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Effect of chemical composition on the flocculation dynamics of latex-based synthetic activated sludge

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Abstract

This study investigates the effect of calcium, alginate, fibrous cellulose, and pH on the flocculation dynamics and final properties of synthetic activated sludges. A laboratory-scale batch reactor, fed with standard synthetic sludges was used. The effects of varying calcium concentration (5–25 mM), alginate concentration (25–125 mg/L), fibrous cellulose concentration (0.2–0.8 g/L) and pH (3–9) on the sludge characteristics were studied by varying one parameter whilst keeping the others constant. The results from experiments indicated that the calcium, alginate, fibrous cellulose, and pH had the critical effect on the aggregation rate, flocs size, and made the improvement of the final properties of sludge. Dynamic measurements have established the optimum conditions for floc formation and can accurately reflect the state of formation of the synthetic activated sludge flocs. These correlate well with measurements of settleability and turbidity of the synthetic activated sludge. The results of this study support the bonding theory and indicate that formation of cations-polymer complexes and polymer gelation are important means of flocculation. The development of synthetic activated sludges is suggested also to be a possible surrogate for studying the final properties of activated sludge.

Keywords: Synthetic activated sludge; Flocculation dynamics; Sludge properties; Photometric dispersion analyser (PDA); Malvern Mastersizer-S

1. Introduction

Activated sludge is now used routinely for biological treatment of municipal and industrial wastewaters. Activated sludge is a heterogeneous mixture of particles, microorganisms, colloids, organic polymers and cations, whose composition depends on the origin of the sample and the date of sampling [1]. The flocculated microbial aggregates, known as flocs, are the essential components of the system. Flocs typically vary in size from 10 to 1000 μm [2]. In the activated sludge process, the flocs remove both colloidal matter and soluble BOD (biochemical oxygen demand) by absorption and biodegradation, and their settling characteristics must also be such that the discharge standards of the final effluent are met to a high degree of consistency [3].

In general, the concept of the structure of activated sludge comprises three levels: bacteria, micro-colonies and flocs [4,5]. The first level of structure is made up of bacteria tightly bound together by a polymeric matrix to form the second level of structure called micro-colonies. The extracellular polymers arise from two origins, either from metabolism and cell lysis of microorganisms or from incoming wastewater [6]. These extracellular polymers or extracellular polymeric substances (EPS) are typically made up of proteins, polysaccharides, humic compounds, nucleic acids and lipids. Polymers and cations further link these micro-colonies to produce the third and final activated sludge flocs.

The flocculation of activated sludge is an active process, and depends on physical, chemical and biological factors. The basis of activated sludge floc formation lies in the abilities of microorganisms to stick to each other and to nonbiological particles. Microbial adhesion mechanisms have been studied widely but still are not understood. It appears that exocellular biopolymers form the bridges between microorganisms; these biopolymers typically contribute 15–20% by weight of mixed liquor suspended solid (MLSS) [6]. At the approximately neutral pH values typical of activated sludge, these polymers carry

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net negative charges. It is thought that divalent cations such as Ca^{2+} and Mg^{2+} interact with negatively charged polymers to form bridges that allow the cells to adhere to each other.

When built up by biopolymer bridging of relatively spherical microorganisms, the flocs themselves will be roughly spherical in shape. To form the irregularly shaped flocs often seen in activated sludge, other ingredients—filamentous organisms—are required [7]. Since floc strength depends on the integrity of the biopolymer bridging, it is possible for strong and weak flocs to exist both with and without filamentous organisms. Due to the complex nature of the flocs, they display a wide variation in physical, chemical and biological properties [8]. Many major operating problems in the process, such as those which occur in solid–liquid separation, can also be attributed to the properties of the flocs.

1.1. Bioflocculation

Biosolid–liquid separation by gravity settling in a clarifier is one of the most critical operations in the activated sludge process. The formation of stable biological flocs is essential for the successful operation of the process. In many cases, the efficiency of the clarifier is the limiting factor in producing a high quality effluent, and it is often regarded as the bottleneck of the process in terms of upgrading or increasing the capacity of the treatment plant. The settling properties of sludge are determined primarily by the conditions prevalent in the aeration basin. Changes in the chemical composition of activated sludge will lead to changes in the nature of the flocs, which can result in poor formation of biological flocs. The most notably adverse effect of poor or no flocculation is inefficient settling in the clarifier, resulting in a turbid effluent. Poorly flocculated sludge can also have an adverse effect on sludge dewatering. The thickened sludge that is produced as waste from the process is often dewatered to reduce the sludge handling costs. Sludge dewatering characteristics are influenced by biologically induced flocculation and a well flocculating sludge will dewater easily.

1.2. Synthetic sludges

The living microorganism consortium in activated sludge is complicated and unstable. It changes the sludge characteristics continuously, making it almost impossible to carry out controlled experiments during sludge studies. Sanin and Vesilind [9] developed a novel chemical surrogate for activated sludge which they named *synthetic sludge* to study sludge dewatering, settling and conditioning characteristics. Synthetic sludge is made up of nonliving particles that resemble activated sludge components. The components of synthetic sludge include: polystyrene latex particles of bacterial size, which simulate individual bacteria; alginate simulates extracellular polymeric substances; fibrous cellulose is used to simulate the filamentous microorganisms found in activated sludge and calcium ions are used as bridging cations. The results obtained by Sanin and Vesilind [9] also showed that it is possible to create a chemical sludge having close resemblance to biological sludge by using bacteria-like particles, polysaccharides, and cations common to activated sludge at quantities typical of those in activated sludge. The analyses of physical synthetic sludge, it is obvious that synthetic sludge have similar filtration properties and their responses to a cationic conditioner to activated sludge [10].

