge supplied by two water treatment plants were tested.

2. METHODOLOGY AND SCOPE OF THE TESTS

The tested substance was the post-coagulation sludge supplied by two water treatment plants. Sludge 1 was sampled from the tank in which there is sludge from the treatment of backwash water and sludge separated from water during coagulation. The treatment line of washings is composed of balancing tanks and the Johnson Lamella Separator units. Aluminium sulphate and/or polyelectrolyte are dosed before the sludge entering the separation units. A coagulated suspension separated in the Lamella Separator units is collected in the sludge tanks placed directly under each separation unit. The sludge collected there is pumped to the sludge storage tanks at regular intervals. Once treated, the sewage flows out of the sedimentation tank through drain gutters. During the treatment of raw water, post-coagulation is also formed in the lamella settling tanks placed in the water production line. These tanks are designed to separate the highest possible amount of suspensions from water coagulated with aluminium sulphate and/or polyelectrolyte. When sludge is formed, it is pumped to the shared sludge storage tanks. When the post-coagulation sludge (resulting from the treatment of backwash water and the coagulation of raw water) is mixed up, it is further thickened gravitationally in the storage tanks, and then mechanically dewatered on the belt press [2].

Sludge 2 was sampled from the accelerator in which process wastewater is treated using aluminium sulphate. This sludge includes backwash water from carbon and contact filters, as well as the sewage produced when primary settling tanks are cleaned. Treated sludge is recycled to raw water and sludge is disposed to the sludge storage tank. Subsequently, the sludge is occasionally dewatered in the belt press installation [14].

Total solids (TS), volatile solids (VS), hydration and capillary suction time (CST) were determined for the tested sludge, both before and after its digestion. The analysis was conducted in accordance with the existing standards: PN-EN 12880

[15] and PN-EN 12879 [16]. The CST was measured using a special gauge consisting of two separate components: an acrylic filtration unit with electrodes and a timer. The CST measurement helps determine how fast a liquid is stripped from hydrated sludge based on the operating principle of the capillary suction forces of Whatman filter paper 17 [14]. The lower the CST value, the more easily (faster) the tested sludge gives off its liquid (water) component, thus showing a higher tendency towards dehydration.

The laboratory tests of anaerobic stabilisation were conducted in a sludge digestion apparatus. The apparatus consisted of flasks with an active volume of 0.5 dm^3. The flasks were combined with columns used to measure the amount of produced sludge-digestion gas. The digestion set was equipped with a thermostat to keep a constant temperature of 37 °C. Before starting the process, the post-coagulation sludge was inoculated with the partially anaerobically digested sludge sampled from the anaerobic digester of a municipal wastewater treatment plant. The content of sewage sludge in each sample was the same – 20%. At the same time, the sewage sludge used as an inoculate was also digested for the purpose of comparison. The amount of released sludge-digestion gas was recorded during the process. The tests were carried out for 35 days because only a slight increase in the volume of the produced sludge-digestion gas could be observed thereafter.

Methane digestion was carried out in accordance with standard PN-75/C-04616/07 [18].

3. TEST RESULTS AND DISCUSSION

The results of the physicochemical analysis of the post-coagulation and sewage sludge subjected to methane digestion are presented in table 1. Blending the post-coagulation sludge with the sewage sludge increased some of the mixture parameters (pH, TS, VS, CST) in comparison with the parameters of cost-coagulation sludge. This was due to the properties of the sewage sludge used as an inoculate.

The sludge had various volatile solids (VS) content. The highest proportion of organic substances (66.0%) could be found in the sewage sludge from separate digestion tanks. In the post-coagulation sludge that was inoculated, however, the VS value amounted to 60.5% and 58.8% for sludge 1 and sludge 2, respectively. The sludge from wastewater treatment plant showed a high CST of 1020 seconds. For the post-coagulation sludge that was inoculated, the CST was considerably lower and it was 306 and 70 seconds for sludge 1 and sludge 2, respectively.

The said sludge demonstrated a high hydration rate of 98.9%. The hydration of the sewage sludge alone was lower – 96.8%. Despite a relatively small proportion of sewage sludge, the post-coagulation sludge that was inoculated was brown and had a typical odour of sewage sludge.

Sludge with the physicochemical properties presented in table 2 was achieved as a result of anaerobic stabilization. It showed better filtration performance, which confirms a multiple decrease in its CST. The impact of digestion on CST reduction is illustrated in figure 1. The CST of sewage sludge dropped to 840 seconds, of sludge 1 to 114 seconds, and that of sludge 2 to 30 seconds.

