Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.24065

155 (2019) 145–154
July

The possibility of using Portland cement to improve the sedimentation properties of activated sludge

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Received 10 September 2018; Accepted 28 February 2019

ABSTRACT

Sludge bulking and foam on the surface of activated sludge tanks, as mainly resulting from the overgrowth of filamentous bacteria, is a problem encountered frequently in WWTPs. Activated sludge sedimentation can be improved through the use of chemical reagents and powdered materials. In that context, the work detailed here, demonstrated the impact of two types of Portland cement on such sedimentation properties, i.e. Portland cement (PC) and Portland-fly ash cement (PFAC). Settling tests showed differing efficiencies where the settlement capacity of activated sludge was concerned, in relation to both the type and amount of cement used. At 1.0 mL/L of cement milk, the decrease in settleability is almost unnoticeable. During tests with the highest dose of cement (10.0 mL/L), the reduction in activated sludge settleability was 16.8% for Portland-fly ash cement. Portland cement may thus represent an effective new reagent in activated sludge technology.

Keywords: Portland cement; Cement milk; Wastewater treatment; Activated sludge; Sludge bulking

1. Introduction

The activated sludge process is the method used most commonly in the treatment of wastewater. Bacteria, essential for the process, remove the soluble and insoluble pollutants by using them as substrates for metabolism. Bacteria exist in the system as aggregates called flocs, which are a heterogeneous flocculated mass of bacteria, organic and inorganic material collectively called activated sludge. Flocs typically vary in particle size between 10 and 300 μm. Floc structure is an essential factor in determining the treatment performance of sludge processes. The formation of flocs is essential for the operation and efficiency of the treatment process. Typically, the separation of bacteria occurs by gravitational solid–liquid separation. If flocculation fails to occur, active biomass essential for the operation of the process is lost from the system. This is not only the cause of a reduction in process efficiency, but it may also result in an excess of solids being discharged into the environment [1,2]. Floc morphological and physical properties have a major influence on sludge compressibility and settlement capacity. There are two main types of settling problems: bulking of sludge due to the proliferation of filamentous bacteria and poor flocculation properties, e.g. the formation of small and light flocs [3].

Sludge bulking and foam formation on the surface of activated sludge tanks, as mainly caused by overgrowth of filamentous bacteria, is a problem encountered frequently in WWTPs [4]. Activated sludge settleability is defined in terms of the sludge volume index (SVI) and zone settling velocity (ZSV). The bulking of sludge is usually characterised by a sedimentation rate of less than 0.3 m/h, and a sludge volume index (SVI) above 150 mL/g [1,5–7]. The SVI is the most important indicator applied in measuring sludge settleability. It reflects an operational test performed to determine settleability over a very short time.

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To prevent and counteract bulking and foaming of sludge, it is necessary, in the first instance, to apply certain technological operations (a high degree of recirculation, addition of digested sludge, and a change in the organic loading rate and oxygen concentration) [5,7]. Improved activated sludge sedimentation may be achieved using chemical oxidants (ozone, sodium hypochlorite, hydrogen peroxide) [8,9], aluminum and iron salts [10–12] or organic synthetic polymers [13]. It is also possible for powdered mineral materials to be used [7,14,15].

Currently, a search is ongoing for unconventional methods by which the sedimentation of activated sludge might be improved and bulking of sludge reduced [16,17].

Against that background, the investigation reported on here has sought to analyse the impact of Portland cement on the sedimentation properties of activated sludge under laboratory conditions. Thus far, Portland cement has not been used in activated sludge technology.

2. Materials and methods

2.1. Activated sludge

Activated sludge was taken from the wastewater treatment plant in Rzeszów (Poland). The Rzeszów WWTP treats approximately 38,000 m^3 of wastewater per day with an anaerobic-anoxic process. The sludge in question was collected from the nitrification tank and transferred to the laboratory of Rzeszow University of Technology, where it was stored at 10°C–20°C until the time the sedimentation tests were performed. In all the experiments conducted, activated sludge samples were examined at a temperature of 20°C.

The activated sludge used in this study was characterised by strong sludge bulking and a wide range of values for the sludge volume index. The samples were collected in autumn and winter, when some problems with bulking at the WWTP were to be noted. The experiments were conducted with various sedimentation properties of activated sludge. The filamentous index (FI) was at the level 4–6. Beyond that, other main characteristics of the activated sludge are as listed in Table 1.

The mixed liquor of suspended solids (MLSS) was determined from the weight loss of activated sludge samples dried at 105°C for 2 h. MLSS concentration and SVI value were appointed in line with Polish Standard Methods. The zone settling velocity (ZSV) was taken as the settling velocity (v_s) of activated sludge, and calculated using the formula (1). A parameter model r_v was also established in line with Eqn. (2) [18]. The average diameter of activated sludge was 34.6 μm, as determined using the Mastersizer 2000 E laser diffraction particle size analyser [19].

$$v_s = 17.4 \cdot e^{-0.0113 \cdot \mathrm{SVI}} \left[\mathrm{m/h} \right] \tag{1}$$

$$r_V = -0.9834 \cdot e^{-0.00581 \cdot \mathrm{SVI}} + 1.043 \left[\mathrm{L/g} \right] \tag{2}$$

Table 1
Characteristics of the activated sludge used in this study

Parameter, unit	Minimum	Maximum	Average	Standard deviation
MLSS, g/L	1.20	3.59	2.46	0.77
SVI, mL/g	167.2	389.8	258.8	84.0
ZSV, m/h	0.213	2.79	1.32	1.01
pH	7.48	7.92	7.70	0.14

2.2. Characteristics of the Portland cement

The two types of Portland cement used in this study were Type I Portland Cement (PC) and Type II Portland-Fly Ash Cement (PFAC). The measured values for density of the samples were at the level 3.10 and 2.85 g/mL for PC and PFAC, respectively.