The study of flocculation processes requires a method of assessing the state of aggregation of suspensions, preferably one which is rapid and does not cause significant disturbance of the sample. An optical method was developed for flocculation monitoring [11]. This method has been found to give a sensitive indication of floc formation, using a rather simple technique which is very well suited to online application.

The specific objective of this work is to investigate and demonstrate the effect of chemical composition such as calcium ions, cellulose, alginate, and pH on the floc formation, stability, settling, and settleability of synthetic activated sludge. Another objective is to adapt the optical method and link dynamic measurement of both the aggregation and flocculation to the final properties of synthetic activated sludge.

2. Materials and methods

2.1. Particles

The concentrated sulphate polystyrene latex particle was 5% by weight with 1 μm mean particle diameter to simulate individual bacteria. The coefficient of variation of particle diameters was usually less than 5%. The procedure of preparing the sulphate latex particles followed the guideline shown elsewhere [12]. About 20% of the surface area of particles is covered with sulphate groups to give them the necessary stability and negative surface charge. The zeta potential is −14 mV. The stock solution was diluted to 0.05% to match the design particle concentration to that of bacteria in activated sludge.

2.2. Polysaccharide

Alginate (low viscosity, sodium form) from brown algae was supplied by Sigma Chemical Company.

2.3. Fibrous cellulose

Fibrous cellulose was supplied by Sigma Chemical Company to simulate filamentous microorganisms in activated sludge. Medium fibrous cellulose having a mean size of 50–350 μm is chosen for the experiments.

2.4. Preparation of synthetic sludge

Sulphate polystyrene latex particles were suspended in deionised water. Samples with pre-selected 0.1% particle concentration and alginate concentration of 100 mg/L were rotated horizontally in an incubator at 12 rpm in a 25 °C for 12 h. Alginate was adsorbed on the particles during the incubation period. When the incubation period was completed, Ca(II) was added to samples in varying concentrations to monitor flocculation dynamics.

Numerous experiments were conducted to determine the minimum, or slight excess, concentrations of alginate, calcium, and cellulose required for floc formation in synthetic sludge. Alginate concentration was varied between 0 and 125 mg/L. The concentration of alginate required for floc formation was observed to be 100 mg/L. Calcium concentration was varied from 0 to 25 mM Ca(II). Tiny flocs were formed after reaching 15 mM Ca(II) concentration in synthetic sludge, larger flocs were observed at 20 mM Ca(II). There are many chemical constituents, which affect the flocculation process. To overcome the complexity caused by these effects, the elimination method has been applied in this research by fixing some parameters, such as polystyrene latex particle concentration, sodium chloride concentration and shear rate. A standard sludge was therefore defined as 20 mM Ca(II), 100 mg/L alginate, and 0.05% latex particles. The standard sludge was used as a reference point to compare the changes that occur in the flocculation dynamic and final properties of synthetic activated sludge upon the changing chemical composition calcium, alginate, cellulose concentration, and pH in these experiments, the target pH was adjusted by adding predetermined amount of NaOH or HCl to the suspension.

2.5. Settleability

Settling was measured in 100 mL graduated cylinders. The height of the interface was recorded after 60 min of settling. The small size of the cylinder was thought to produce on unwanted wall effect, but the cost of producing larger quantities of various types of synthetic sludge would have been prohibitive. The low solids concentration would also minimize the effect of the small cylinder diameter.

2.6. Turbidity

The turbidity of the supernatants was measured using a Hach 2100AN turbidimeter after 60 min of settling.

2.7. Settling properties

Total suspended solids (TSS) were analyzed using method 2540D in *Standard Methods* (1998). The settling properties of biological suspensions were characterized by sludge volume index (SVI), as described by method 2710D in *Standard Methods* (1998).

2.8. Calcium analysis

Calcium used in this investigation was added as chloride salt. Analysis of the cations Ca^{2+} was carried out by flame atomic absorption spectrometer (AAS), using method 3111 in *Standard Methods* (1998).

2.9. Flocs size and flocs structure

A Malvern Mastersizer-S instrument was used to measure the floc size and size distribution. This instrument is a light scattering instrument that operates on the principle of Fraunhofer diffraction theory. Scattering light from the diluted sample is detected on the custom designed detector. The size distribution is base on the volume and the average size is quoted as the mass mean based on volume equivalent diameter.

The flocs structure of synthetic activated sludge was examined through scanning electron microscope (SEM).

2.10. Monitoring the dynamics of flocculation

A simple but sensitive optical technique, the photometric dispersion analyser (PDA) has been developed to monitor the state of aggregation of colloid suspensions [13,14]. In this instrument, light scattering with a flow-through detector is used to monitor the dynamics of coagulation. PDA 2000 provides an indication of changes in the state of aggregation of suspensions—either aggregation (flocculation) or disaggregation (dispersion, deflocculation). It is applicable over a wide range of suspension concentrations and particle sizes.

The output value of PDA can accurately reflect the state of formation of flocs. A schematic description of the experimental set up for monitoring the dynamics of coagulation by PDA 2000 is shown in Fig. 1. A 1 L standard sludge latex particles suspension was used in the flocculation dynamic experiments. When chemical was added to the suspension, rapid mixing was performed with a stirrer in a batch reactor at a speed of 250 rpm (200 s^{-1}) for 30 s, in order to provide blending of chemical with synthetic sludge, and was followed by slow mixing at speed 100 rpm (50 s^{-1}) for 100 s to promote flocculation.

