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A novel method of sludge pretreatment using the combination of alkalis

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Abstract

The present study aims to utilise the advantage of higher sludge solubilisation potential of sodium hydroxide (NaOH) and sludge management properties of lime to achieve sludge pretreatment and its subsequent management. The optimum dosage and time required for sludge pretreatment using NaOH was found to be 1.6 g l^{-1} and 3 hr, respectively. At the optimized condition, lime was added at varying concentration (0.3 to 1.6 g l^{-1}) to study its effect on capillary suction time, soluble chemical oxygen demand (SCOD) release and total phosphorous (TP) removal. A lime dosage of 0.7g l^{-1} was found to be beneficial for soluble chemical oxygen demand (COD) release. When compared to control, the combination of alkalis (NaOH and lime) reduced the TP and capillary suction time (CST) in the supernatant of the sludge. The TP removal was from 100 to 40 mg l^{-1} and CST reduction was from 1360 to 350 sec, respectively. The combined alkali pretreatment not only prevent the subsequent TP increase in the effluent, but also decreased the time to filter the sludge, thus makes the digested sludge easier to manage.

Key words

Sludge pretreatment, Capillary suction time, Sodium hydroxide, Lime, Phosphorous removal

Introduction

The main by-product of biological wastewater treatment is the waste activated sludge. The expense for the treatment of the excess sludge has been estimated to be as much as 50-60% of the total expense of wastewater treatment plant (Nowak, 2006 and Banu *et al.,* 2009). It must be realized that the excess sludge generated from the biological treatment process is a secondary solid waste that must be disposed off in a safe and cost effective way. Sludge pretreatment can be achieved by cryptic growth of microorganisms, *i.e.* microbial growth on its lysates. Recently, various sludge disintegration techniques have attracted attentions as promising alternatives to reduce sludge production. Advances in sludge disintegration techniques offer a few promising options including ultrasound (Guo *et al.,* 2008), pulse power (Choi *et al.,* 2006), ozone (Weemaes *et al.,* 2000), thermal (Kim *et al.,* 2003), alkaline (Li *et al.,* 2008) and thermochemical (Banu *et al.,* 2009; Uan *et al.,* 2009; Vlyssides and Karlis, 2004). Among the various methods, alkali sludge pretreatment using NaOH is found to be efficient (Rocher *et al.,* 1999). During the sludge pretreatment process, the phosphorus was released from the sludge and it accounts for 2 to 3% of its solid content (Banu *et al.,* 2009). After pretreatment, the digested liquor was sent back to anoxic or aerobic basin for organics oxidation, which resulted in the increase of total phosphorus (TP) load to the system. This makes the biological treatment process difficult to achieve the effluent wastewater with the regulatory TP value of 0.5 mg l^{-1} (Metcalf and Eddy, 2003). Sewage sludge contains a considerable amount of water that cannot be easily removed by conventional dewatering methods. The efficiency of sludge dewatering is generally expressed by two ways, firstly the amount of water removed and secondly dewatering rate. The capillary suction time (CST) test has been used as a relative indicator to characterize the performance of most sludge dewatering processes

(Kwon *et al.,* 2001). Most of the sludge pretreatment techniques such as alkali, sonification and ozonation are found to increase CST value of the sludge (Bougrier *et al.,* 2006). Sonification and ozonation increases CST by decreasing the particle size of the sludge, where as NaOH increases CST by reducing the strength of the bonds between sludge particles (Nowak,2006). Thus render the digested sludge very difficult to manage. To overcome the disadvantages attributed to NaOH sludge pretreatment, lime was added along with it during pretreatment. In the present study, the lime was used to condition the sludge as well as to remove TP in the supernatant.

Materials and Methods

Experimental design and analysis: Waste activated sludge (WAS) collected from the municipal sewage treatment plant was used for the experiment. Mixed liquor suspended solids (MLSS) content in the waste activated sludge was found to be in the range of 5000 to 7000 mg l^{-1}. Solid content in the WAS plays an important role in determining the alkali dosage and subsequent pH increase (Shuzo *et al.,* 1997). So, throughout the experiments, the MLSS was maintained around 6500 mg l^{-1} using dilution by distilled water.