The chemical composition of the cement samples used in this study is as given in Table 2. The data there were obtained using the XRF spectrometry method, and make it clear that cement samples consisted primarily of CaO and SiO_2. Fly ash is an essential component that modifies the characteristics of Portland cement. Its addition can increase packing density and reduce the voids ratio of the cement materials [20]. Clearly, the examined samples were significantly different with respect to the presence of silica, aluminum, calcium and iron (Table 2). In addition to these components, other trace elements may be present in the cement. These originate from the raw materials and fuels used in cement production, and are bound to some extent during cement hydration, while a small fraction remains dissolved in the pore solution [21].

Portland cement is a highly alkaline material, and pH values of the tested PC and PFAC samples were of 12.4 and 12.8, respectively.

To perform a particle-size analysis of PC and PFAC samples, particle size distributions (PSDs) were determined for these using a Malvern Mastersizer 2000 E Analyzer. The PSD parameters for the samples are *d*(0.5), *d*(0.1) and *d*(0.9), Span, Uniformity and Specific Surface Area [20]. The *d*(0.5) is the

Table 2
Chemical characteristics of PC and PFAC cement used in these studies

Component (%)	PC	PFAC
LOI	3.49	2.95
IR	0.69	1.36
SiO_2	18.71	27.2
Al_2O_3	5.33	10.4
Fe_2O_3	2.85	3.42
CaO	61.29	46.75
MgO	1.42	2.42
Na_2O	0.18	0.68
K_2O	0.85	1.40
$eqNa_2O$	0.73	1.36
SO_3	3.23	3.12
Cl^-	0.069	0.072
Content of fly ash (FA)	–	29.4

LOI – the loss of ignition; IR – insoluble residue; $eqNa_2O$ – calculated as $Na_2O + 0.66K_2O$.

size of particle at which 50% of the sample is smaller and 50% is larger. This value is also known as the Mass median diameter. The $d(0.1)$ and d(0.9) values represent the sizes of particle for which 10% or 90% of the sample is smaller. The Span is a measure of the width of the distribution, calculated as:

$$\text{Span} = \frac{d(0.9) - d(0.1)}{d(0.5)} \quad (3)$$

Uniformity is in turn a measure of absolute deviation from the median, in line with the formula:

$$\text{Uniformity} = \frac{\sum x_i \left| d(0.5) - d_i \right|}{d(0.5) \sum x_i} \quad (4)$$

where d_i and x_i are respectively the mean diameter of, and result in, size class i.

Specific surface area (SSA) is defined as the total area of particles divided by their total weight:

$$\text{SSA} = \frac{6 \sum \frac{V_i}{d_i}}{\rho \sum V_i} = \frac{6}{\rho d[3,2]} \quad (5)$$

where V_i is the relative volume of particles in class i with a mean class diameter of d_i, and r is particle density. The $d(3,2)$ is a surface weighted mean or Sauter mean diameter.

Other PSD parameters are the coefficients of uniformity and of curvature. The coefficient of uniformity, C_U, is a distribution shape parameter and is calculated as:

$$C_U = \frac{D_{60}}{D_{10}} \quad (6)$$

where D_{60} is the particle diameter at 60% passing, and D_{10} the particle diameter at 10% passing. Solids with C_U greater than 4–6 are considered well-graded (not uniform), while those with C_U below 4 are poorly graded or uniform in size.

The coefficient of curvature (or coefficient of gradation), C_C, is given as:

$$C_C = \frac{\left(D_{30}\right)^2}{D_{10} \cdot D_{60}} \quad (7)$$

where D_{30} is the grain diameter at 30% passing. For well-graded (non-uniform) solids, C_C values are in the range 1–3.

A summary of the PSD parameters used in identifying particle fineness and their uniformity is given in Table 3. Values for the specific surface area of PC and PFAC samples were found to be at a similar level and amounted to 4,090 and 4,150 cm^2/g, respectively. The materials were characterised by various particle-size distributions. PSD curves for particle sizes between 1.0 and 10.0 µm largely overlap for the PC and PFAC samples, only for there to be marked divergence where particle size is above 10.0 µm (Figs. 1 and 2). The values measuring uniformity (Uniformity, C_U and C_C) as given in Table 2 are such as to imply that the size gradation of the examined cement samples falls into a transitional region between poorly or uniformly graded solids.

Table 3
Parameters characterising the particle-size distribution of PC and PFAC cement

Parameter	Unit	PC	PFAC
Surface weighted mean $d[3,2]$	µm	13.9	13.7
Volume weighted mean $d[4,3]$	µm	32.2	44.1
Diameter $d(0.1)$	µm	6.1	5.5
Diameter $d(0.5)$	µm	23.0	24.7
Diameter $d(0.9)$	µm	66.7	108.6
Span	–	2.64	4.163
Uniformity	–	0.884	1.31
The coefficient of uniformity (C_U)	–	4.49	5.54
The coefficient of curvature (C_C)	–	0.86	0.80