The flowing suspension is illuminated by a narrow beam of light perpendicular to the direction of flow. The light source is a high intensity light-emitting diode and transmitted light is continuously monitored by a sensitive photodiode. The output from the photodiode is converted to a voltage, which consists of a large dc component, together with a small, fluctuating (ac) component. The dc component is simply a measure of the average transmitted light intensity and is dependent on the turbidity of the suspension. The ac component arises from random variations in the number of particles in the sample. Because the suspension flows through the cell, the actual sample in the light beam

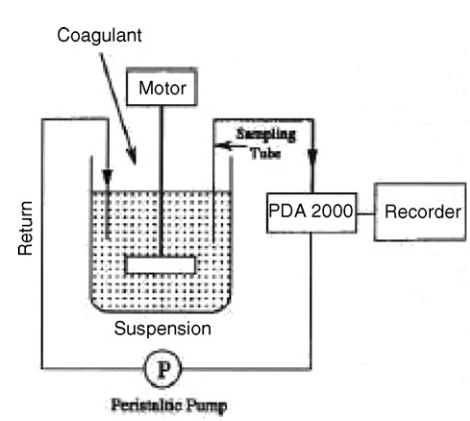

Fig. 1. Schematic description of the experimental set up for monitoring the dynamics of flocculation.

is continually being renewed and local variations in particle number concentration give fluctuations in the transmitted light intensity. These fluctuations cease when the flow is stopped.

The root mean square (RMS) value of the fluctuating (ac) signal is related to the average number concentration and size of the suspended particle. For uniform suspensions, estimates of particle size and number concentration can be made, but main use of the PDA 2000 is in the monitoring of flocculation and dispersion processes. The RMS value of the fluctuating signal increases, when aggregation of particles occurs. Measurable changes in the RMS value occur long before any visible signs of aggregation are apparent. Conversely, when aggregates are disrupted, the RMS value decreases, reaching a minimum when disaggregation (or dispersion) is complete. The term flocculation index (FI) present in this paper is referred to "the state of flocculation dynamics".

3. Results and discussion

3.1. Effect of calcium on floc dynamics and synthetic sludge settleability

Standard synthetic sludges (0.05% latex particles, pH 7.5, 100 mg/L alginate) were prepared in 1 L samples and the calcium concentration of the sample was varied between 0 and 25 mM Ca(II). Calcium was added in the form of $CaCl_2{\cdot}2H_2O$, and there was no significant change in the pH of the sample after calcium addition. The results showed that no floc formation occurred without adding calcium ions. The floc formation occurred when Ca(II) ion concentration increased to 15 mM, and was readily apparent for 20 mM Ca(II), and above, see Fig. 2. The flocculation index (FI) dramatically increased at 20 mM Ca(II) ions. Visual observation showed that, at higher concentrations of calcium (>20 mM), larger flocs were formed and sludge started to settle to the bottom of the stirred batch reactor at the slow mixing speed of 100 rpm ($50\,s^{-1}$). At lower concentration of calcium, the slower floc dynamics lead to a lower of FI. It is also apparent that the higher calcium concentrations, the faster rate of aggregation.

Table 1
Calcium ions concentration change in solution during experiments

Calcium concentration added (mM/L)	Ca^{2+} in samples after flocculation (mM/L)	Change in Ca^{2+} concentration (mM/L)
0	0	0
5	4.89	-0.11 ± 0.02
10	9.85	-0.15 ± 0.06
15	14.58	-0.42 ± 0.05
20	19.40	-0.60 ± 0.12
25	24.03	-0.97 ± 0.10

This result is in agreement with the work of Biggs et al. [15]. They found that the initial rate changes of floc size increase initially with the addition of calcium concentration and then approaches a steady state rate at the higher concentrations. This suggests that at a higher calcium concentration, saturation of the floc has occurred, and rate of change of floc size is independent of calcium concentration.

The interesting features can be observed for the change in floc size with calcium concentration as shown in Fig. 3. As flocculation occurs, the floc size increased with the increasing of calcium concentration, the size distribution shifts into the larger sizes.

The uptake of calcium was measured as the difference in calcium concentration before and after flocculation during batch tests. Table 1 shows the uptake of calcium for each flocculation experiment.

The concentration of calcium ions in the solution after flocculation was generally less than the initial concentration for each experiment. This indicates that an uptake of calcium ions was occurring during the flocculation process, which confirms that calcium ions are used a medium in the formation of synthetic activated sludge.

The results for the settling and settleability of synthetic sludge are illustrated in Figs. 4 and 5. No sludge settling was observed until the Ca(II) concentration reached 10 mM. All the flocs were dispersed in a turbid environment below 10 mM. When the calcium concentration exceeded 15 mM, a sudden improvement in the settleability of synthetic sludge was observed.