Table 1

Physicochemical characteristics of the sludge prior to digestion

Factor	Unit	Wastewater sludge	Sludge 1 + 20% wastewater sludge	Sludge 2 + 20% wastewater sludge	Sludge 1 + 20% wastewater sludge	Sludge 2 + 20% wastewater sludge
			Before mixing		After mixing	
pH	–	7.99	6.72	6.42	7.1	6.9
TS	%	3.2	0.6	0.6	1.1	1.1
	g/kg	32.0	6.0	5.8	11.2	11.1
VS	% TS	66.0	52.9	48.7	60.5	58.8
	g/kg	21.1	3.2	2.8	6.8	6.5
Hydration	%	96.8	99.4	99.4	98.9	98.9
CST	S	1020	121	25	306	70

Table 2

Physicochemical characteristics of the sludge following digestion

Factor	Unit	Wastewater sludge	Sludge 1 + 20% wastewater sludge	Sludge 2 + 20% wastewater sludge
pH	–	7.3	7.0	6.7
TS	%	2.8	1.0	1.0
	g/kg	28.0	10.5	10.8
VS	% TS	61.1	57.1	56.7
	g/kg	17.1	6.0	6.1
Hydration	%	97.2	98.9	98.9
CST	s	840	114	30
TS reduction	%	12.5	6.5	2.3
VS reduction	%	19.0	11.8	5.8
Sludge–digestion gas	M^3/kg VS input	0.19	0.09	0.05
Sludge-digestion gas	M^3/kg VS spread	1.00	0.81	0.81

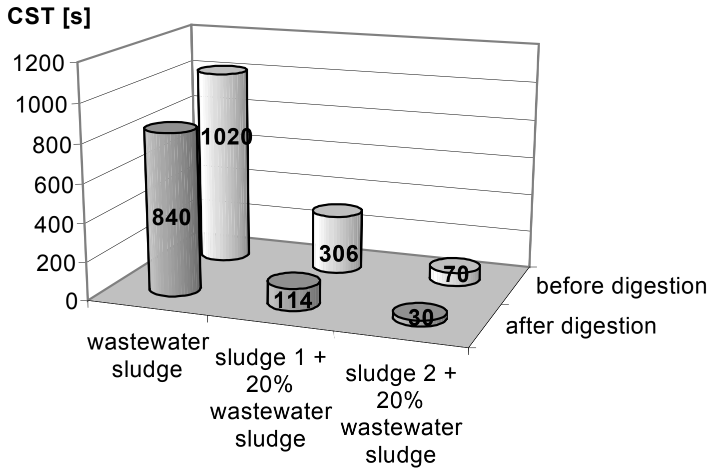

Fig. 1. Changes of CST in the digestion process

Due to biochemical changes, each sludge showed a decrease in VS content (figure 2). After the digestion the VS proportion in the sewage sludge was 61.1% and in post-coagulation sludge 1 – 57.1% and sludge 2 – 56.7%. The mineralization rate calculated as a percentage of VS loss is one of the key parameters enabling the assessment of digestion effectiveness. The highest VS loss (19%) was obtained for the sewage sludge. For the post-coagulation sludge, this loss was considerably lower and was 11.8% (sludge 1) and 5.8% (sludge 2).