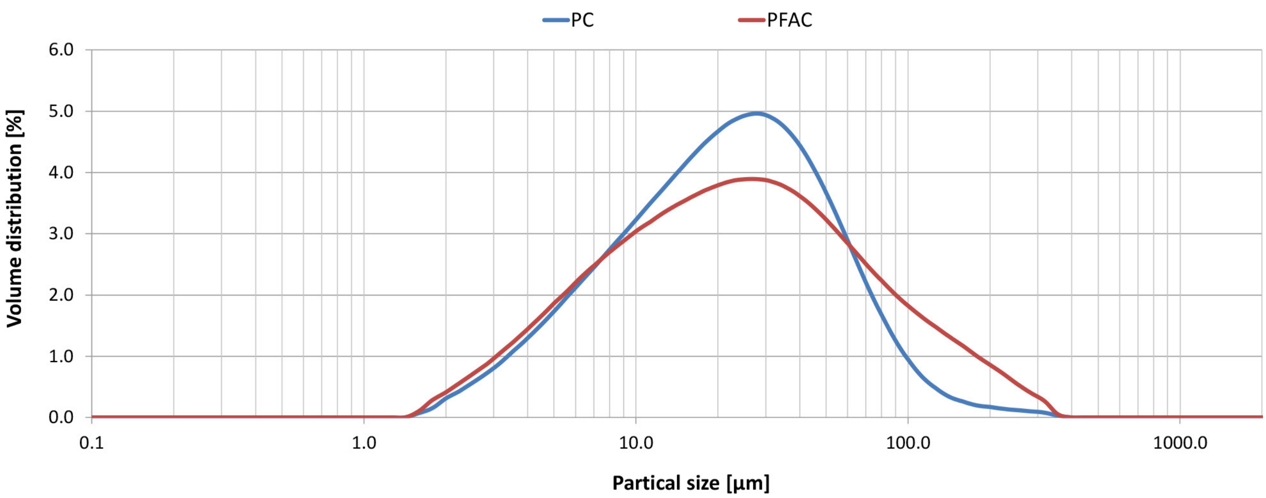

Fig. 1. Particle-size distributions characterising the cement powders used.

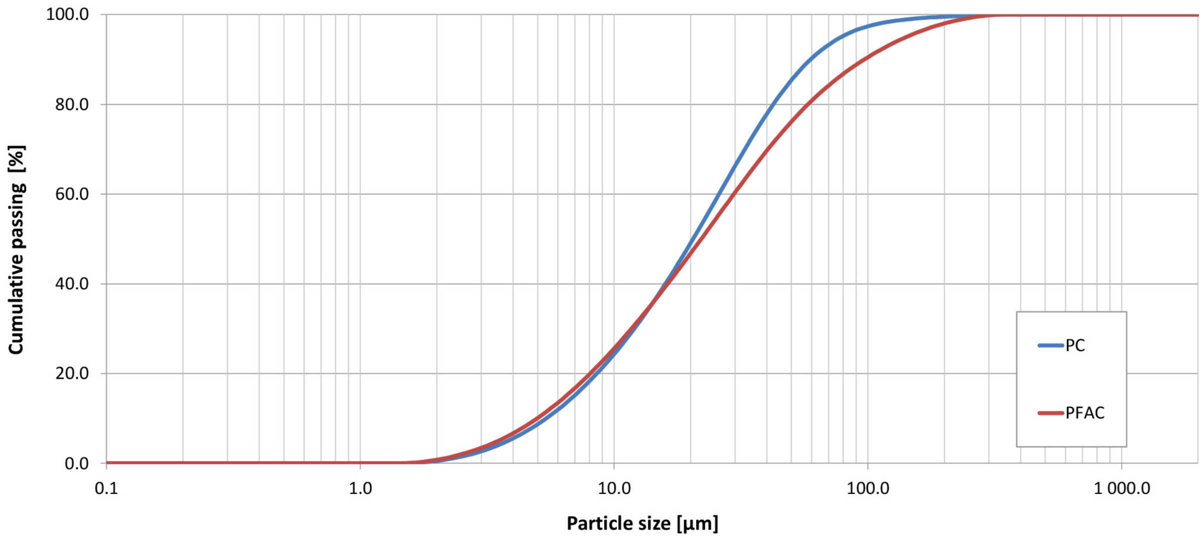

Fig. 2. Graphs of cumulative percentage volume for Portland cement particles.

To the authors' knowledge no information has thus far been made available on the use of Portland cement in relation to activated sludge technology. It is most often used as an agent for the solidification and stabilisation of sewage sludge, and also for heavy-metal adsorption [22,23]. Other possible applications of Portland cement include those in research in the field of wastewater technology, e.g. for the removal of phosphate ions from aqueous solution [24].

2.3. Settling tests

The experimental assays were conducted in batch systems. The tests were carried out using a new sample of cement in each of the five measurement series. Depending on the content of the cement in the activated sludge, the scope of research included analysis of settleability after 30 (V_{30}) and 60 (V_{60}) minutes, estimation of SVI, mixed liquor suspended solids (MLSS) and settling velocity. pH measurements were made using a flexi HACH HQ30d Multi-Parameter Metre.

A volume of activated sludge of 1200 mL was introduced to each of five beakers of 2 L capacity and relevant quantities of Portland cement were then added. The addition was in the form of a 2% solution of so-called "cement milk". Final concentrations of the latter in the five beakers were of: (1) 1.0; (2) 2.0; (3) 5.0 and (4) 10.0 mL/L respectively. The reference level (0) represented activated sludge to which no cement milk had been added. Beakers were placed in a mechanical stirrer with rapid (1 min) or slow (10 min) mixing programmes. The concentrations of the activated sludge were quantified as MLSS, and were determined for each sample. Cylinders of 1 L capacity were then supplemented with a sample of sludge, and the subsequent sedimentation process examined for 60 min. The height of the activated sludge layer as SBH (the Sludge Blanket Height) was determined as heights of the suspension-liquid interface in relation to different settling times.

A settleability curve was plotted on the basis of the results of the 60 min settling test. After 60 min, 50 mL samples of wastewater were collected to determine the total suspended solids (TSS). TSS measurement was determined in line with Polish Standard Methods.

2.4. Statistical analysis

Statistical analyses were performed to identify the major cause-and-effect relationships. Univariate linear correlations were used as a simplifying measure. All statistical analyses were conducted using the *Excel* software. Since a normal distribution was not obtained for many of the properties examined, a distribution-free statistical method was used. Pearson's product momentum correlation coefficient (rp) was applied in linear estimations. Values of this coefficient are always in the −1/+1 range, with −1 denoting a perfect negative correlation and +1 a perfect positive correlation, while 0 suggests the absence of any relationship. Non-linear relationships were assessed by means of regression analysis. Correlations were considered statistically significance at a 95% confidence interval ($p < 0.05$).