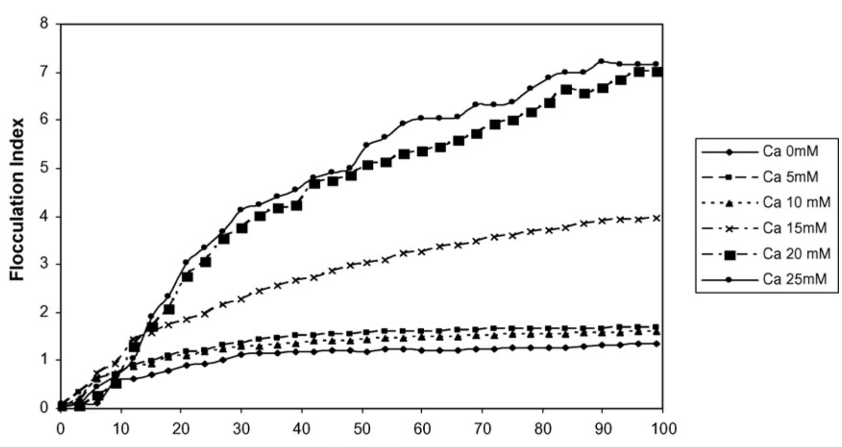

Fig. 2. Synthetic sludge floc dynamics via PDA with varying concentration of calcium.

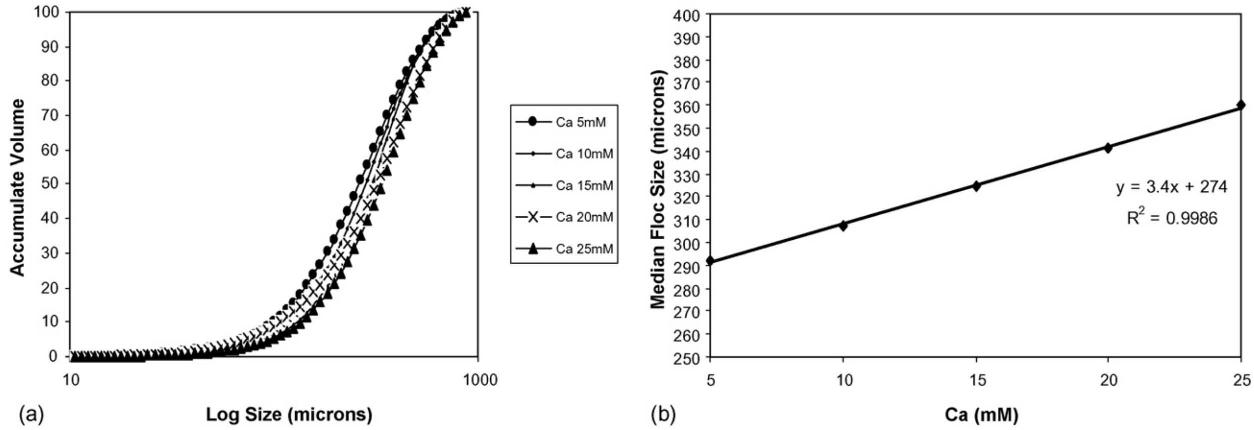

Fig. 3. Change in floc size with increasing concentration of calcium: (a) log size; (b) mean floc size.

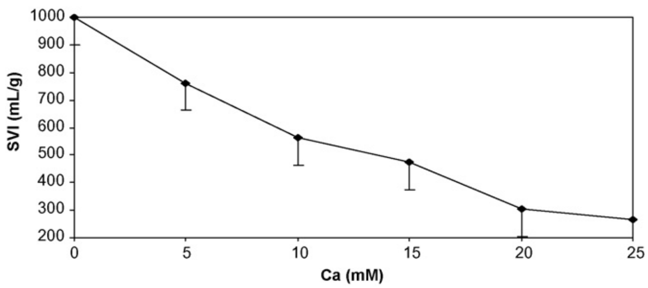

Fig. 4. Synthetic sludge settling increases with increasing concentration of calcium.

The results for the clarity of supernatant after settling are illustrated in Fig. 6. The turbidity of supernatant after settling was decreased significantly when calcium concentration reached 15 mM.

Calcium ion was directly related to changes in settling and dewatering properties of the synthetic sludge. Sanin and Vesilind [16] demonstrated that the removal of calcium ions from the sludge floc matrix causes the sludge flocs to disintegrate, as indicated by a decrease in filterability and particle size, an increase in turbidity and solution carbohydrate concentration. The results from this study also suggested that calcium ions are effective in a two-stage floc formation. The latex particle formation is the initial stage of floc formation, and then, once the floc is formed, calcium ions are further used to bridge the floc which each other in forming flocs.

The result obtains from Figs. 2–6 show that the optimum calcium ion concentration under these conditions is 20 mM. This result would also seem to support the divalent cation bridging theory. Thus, Ca(II) ions could improve floc formation and synthetic sludge settleability, and decrease the turbidity of supernatant. Ca(II) ions can be used as an indicator for monitoring and predicting the activated sludge settling properties of industrial wastewater [17]. A maximum in FI corresponds to the lowest value of the residual turbidity, thereby verifying the effectiveness of the FI for the determination of optimal calcium dosage in promoting flocculation and settling.

3.2. Effect of fibrous cellulose on floc dynamics and synthetic sludge settleability

Standard synthetic sludges (0.05% latex particles, pH 7.5, 100 mg/L alginate) were prepared in 1 L samples and the optimum calcium concentration from the previous experiment of 20 mM Ca(II) was used. Medium fibrous cellulose was added to these samples to give final concentrations of sludge loading of 1.2, 1.4, 1.6 and 1.8 g/L. It has been observed that the presence of filamentous organisms has an effect on the structure of the flocs; according to one theory, it is probable that the filamentous organisms' network provide a "backbone" for the build up of the floc, which is subsequently formed with the additional assistance of various polymer bridges between primary particles and smaller flocs [7].