Sludge pretreatment experiments were carried out in triplicate at laboratory temperature (30±2°C) using a jar apparatus (Model SJ-10, Young Hanna Tech Co., LTD) with six paddle stirrer. A 500 ml of WAS was taken in 1 l beaker and alkalis were added to samples during stirring. Both the alkalis were added to the samples in the form of solution. After the addition of alkalis to the beaker, a rapid mixing of samples was done at 200 rpm for 1 min. This was done to ensure the uniform mixing of added alkali. Rapid mixing was followed by slow mixing of samples at 30 rpm for 3 hr.

Total phosphorous (TP), Soluble total phosphorous (STP), capillary suction time (CST) and pH were analysed employing methods detailed in APHA (2005). Capillary suction time was estimated by CST apparatus (Make: Triton electronics, model 304) by placing 6.4 ml of sludge in a sample holder which was placed above a sheet of chromatography paper. The time required for the liquid to travel a specified distance is recorded automatically by monitoring the conductivity change occurring at two contact points appropriately spaced and in contact with the chromatography paper. The elapsed time is indicative of the water drainage rate and is usually expressed in seconds. Chemical oxygen demand (COD) was measured using a colorimetric method after digesting the samples in the COD reactor. Soluble COD and STP of the sample were measured by filtering the sample using 0.4 μm filter. The degree of COD solubilisation was calculated by dividing of soluble COD with total COD measured after pretreatment and quotient being multiplied by 100 (Yoon *et al.,* 2004; Uan *et al.,* 2009). All the values expressed in this study are an average of triplicate.

Results and Discussion

Optimizations of reaction variables in sludge pretreatment experiments are inevitable to get higher solubilisation efficiency (Valo *et al.*, 2004). The dosage of alkali and its pH plays an important role in the pretreatment of sludge (Uan *et al.,* 2010). In the present study, NaOH was used as a sludge solubilizing agent. Initial optimization experiments were carried out using NaOH, to find the optimum dosage and pH required for sludge pretreatment. During sludge pretreatment experiments, the cell wall of the bacteria are lysed, which inturn release soluble intracellular content (SCOD and STP) to the surrounding medium (Liu *et al.,* 2008). The efficiency of the sludge pretreatment can be assessed by monitoring