3. Results and discussion

3.1. The cement content in activated sludge

Dosage of cement milk was reflected in its content in activated sludge. Table 4 presents mean values for PC and PFAC. The presence of cement in activated sludge led to a significant increase in the MLSS. Depending on the dose, cement contents were in the range 0.0063–0.2 g/g MLSS. The increase in MLSS resulting from the presence of cement particles is followed to only a limited degree. Maximum cement-particle content was 20%. In comparison, in other studies by the author, powdered materials of particle size <200 µm were used in amounts between 0.038 and 0.54 g/g MLSS, with percentage values for mineral particles ranging from 8.1% to 32.5% [15]. A large quantity of mineral substances in the activated sludge is not indicated, given the way physicochemical characteristics changed to those of a mineral nature. Then the activated sludge has a high content of inorganic particles. Nevertheless, there have been cases of the application of large amounts of powdered materials to activated sludge. For example, Cantet et al. [25] applied powdered talc (<300 µm) to activated sludge at a rate of 3.0–4.0 g/L.

Table 4
Average content of Portland cement in activated sludge samples

No. beakers	Dose of cement milk to activated sludge (mL/L)	Dose of cement to activated sludge (g/L)	Cement content in activated sludge (Mean ± SD) (g/g MLSS)	
			PC	PFAC
0	0.0	0.0	–	–
1	1.0	0.02	0.0112 ± 0.006	0.0072 ± 0.002
2	2.0	0.04	0.0224 ± 0.012	0.0144 ± 0.005
3	5.0	0.1	0.0560 ± 0.030	0.0361 ± 0.012
4	10.0	0.2	0.1120 ± 0.060	0.0721 ± 0.023

Given the chemical composition of the PC and PFAC cement, various amounts of aluminum, calcium and iron were noted in the activated sludge. Depending on the dose of PC cement milk, the contents of Fe, Al and Ca in the activated sludge amounted to 0.4–4.0 mg Fe/L, 0.56–5.6 mg Al/L and 8.75–87.5 mg Ca/L, respectively. In turn, in the case of PFAC cement application the contents of individual metals in the activated sludge in the settling tests were: 0.48–4.8 mg Fe/L, 1.1–11.0 mg Al/L and 6.67–66.7 mg Ca/L. Consequently, the contents of iron, aluminum and calcium in activated sludge were: 0.24–2.39 mg Fe/g MLSS, 0.34–3.37 mg Al/g MLSS and 5.23–52.29 mg Ca/g MLSS for probes with PC cement and 0.17–1.73 mg Fe/g MLSS, 0.4–3.97 mg Al/g MLSS and 2.41–24.07 mg Ca/g MLSS for probes with PFAC cement (Table 5). The activated sludge to which PC cement had been added differed from the sludge containing PFAC in its smaller amounts of iron, aluminum and calcium. The presence of these metals was reflected in sedimentation properties of the activated sludge. The cations Ca, Mg, Al and Fe have been found to improve sludge compressibility and settlement capacity significantly [3,26]. The addition of calcium and magnesium compacts the flocs, promotes bioflocculation, and consequently increases the capacity of sludge to settle and dewater [26].

Due to the Fe and Al content, dosage of cement milk may be related to the application of chemical coagulants to activated sludge. Improved sedimentation properties of activated sludge (and consequently reduced bulking) may be achieved using salts of aluminium and iron [7,11]. Kida et al. [7] showed that large amounts of the latter reduce the SVI of activated sludge. In other studies, Iron(II) sulphate ($FeSO_4 \cdot H_20$) dosed at 30 mg Fe/L was shown to result in a reduction of SVI from >300 to 50 mL/g [10].

For comparative purposes, a study by Drzewicki [27] applied polyaluminium chloride (PAX 18) at 0.63–2.13 mg Al^{3+}/g MLSS, with this producing a minor improvement in the efficiency of activated sludge sedimentation, on account of low SVI values not being achieved. In turn, Geneja [28] demonstrated that prolonged use of polyaluminium chloride (PAX 16) at 1.4–3.2 mg Al^{3+}/g MLSS contributes to a significant reduction in the degree to which sludge becomes bulked. This revealed significantly lower maximum values for SVI in relation to the extreme level (of 247–317 mL/g) observed prior to the application of aluminium salts. The author noted SVI values in the range 135–155 mL/g during the period of application with polyaluminium chloride [28]. Masłoń and Tomaszek [12] showed that the degree to which sedimentation properties improved was what determined the size of the SVI decrease, in line with the content of Al^{3+} or Fe^{2+}/Fe^{3+} in the activated sludge. A statistical model in turn suggested that the greatest improvement in sedimentation was found for PAX 25 (polyaluminium chloride + iron(II) chloride), as well as SAX 18 (sodium aluminate).