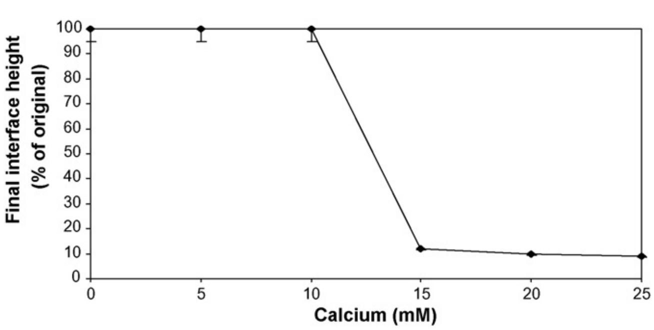

Fig. 5. Synthetic sludge settleability increases with increasing concentration of calcium.

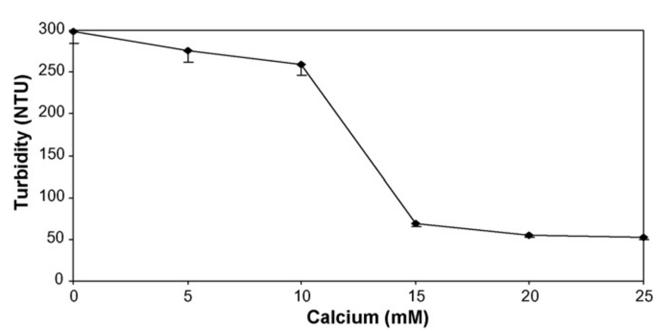

Fig. 6. Supernatant turbidity decreases with increasing concentration of calcium.

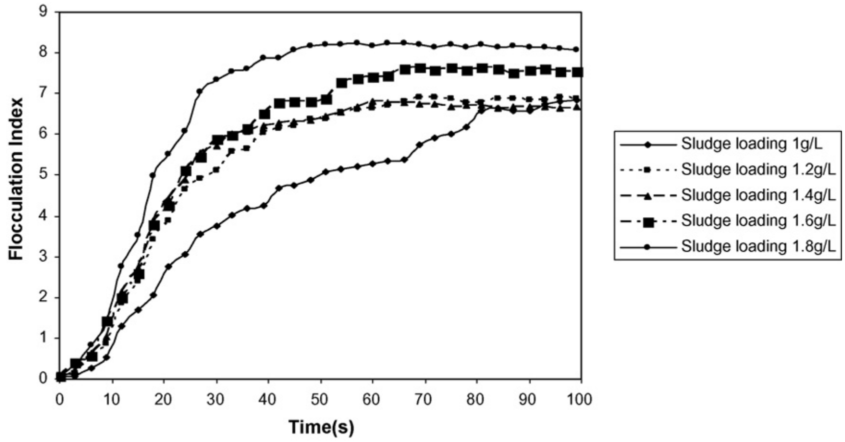

Fig. 7. Synthetic sludge floc dynamics with variation in the concentration of cellulose.

The flocculation dynamic curve in Fig. 7 showed that the slope increased dramatically after adding cellulose to the samples. The flocs were larger when a higher concentration of fibrous cellulose was added. The FI increased when the amount of cellulose increased, which was clearly shown by Fig. 7.

As shown in Fig. 8, the settleability of synthetic sludge was greatly improved upon increasing the fibrous cellulose concentration up to an optimum concentration of sludge loading of 1.4 g/L. Filamentous organisms cause an improvement in the compaction and settling of synthetic sludge. The types of compaction and settling interferences depend on the causative filamentous organism involved [18]. This finding seems to agree the views of Örmeci [19]. These views stated that the presence of cellulose also ensured good settling and compaction of synthetic sludge. The settling ability of synthetic sludge was greatly improved upon increasing the cellulose concentration. However, the settleability deteriorated when fibrous cellulose concentration was added at concentrations beyond 1.4 g/L. This phenomenon could be explained where the filamentous organism causes the sludge bulking as an overabundance of fibrous cellulose present in the synthetic sludge sample. Excess amounts of the fibrous cellulose could interfere with the settling and compaction of synthetic sludge by producing a diffuse floc structure or by growing in profusion beyond the confines of the flocs into the bulk solution and bridging between them.

The turbidity of supernatant above the settled sludge interface also starts to improve after the addition of cellulose. As shown in Fig. 9, the turbidity was lowest at a sludge loading concentration of 1.4 g/L, corresponding to the maximum in settleability in Fig. 8. At this concentration, the amount of cellulose might be large enough to form a backbone and the flocs are resistant to break up during settling, due to the presence of a strong cellulose backbone. This seems to agree with Jenkins's work [18]. This concluded that when a filamentous, bulking activated sludge settles, it produces a very clear, low turbidity supernatant, because the filamentous organism network filters out the small particles that can cause turbidity. However, the turbidity of the supernatant slightly increased when the sludge loading concentration was beyond 1.4 g/L. These phenomena might be the result of an excess amount of cellulose. Cellulose probably escapes from the backbone into the bulk solution, resulting in deterioration in the clarity of supernatant.

The addition of fibrous cellulose to the synthetic sludge helped to improve the floc size. The typical flocs size was examined through scanning electron microscope (SEM) with and without cellulose addition. When sludge loading added at 1.4 g/L to the sample the flocs size of synthetic activated sludge were found to be in the range 60–400 μm. The characteristic of synthetic sludge flocs structure is shown schematically in Fig. 10.