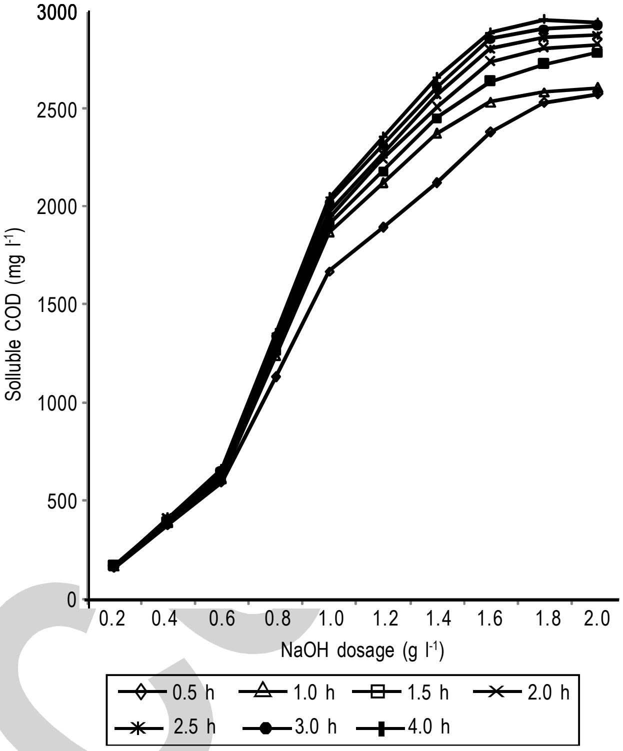

Fig. 1: Influence of digestion time on Soluble COD release

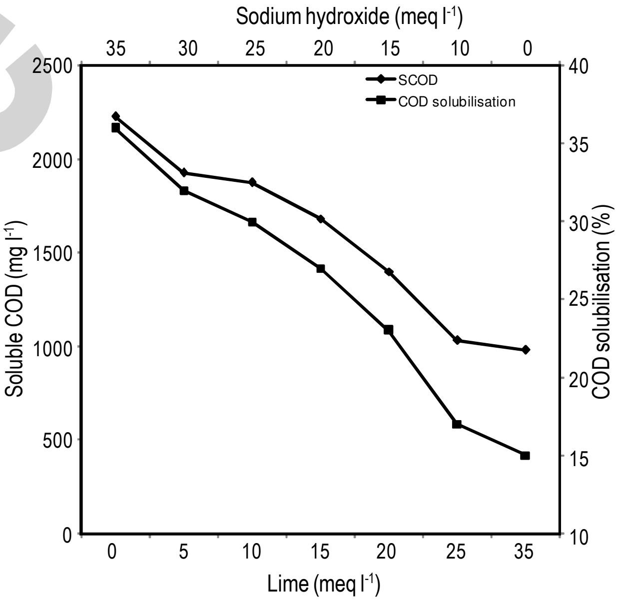

Fig. 2: Chemical oxygen demand (COD) solubilisation efficiency of alkalis

Table - 1: Effect of NaOH dosage on the release of soluble chemical oxygen demand (SCOD) and soluble total phosphorous (STP) during pretreatment of waste activated sludge

NaOH (g l^{-1})	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	6	8	10
SCOD (g l^{-1})	0.16	0.4	0.6	1.3	2.0	2.3	2.6	2.8	2.8	2.9	2.9	2.9	2.9	3.0	3.0	3.1	3.1	3.2	3.2	3.3	3.4	3.4	3.4
Final pH	7.2	7.9	8.5	9.3	10.1	11	11.3	11.5	11.8	12	12.1	12.2	12.2	12.3	12.3	12.4	12.4	12.5	12.5	12.5	12.6	12.8	13
STP (mg l^{-1})	11	16	26	52	72	85	99	106	110	114	117	120	123	127	130	132	134	136	138	141	145	150	154