Table 5
Content of Al, Fe and Ca in the activated sludge depending on dose of cement milk

Amount type	Unit	Dose of cement milk (mL/L)				
		0	1.0	2.0	5.0	10.0
PC	mg Fe/g MLSS	0	0.24	0.48	1.19	2.39
	mg Al/g MLSS	0	0.34	0.67	1.68	3.37
	mg Ca/g MLSS	0	5.23	10.46	26.14	52.29
PFAC	mg Fe/g MLSS	0	0.17	0.35	0.87	1.73
	mg Al/g MLSS	0	0.40	0.79	1.99	3.97
	mg Ca/g MLSS	0	2.41	4.81	12.03	24.07

3.2. The settleability of activated sludge with Portland cement

Settling tests showed different efficiencies to activated sludge settleability, in relation to the type and amount of cement applied (Figs. 3 and 4). The presence of the lowest dose of cement milk (1.0 mL/L) failed to produce any apparent improvement in sedimentation of activated sludge above the level noted where cement material was absent. Sedimentation of activated sludge with PFAC was lower than with PC cement. While activated sludge settleability with PC cement was very intense for 4–5 min, progress tailed off after that. In contrast, while the sedimentation of activated sludge with PFAC remained poor for 5–7 min, the process intensified subsequently. For activated sludge samples with PC the best sedimentation was obtained at a dose of 5.0 mL/L. With remaining doses the impact in improving sludge settleability was more limited. In turn, in the case of sludge with PFAC, the best results as regards improved settling were with 10.0 mL/L. Fig. 3 compares activated sludge settleability with the different types of cement added. The addition of the PC cement had a greater effect on activated sludge sedimentation than adding the same amount of PFAC cement.

Reduction of V_{30} and V_{60} settleability and the sludge blanket height of activated sludge are determinants of the degree to which sedimentation properties of activated sludge may be improved. Settling tests showed that PC cement had the

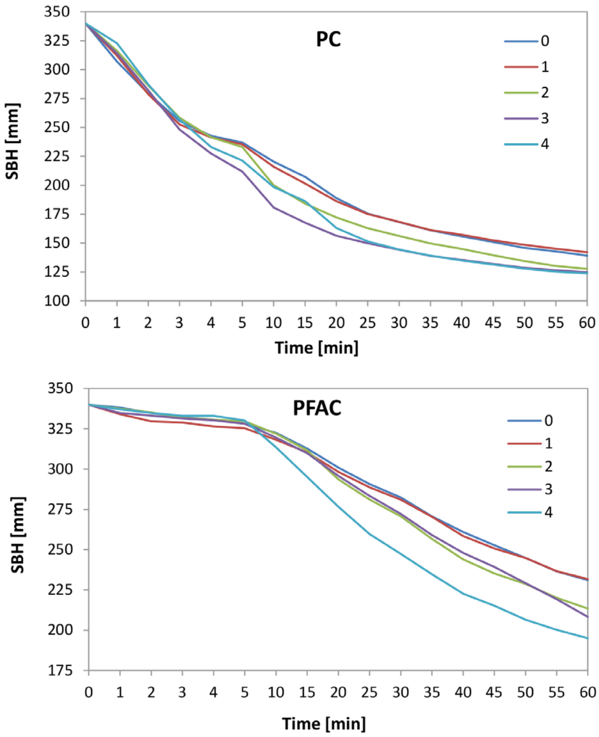

Fig. 3. Activated sludge settleability with different cement additions (average values); (0) without cement, (1) 1.0 mL/L, (2) 2.0 mL/L, (3) 5.0 mL/L, (4) 10.0 mL/L.

greatest impact on V_{30} and V_{60} settleability over the range of doses used (Fig. 5). Dosing of 1.0 mL/L of PC and PFAC supported an improvement in V_{30} settleability of less than 1%. With a greater amount of cement milk the improvement in settleability was more noticeable. At the 2.0 mL/L of PC and PFAC the obtained decrease in V_{30} was of around 5.8% and 4.3% respectively. With 5.0 mL/L of cement milk the V_{30} improvements were of 13.2% (PC) and 3.8% (PFAC). Finally, the highest doses of PC and PFAC were shown to reduce the values of the V_{30} index by 14.8% and 12.8% respectively.

With 1.0 mL/L of cement milk, the V_{60} decreases were almost unnoticeable, at 0.8% (PC) and 0.1% (PFAC). Higher doses of Portland cement yielded improved sedimentation of activated sludge. Doses of 2.0 mL/L of PC and PFAC reduced values of the V_{60} index by 7.1% and 7.9%, respectively. In turn, at the dose of 5.0 mL/L of reagent, the V_{60} improvements obtained were of around 10.3% (PC) and 10.1% (PFAC). During tests with the highest dose of cement (10.0 mL/L), the V_{60} decreases stood at 12.3% and 16.8% for PC and PFAC respectively.

3.3. Analysis of the sludge volume index

The mean initial values for the sludge volume index of the control samples was 221.1 and 303.6 mL/g respectively, in the cases of PC and PFAC. Depending on the tested activated sludge and Portland cement doses, the SVI reached a range of different values (Fig. 6). The decreases are as shown in Fig. 7. The minimum reduction of approximately 1% in the sludge volume index was achieved when 1.0 mL/L of cement milk was applied. Resort to higher doses of Portland cement only brought a 7% reduction of SVI, while the maximum decrease obtained was of up to 21%, at a dose of 10.0 mL/L of PC. Statistical analysis pointed to a significant difference between PC and PFAC in terms of the effect on SVI ($p < \alpha$).