The excess amount of filamentous microorganisms in the bulking activated sludge also results in a higher concentration of extracellulose polymers, and possibly various cations, which in turn help to bind the filamentous microorganisms to the floc structure. As a result, the flocs with a well-developed filament backbone are not susceptible to break up, and leave a clear supernatant after settling. In contrast, during the experimental

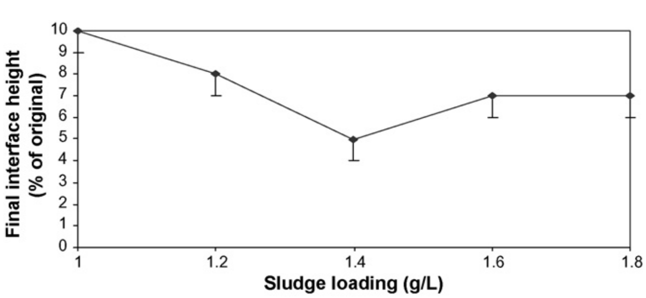

Fig. 8. Synthetic sludge settleability changes with concentration of cellulose.

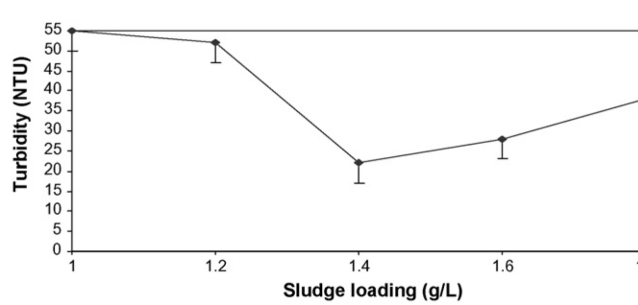

Fig. 9. Supernatant turbidity changes with concentration of cellulose.

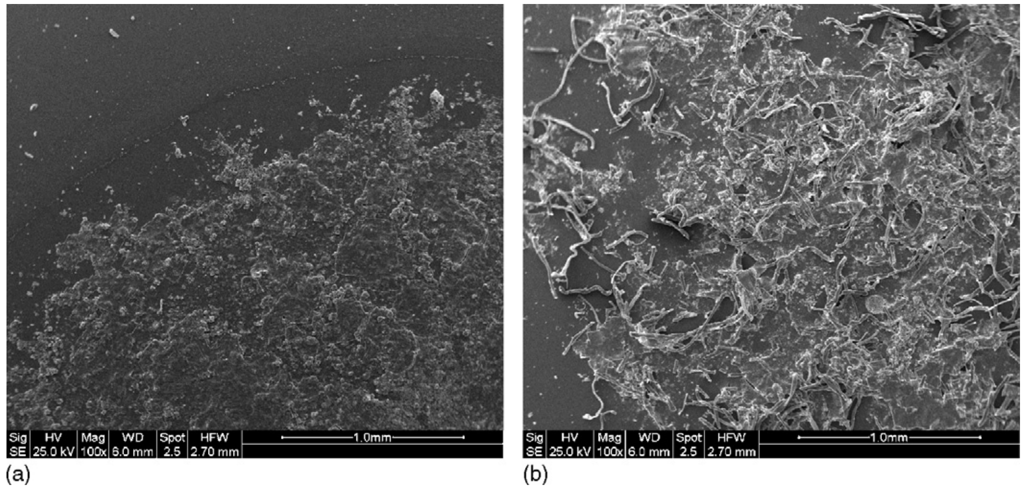

Fig. 10. Structure and size of synthetic activated sludge: (a) without cellulose; (b) with cellulose of sludge loading concentration at 1.4 g/L.

study with synthetic sludge, the cellulose concentration was increased gradually, while alginate and calcium concentration were fixed in a certain amount. Therefore, the excess amount of cellulose could not be bound to the floc structure. Instead, either it leads to deterioration in the sludge settleability or releases to the supernatant, increasing its turbidity.

In comparing the settleability of synthetic sludge and the turbidity of the supernatant, with (Figs. 8 and 9) and without (Figs. 5 and 6) cellulose addition, it could be said that adding a certain amount of fibrous cellulose helps to enhance the settleability of synthetic sludge and lower the turbidity of supernatant. The result obtains from Figs. 7–9 show that the optimum fibrous cellulose sludge loading concentration under these conditions is 1.4 g/L.

3.3. Effect of alginate on floc dynamics and synthetic sludge settleability

Standard synthetic sludges (0.05% latex particles, pH 7.5, 20 mM Ca(II)) were prepared in 1 L samples, and the optimum fibrous cellulose concentration 0.4 g/L determined from the previous experiment was used. Alginate was added to these samples to give final concentrations of 25, 50, 75, 100 and 125 mg/L. No flocculation was observed without the addition of alginate. As shown in Fig. 11, the slope of the FI curve and the rate of aggregation increased dramatically when the concentration of alginate increased. This result supports the alginate theory, in which flocculation is based on the formation of alginate gels in the presence of calcium ions.

The floc dynamics also showed that the rate of aggregation was constant at a certain calcium concentration when alginate was added between 75 and 125 mg/L. This result from experiments supports the confirmed the expected the role of calcium in attachment of alginates to surfaces, bridging of alginate molecules to each other, and inducing flocculation of the entire system [12].