All values are mean of triplicate

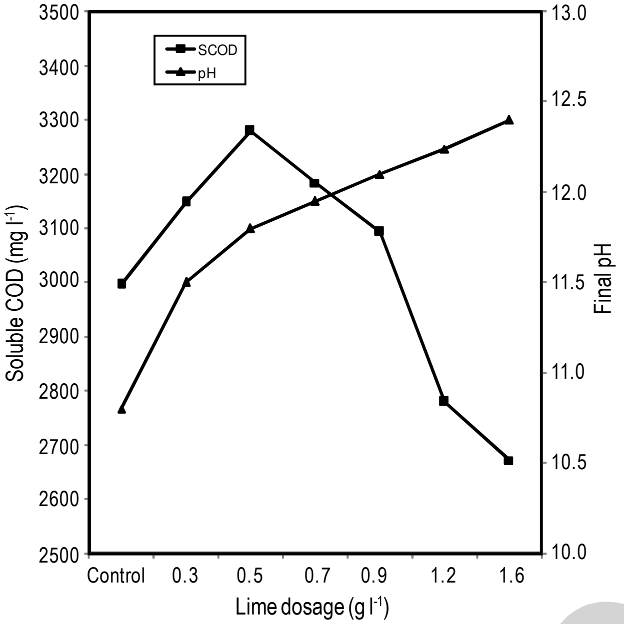

Fig. 3: Influence of lime on soluble COD during the pretreatment of sludge

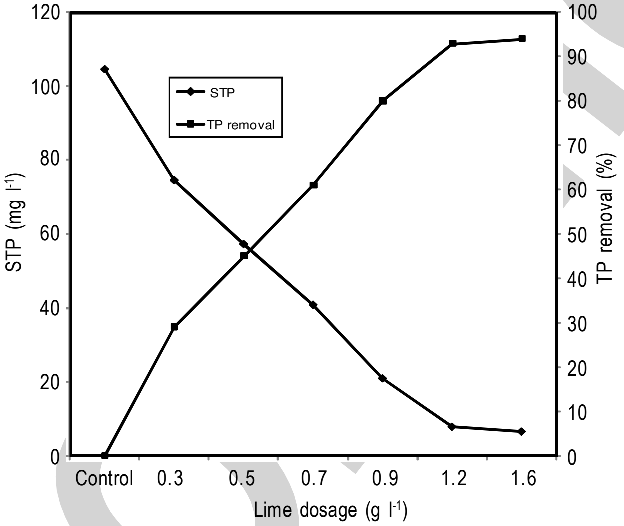

Fig. 4: Influence of lime dosage on total phosphorus (TP) removal

the release of these components. Table 1 shows the influence of NaOH dosage and pH on release of SCOD and STP. During the initial stages of sludge pretreatment, there was a sharp increase in the release of SCOD from 0.16 to 2 g l^{-1} and STP from 11 to 166 mg l^{-1} with increase in NaOH dosage up to 1 g l^{-1}. From then onwards there was a slight decrease in the release of SCOD and STP with increase in NaOH dosage. It is evident from the Table 1 that, SCOD and STP release were stabilized around a value of 2.8 g l^{-1} and 106 mg l^{-1}, respectively. This stabilization in the release of SCOD and STP occured at an alkali dosage did not of 1.6 g l^{-1} and pH 11.5. Further increase in NaOH dosage doesn't increase the SCOD and STP release significantly. For example even after increasing the NaOH dosage to 10 g l^{-1}, which is 6.25 higher than that of 1.6 g l^{-1} causes a mere increase in the release of 0.67 g l^{-1} of SCOD and 48 mg l^{-1} of STP. Based on the fact it was decided to keep an alkali dosage of 1.6 g l^{-1} for further experiment. The pH of the pretreated sludge at this optimized dosage was found to be 11.5 and it gives additional advantage to present study as the optimum pH for lime to remove phosphorous was reported to be 11 (Sedlak, 1991).

The effect of reaction time on sludge pretreatment was shown in Fig. 1. From the figure, it is clear that there was a gradual increase in SCOD release with corresponding increase in reaction time and alkali dosage. In the case of NaOH dosage 1.6 g l^{-1}, the SCOD release was 2376 mg l^{-1} at 30 min interval. It started to increase with increase in reaction time. At the end of 3 hr reaction time, the SCOD release was found to be 2850 mg l^{-1}, further increase in reaction time did not increase SCOD release significantly. For an example increasing the reaction time from 3 to 4 hr, increases the SCOD release from 2850 to 2880 mg l^{-1} and it accountable for an increase of 30 mg l^{-1}. From this, it can be concluded that reaction time beyond 3 hr did not significantly affect SCOD release. Based on the results of optimization experiments (Table 1 and Fig. 2), for further studies it was decided to keep NaOH dosage 1.6 g l^{-1} and reaction time 3 hr.

The efficiency of sludge pretreatment depends on the extent of sludge solubilisation (Young *et al.,* 2007). Working on the effect of sludge pretreatment on excess sludge reduction in membrane bioreactor (MBR) Banu *et al.* (2009) have reported that sludge reduction in MBR depends on its biodegradation. It is known that increase in sludge solubilisation increases the sludge biodegradability. In the present study, two alkalis namely, NaOH and lime were used as sludge solubilizing agent. The sludge solubilizing powers of both the alkalis were assessed and the results were depicted in Fig. 2. The experiments were conducted at fixed alkali strength (35 meq l^{-1}) and varying concentration of NaOH and lime to demonstrate the role of alkalis in solubilzing sludge. From the figure it was evident that, increase in NaOH dosage increases the SCOD release from 1032 to 2228 mg l^{-1} whereas, in case of lime, the increase in dosage decreases the release of SCOD from 1928 to 980 mg l^{-1}. At highest applied alkali dosage (35 meq l^{-1}) COD