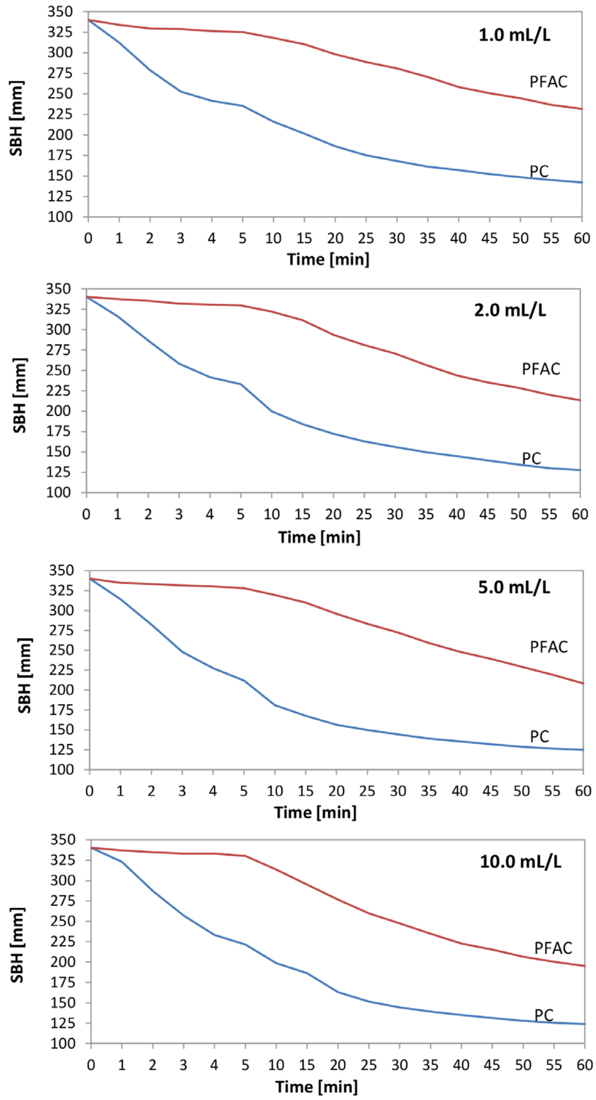

Fig. 4. Comparison of the sedimentation of activated sludge with the different cement milk additions.

Better results have been obtained in other studies on the use of powdered materials in activated sludge technology. Masłoń et al. [14] obtained more than a 20% decrease in SVI by applying powdered expanded clay (keramsite) at 1 g/L. Other studies have shown improvements in the sludge volume index (from 128 to 83 mL/g) with a dose of zeolite equal to 0.08 g per 1 g of activated sludge [29]. In turn, extreme results were obtained by the authors, when dosed talc and chlorite at 0.6 g/g MLSS yielded a reduction in SVI from 850 to 100–125 mL/g [30].

3.4. The sedimentation velocity of activated sludge

An appropriate sedimentation velocity for activated sludge is of importance when it comes to the clarification of wastewater in a secondary clarifier. Any disturbance to the process by which activated sludge and wastewater separate has its adverse effect on the quality of the effluent from a wastewater treatment plant, and mainly on its concentration

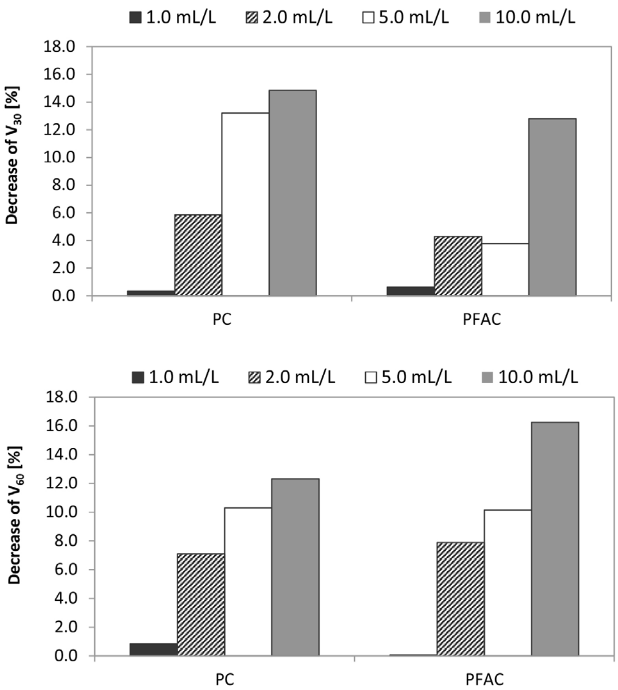

Fig. 5. The impact of cement milk in improving the V30 and V60 settleability of activated sludge (mean values).

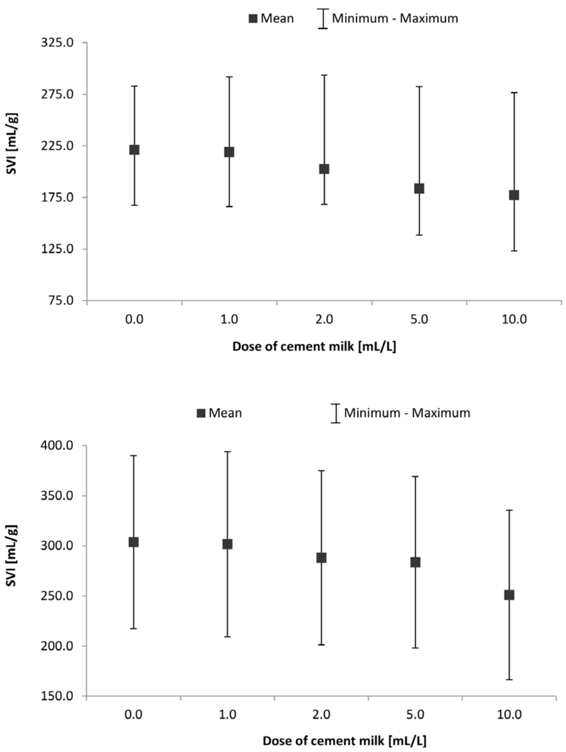

Fig. 6. The influence of PC and PFAC in reducing the sludge volume index (mean values); (0) without cement, (1) 1.0 mL/L, (2) 2.0 mL/L, (3) 5.0 mL/L, (4) 10.0 mL/L.

of total suspended solids [1]. Our dosing of cement milk led to a slight intensification of sedimentation velocity, up to 12%. Furthermore, in line with the test of activated sludge and the type and dose of cement milk, differential effects in enhancing velocity were obtained (Fig. 8). The average values of v_s were 2.34; 2.65; 3.16 and 3.43 m/h in the cases of PC doses (1), (2), (3) and (4) respectively, as opposed to 2.30 m/h in the case of the control sample (0).