The settleability of synthetic sludge is illustrated in Fig. 12. No settling was observed without the addition of alginate. A sudden increase in settleability occurred when alginate was added up to 50 mg/L. This result implies that the flocs start to form when alginate is added above a certain concentration. However, the settleability deteriorated when alginate concentration was added at concentration higher than 75 mg/L. An excess of polysaccharide in the synthetic sludge could explain this phenomenon; as a

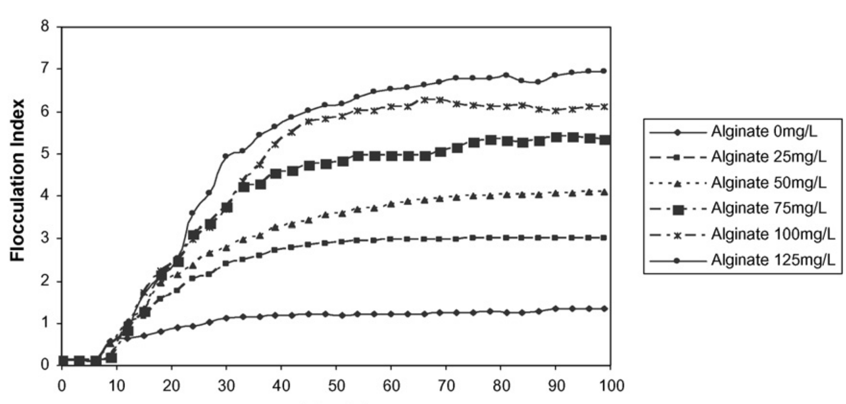

Fig. 11. Synthetic sludge floc dynamics with concentration of alginate.

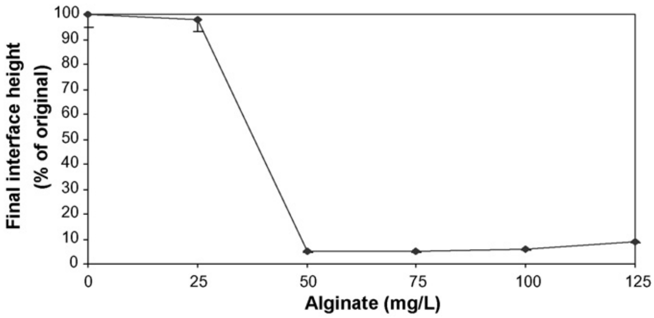

Fig. 12. Synthetic sludge settleability increases with concentration of alginate.

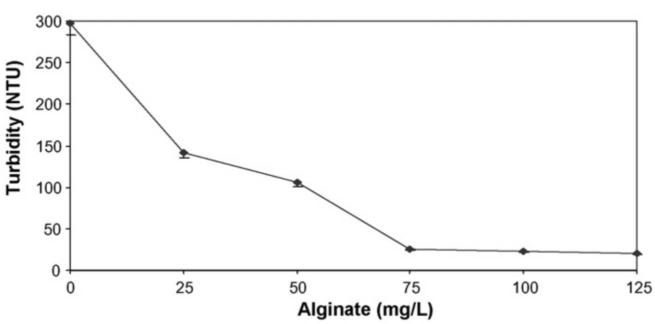

Fig. 13. Supernatant turbidity decreases with increasing concentration of alginate.

result, the viscosity of sludge increases and floc settling velocity is decreased.

The turbidity of supernatant is shown in Fig. 13. The turbidity of supernatant decreased when the alginate concentration added to the synthetic sludge increased. The reduction of the supernatant turbidity followed an orderly pattern, being lowest at the lowest alginate dose, medium in the medium dose, and highest at the highest alginate dose used, indicating that the alginate interacting with calcium and particle surfaces cause some degree of destabilization and flocculation of the particles. The highest alginate dose gave the lowest turbidity. Since concentration of alginate at 75 mg/L and higher, the turbidity difference among these alginate doses had almost disappeared, most likely indicating an optimum flocculation had been reached. This result explain why the poor settling in activated sludge often produces crystal clear supernatants, due to the high degree of colloid removal by the settling sludge. The consistent decrease in turbidity when alginate and calcium were added indicated that the particles together with alginate and calcium were taking part in forming a floc structure. The results obtained from Figs. 11–13 show that the optimum alginate concentration under experimental conditions is in the range from 75 to 125 mg/L. The results shown in Figs. 12 and 13 seem similar to Figs. 5 and 6. Again, it is suspected both addition of calcium and alginate may share the similar flocculation mechanism.

3.4. Effect of pH on floc dynamics and synthetic sludge settleability

Standard synthetic sludges (0.05% latex particles, 100 mg/L alginate, 20 mM Ca(II), fibrous cellulose 0.4 g/L) were prepared in 1 L samples. The target pH was adjusted by adding NaOH or HCl to these samples to give a final pH of 3, 4.5, 6, 7.5 and 9. The fluctuations in pH in the influent, and the resulting changes in reactor pH, hamper the operation of a biological treatment plant. Generally, the sludge organisms function in an optimum pH range of 6.5–8. Sludge organisms will die or be reduced in function if the pH decreases to less than 4 or increase to greater than 10 [20].