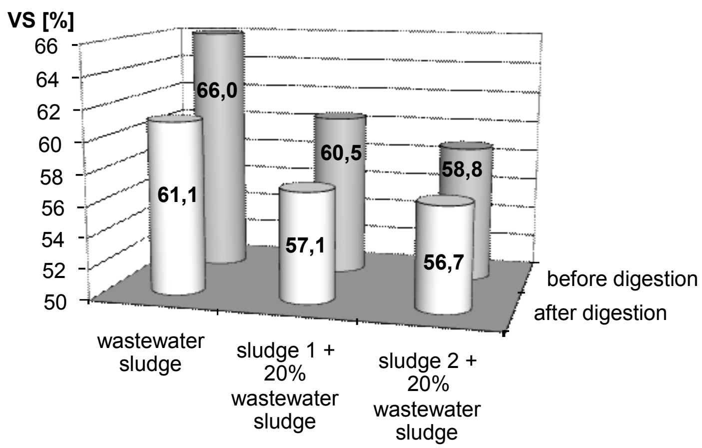

Fig. 2. VS reduction in sludges in the digestion process

Another parameter enabling us to determine the effectiveness of digestion is the amount of the produced sludge-digestion gas. Continuous production of sludge-digestion gas was observed in the present tests, however, the intensity of this process in the sewage and the post-coagulation sludge was different (figure 3). The intensity of sludge-digestion gas production depends predominantly on the sludge content in organic compounds which are the main substrate for microorganisms. For the sludge from wastewater treatment plant, the intensity of sludge-digestion gas evolution was the highest in the initial stage of the tests, whereupon its production decreased, with the daily production of sludge-digestion gas remaining already constant until the end of the tests. During the digestion of the post-coagulation sludge it was observed that compared to the sewage sludge, the intensity of sludge-digestion gas evolution was substantially lower. This suggests that the components of such sludge have an inhibitive effect on the digestion process. This may be due to the fact that the water treatment technology is based on mineral coagulants. Excessively high concentrations of both aluminium compounds and sulphates may inhibit the development of the bacteria responsible for anaerobic decomposition of organic compounds. The low production of sludge-digestion gas in post-coagulation sludge correlates well with sludge-digestion gas evolution levels, which are lower here than in the case of sewage sludge (table 2). For the sewage sludge, the sludge-digestion gas evolution rate per volatile solids input was 0.19 m^3/kg VS, whereas for the post-coagulation it was 0.09 m^3/kg VS (sludge 1) and 0.05 m^3/kg VS (sludge 2).

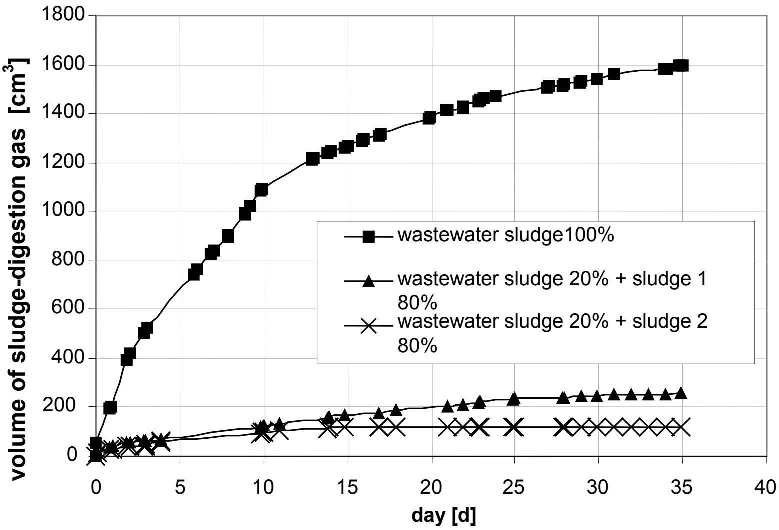

Fig. 3. Total volume of sludge-digestion gas evolution during digestion

In the digestion of post-coagulation sludge, the VS loss and the sludge-digestion gas evolution levels, being lower compared to those of sewage sludge, are probably directly related to sludge composition. Post-coagulation sludge contains contaminants removed from water as well as aluminium compounds and sulphates which are the components of the employed coagulant.

4. SUMMARY

The growing eutrophication of surface waters deteriorates the quality of treatable water. This means that there is a need for more powerful treatment processes which produce relatively large volumes of organic substances. Keeping sludge in drying beds involves putrefaction and emission of unpleasant odours. Accordingly, the introduction of sludge stabilization may become a necessity in the future.

The tests were conducted to identify the potential for the anaerobic digestion of post-coagulation sludge in order to obtain sludge with a reduced content of organic substances that could be easily dewatered. The test results showed that, despite a relatively high proportion of volatile solids in such sludge (58.8% and 60.5%), the effectiveness of digestion was considerably lower than in the case of the sewage sludge alone. Despite a 20% share of the sewage sludge, the post-coagulation sludge put under digestion showed small levels of sludge-digestion gas evolution and low mineralization rates calculated as VS loss. Digestion helped obtain better filtration properties of the sludge which can be seen in a sharp CST drop.

The test results do not provide a clear explanation whether choosing digestion as a way of stabilizing post-coagulation sludge is substantiated or not. Considering the poor effectiveness of the process, further research should address the digestion of the post-coagulation sludge which is available in the summertime, when its VS content largely exceeds 50%. It can be stated, however, that the digestion of post-coagulation sludge alone would not be technically or economically profitable. Co-digestion of sewage and post-coagulation sludge should be considered more reasonable. Such a solution would provide a potential opportunity for resolving the problem of post-coagulation sludge through its disposal in wastewater treatment plants. Further research into the digestion of post-coagulation sludge mixed up with various proportions of sewage sludge should be conducted to determine the best possible share of each type of sludge for their effective disposal.

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