In turn, the use of PFAC was associated with average values for sedimentation velocity equal to 0.92; 1.02; 1.07 and 1.53 m/h in the cases of dose (1), (2), (3) and (4) respectively. The v_s of the control sample (0) for these tests were 0.85 m/h.

Doses of powdered materials below 0.5 g/L only minimally affect the rate of sedimentation of activated sludge flocs. Only greater amounts above 0.5 g/L act to increase the viscosity of activated sludge more noticeably, with consequent higher sedimentation velocity [14]. Masłoń [15] achieved a more than 120% v_s intensification using powdered burned clay and powdered red clay at doses of 1.0 g/L. However, other studies indicate an even more dynamic intensification of activated sludge sedimentation. For example, Hosseinlou and Taebi [31] showed that a clay additive supplied at 1.863 g/L could more than double sedimentation velocity, from 1.22 to 3.83 m/h.

3.5. The influence of Portland cement on the pH of activated sludge

pH analysis of activated sludge in the course of the tests showed a dose-dependent effect for the cement milk

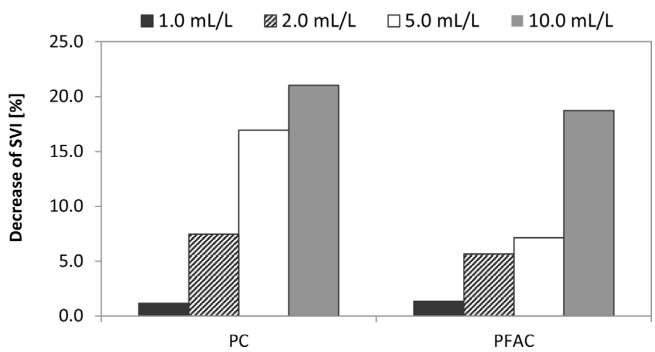

Fig. 7. The influence of cement milk in reducing the SVI of activated sludge (mean values).

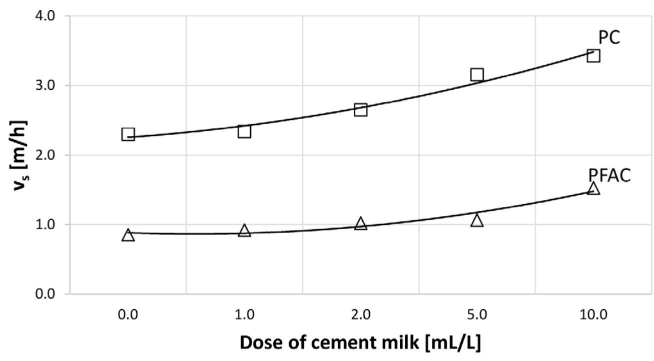

Fig. 8. The impact of cement milk in changing sedimentation velocity (mean values); (0) without cement, (1) 1.0 mL/L, (2) 2.0 mL/L, (3) 5.0 mL/L and (4) 10.0 mL/L.

(Fig. 9). With successively-higher doses of PC or PFAC, there was an increase in pH of activated sludge from approximately 7.7 to more than 8.2. A relatively marked linear correlation between the dose of cement milk and the pH of activated sludge was obtained, with $r = 0.84$ for PC and $r = 0.79$ for PFAC. This may reflect the presence of aluminum and iron oxides and fly ash in the Portland cement. Fly ash is characterized by an alkaline reaction, with water extracted from it sometimes reaching pH values above 12 [32]. Due to the inhibiting effect of such alkaline pH values on the activated sludge microorganisms observed in these tests, the increases justify additional improvement of the sludge volume index. For example, Ghanizeh and Sarrafpour [33] have demonstrated the impact of changes in pH on the sedimentation capacity of activated sludge. The authors obtained a decrease in the SVI for activated sludge from 96 to 44 mL/g with an increase of pH from 5 to 9 [33].

Our studies reveal a significant correlation between changes in pH and in the sludge volume index (Fig. 10). The observed effect of pH changes in improving the sedimentation properties of activated sludge depends largely on the types of samples tested. The relationship between pH and SVI was tested and described by a linear regression. The correlation between the pH of the mixture of activated sludge and cement milk and SVI was found to be high, with values of $r = 0.88$ for PC and $r = 0.98$ for PFAC. While a 1.0 mL/L dose of cement milk gave rise to an increase in pH of less than 2%, use of 10.0 mL/L gave rise to pH increases of 12.8% (PC) and 7.3% (PFAC) (Fig. 11).

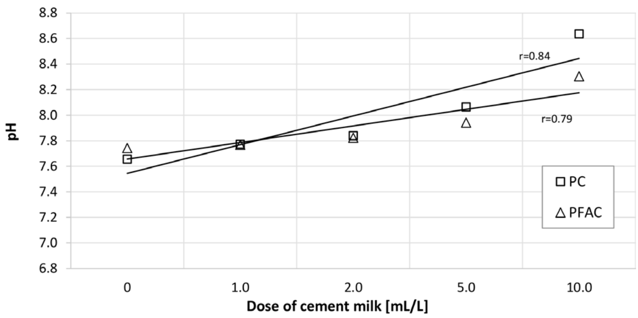

Fig. 9. The relationship between pH and change in the sludge volume index for activated sludge.