The change of FI with pH value is shown in Fig. 14. The results also showed that the change of pH in the range of 6–9 helps to improve the floc size. These phenomena could be explained by the fact that formation of large hydroxide precipitates is favoured in the pH range of 6–9. These precipitates increase the solids concentration in suspension and, as a result, the coagulation rate increases. In wastewater treatment facilities, metals are precipitated most commonly as metal hydroxides through the addition of lime or caustic to a pH of minimum solubility. The location of the minimum solubility will vary depending on the constituents in the wastewater [21]. In practice, the minimum achievable residual metal concentrations will also depend on the nature and concentration of organic matter in the wastewater as well as temperature. In the magnitude of the variation of FI with pH increased from 3 to 9, compared with Figs. 2 and 11, pH does not affect the FI significantly, which implies that physical flocculation such as sweep flocculation plays a major role in the flocculation dynamics in this study. The slope of the FI curve was highest at pH 7.5. This

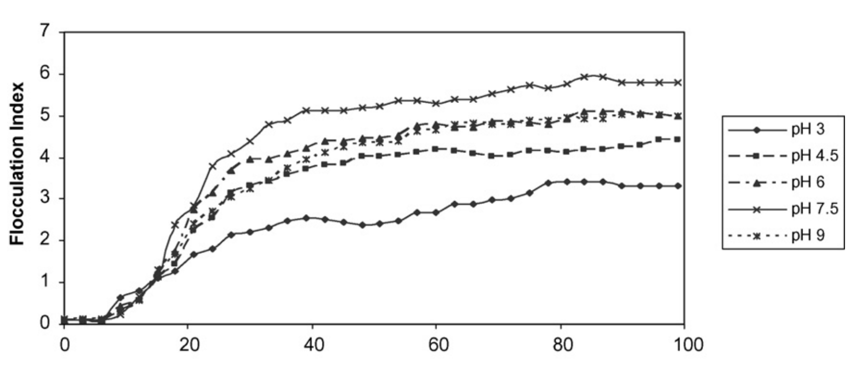

Fig. 14. Synthetic sludge floc dynamics with variation of pH.

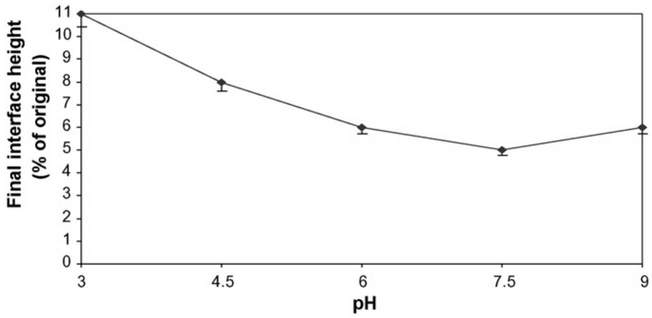

Fig. 15. Synthetic sludge settleability changes with pH.

implies that the largest and fastest floc formation occurs at this pH value.

Results indicated that the most interesting of this part of the study was the relatively high improvement of settleability of sludge and the turbidity of supernatant at pH 6 and 9 were similar in magnitude. These results are supported by the report [22]. This relationship is presented in Figs. 15 and 16. Visual observation showed that, at these pH values these flocs were big and well settling, with a very clear supernatant. The presence of divalent cations has significant influence on the settling rate in alkaline solution and dramatically improves the quality of the supernatant [23]. The addition of sodium hydroxide to the samples to adjusting the pH ranges could form the calcium carbonate is then easily precipitated, as the result the sludge will settle faster. This could be explained by the fact that $CaCO_3$ precipitation and latex particles are both negatively charged [24]. The $CaCO_3$ precipitation induces then a sweep coagulation process where the larger particles only entrapped and formed the big flocs.

At low solution pH, the adsorption of calcium and hydroxide precipitates which can form positively charged patches on the surface of latex particles, and thus induce aggregation. In addition, the formation of hydroxide precipitates can increase the solids concentration and, hence, the interparticle collision rate. Because of low interparticle collision rates, aggregates do not increase in size significantly and removal of turbidity by settling is low. The result obtained from Figs. 14–16 show that the optimum pH value under experimental conditions is in range from 6 to 9. At these pH ranges, the microbes in an activated sludge reactor can grow and function properly.

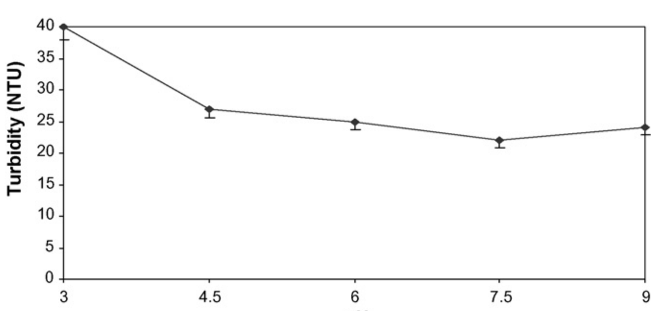

Fig. 16. Supernatant turbidity changes with pH.

4. Conclusions

- The changes in specific chemical component such as calcium, alginate, cellulose, and pH of synthetic sludge have significant effect on characteristic of activated sludge. Calcium ions have a critical effect on the aggregation rate of flocs and well correlation with the final properties of synthetic activated sludge. Addition of calcium ion greater than 15 mM resulted in dramatic increase flocs size and improved the final properties of sludge. Cellulose is essential constituent in the formula of synthetic activated sludge, contributing to the formation of strong flocs, resulting in well sludge settling with very clear supernatant. Alginate is important in floc formation in synthetic activated sludge. No flocculation observed in the absence of alginate. However, high concentrations of alginate (>75 mg/L) may deteriorate sludge characteristics. The final properties of synthetic activated sludge grown at pH 6–9 are similar in magnitude. However, at low pH (<4.5) it make detrimental to the flocculation.
- The development of synthetic sludges have suggested as a possible surrogate for studying the flocculation dynamic and final properties of activated sludge. Dynamic measurements have established optimum conditions for floc formation. These correlate well with measurement of settleability and turbidity of synthetic activated sludge.

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