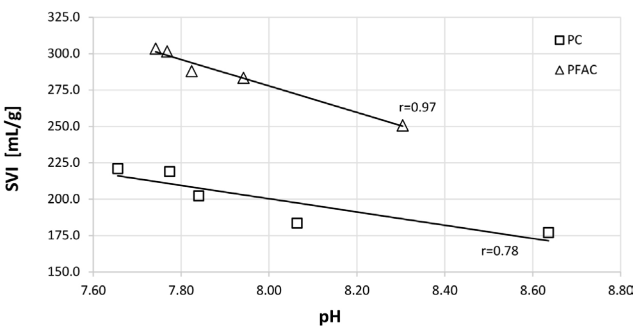

Fig. 10. The relationship between the pH of mixtures of activated sludge and cement milk and the SVI of activated sludge

3.6. The mechanism underpinning improved activated sludge sedimentation

An improvement in activated sludge sedimentation attributable to Portland cement may be a direct reflection of the presence of microparticles incorporated in flocs. The cement does consist of powdered-mineral particles. The dosage of cement milk is similar for the dispensing of powdered mineral materials. Those of particle size below 300 μm may, in line with their physical and chemical properties, serve various, complementary roles in activated sludge, as: (1) biomass microcarriers, (2) sorbents of chemical substances and (3) modifiers of the weight of activated sludge flocs [14]. The presence of powdered substances affects the morphological characteristics of activated sludge, particularly the shape, appearance, structure and consistency of flocs, as well as their sizes, given the way powdered particles integrate with the sludge. Probably, there is an interaction between the structures of powdered particles and flocs of activated sludge, such that the mineral particles incorporate very firmly into the floc and do not degrade in either an aeration chamber or a secondary settling tank. The incorporation of particles of powdered substances into flocs of activated sludge serves to increases relative density [7,15,25].

Another factor working to facilitate activated sludge sedimentation thanks to the addition of Portland cement concerns the presence of aluminum and iron. The chemical reagents used most commonly are salts of aluminum and iron, applied in the form of PIX and PAX coagulants of diverse Al^{3+}, Fe^{2+} and Fe^{3+} content [7]. The addition of coagulants and flocculants gives rise to significant improvements in the structure of flocs of activated sludge, and the growth in their size. Masłoń and Tomaszek [12] showed that the application of large amounts of iron and aluminum improves the sedimentation parameters of activated sludge significantly. An important correlation between aluminum content and SVI change was obtained with respect to the Al-coagulants. For the Fe-coagulants, the correlation between iron content and the reduction in SVI was definitely a lesser one. Despite the technological justification in terms of bulking sludge limitation, the use of a large amount of coagulant or synthetic polymer induces aluminium- and iron-induced toxic effects on the activated sludge biocoenosis [34,35]. The calcium in the Portland cement can also work to improve activated sludge sedimentation. Luo et al. [26] indicated that calcium and magnesium addition could improve bio-floc settleability

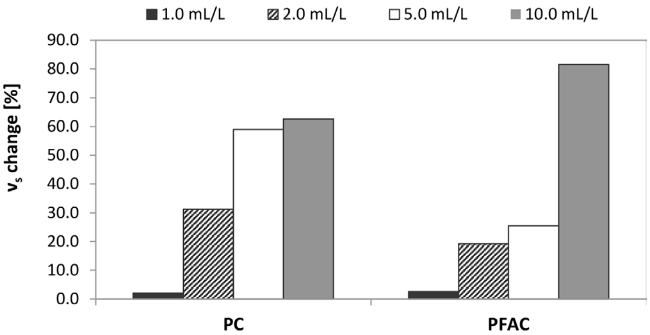

Fig. 11. The impact of cement milk in raising the pH of activated sludge (mean values).

and increase saturated fatty-acid content, while also decreasing the crude protein content of bio-flocs. The original sludge flocs are porous and wrapped, while the surfaces of cationically flocculated samples appear extremely compact. Portland cement can serve as the source of calcium for the activated sludge.

The dosage of cement milk and attendant content of Fe, Al and Ca may relate to the application of chemical coagulants to activated sludge. Some particles of Portland cement may be soluble and pass into wastewater and activated sludge. The pH change of such sludge containing cement milk is such as to indicate the leaching of iron and aluminum oxides from the Portland cement. The pH increase may also lead to improved sedimentation of activated sludge.

4. Conclusions

The present study examines the feasibility of Portland cement being used to improve the sedimentation properties of activated sludge. Given the presence of mineral particles and Fe, Al and Ca content, the dosage of cement milk may relate to the application of chemical coagulants or mineral powdered substances in activated sludge. The dosage of Portland cement can affect sedimentation rate in line with the presence of particles and Ca, Fe and Al, and does help improve activated sludge sedimentation. Settling tests in turn revealed differing efficiencies as regards settleability of activated sludge, depending on the type and amount of cement. The greatest decrease in SVI obtained was of up to 21%, at a cement-milk dose of 10.0 mL/L. The milk was found to raise the velocity of activated sludge sedimentation by up to 12%. Better effects in improving sedimentation of activated sludge were obtained using PC than PFAC. Portland cement may thus be a new effective reagent as regards activated sludge technology in wastewater treatment systems.

Symbols

C_C	–	Coefficient of curvature, –
C_U	–	Distribution shape parameter, –
$d(0.1)$	–	Size of particle for which 10% of the sample is below this size, µm
$d(0.5)$	–	Size of particle for which 50% of the sample is smaller and 50% is larger than this size, µm
$d(0.9)$	–	Size of particle for which 90% is below this value, µm
$d(3,2)$	–	Surface weighted mean (Sauter mean diameter), µm
D_{10}	–	Particle diameter at 10% passing, µm
D_{30}	–	Grain diameter at 30% passing, µm
D_{60}	–	Particle diameter at 60% passing, µm
d_i	–	Mean diameter, µm
r_v	–	Parameter model, L/g
SSA	–	Specific Surface Area, cm^2/g
SVI	–	Sludge volume index, mL/g
V_i	–	Relative volume of particles in class i with mean class diameter of d_i, mL
v_s	–	Settling velocity of activated sludge, m/h
x_i	–	Result in size class i
r	–	Particle density, g/mL

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