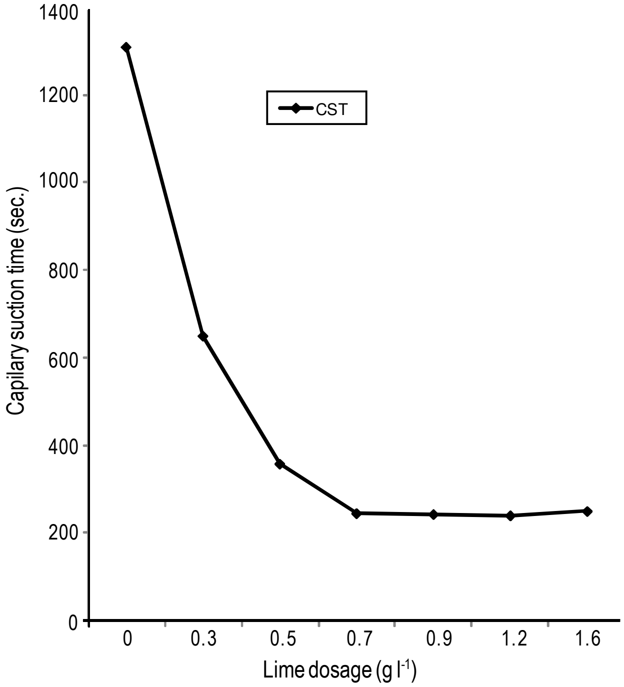

Fig. 5: Effect of lime on capillary suction time during the pretreatment of sludge

solubilisation was found to be 15% for lime and 36% for NaOH, respectively. From the above, it is clearly evident that NaOH proved to be better solubilizing agent than lime. So, further experiments were planned to utilize the maximum sludge solubilizing properties of NaOH.

Bruus *et al.* (1992) have listed out the difficulties (poor settling and dewatering of digested sludge) associated with NaOH sludge pretreatment. Considering the negative effects associated with NaOH pretreatment, it was planned to carryout NaOH sludge pretreatment in combination with lime. Lime was commonly used as a sludge conditioner in wastewater treatment plant to increase settling and dewatering properties of the sludge (WEF, 2005). But the main disadvantage of lime is that it cannot be used as a sole sludge solubilzing agent as its solubilzing power is far below than NaOH (Fig. 2). Due to the above reason, the present study aims to find out the combination of alkalis (NaOH and lime) for efficient sludge pretreatment and its management. Lime was added along with NaOH (1.6 g l^{-1}) at varying concentrations in the range of 0.3 to 1.6 g l^{-1} to study its effect on SCOD release. Fig. 3 depicts the influence of lime dosage on SCOD release during the NaOH pretreatment of sludge. From the figure it was evident that the lime addition initially increased the release of SCOD. For *e.g.*, the SCOD release for the control experiment was found to be 2996 mg l^{-1} and the experimental setup with lime dosage 0.7 g l^{-1} was found to be 3280 mg l^{-1}. The addition of lime enhanced the SCOD release upto the dosage of 0.7 g l^{-1}. The initial increase in SCOD release may be due to alkali action of lime which enhanced the SCOD release. Lime dosage beyond 0.7 g l^{-1} decreases SCOD release. The SCOD release for the lime dosage 1.6 g l^{-1} was found to be 2672 mg l^{-1}. This decrease in SCOD release at higher dosage of lime may be due to the fact that, a part of SCOD released can be precipitated by lime. From this it is clearly evident that, mere increase in concentration of lime doesn't play any role in sludge solubilisation.

TP is an important nutrient and will cause eutrophication if its concentration exceeds 2 mg l^{-1} (Metcalf and Eddy, 2003; Banu *et al*., 2008) in the treated wastewater. TP removal through biological phosphorous removal (BPR) is a difficult process and any fluctuation in influent TP load will affect the efficiency of BPR process. Saktaywin *et al.* (2005) have reported that pretreatment of activated sludge resulted in the release of biologically bound phosphorous into the solution. Normally after side stream sludge pretreatment, the pretreated sludge used to send back to the mainstream reactors for further degradation. This phenomena increase TP load to the treatment plant and as a result of that, the TP concentration in the effluent stream increases which inturn cause eutrophication. So, it is necessary to remove the solublized TP before it enters into main stream biological treatment. Fig. 4 shows influence of lime dosage on TP removal efficiency. Phosphorus removal through lime depends upon the solution pH. The optimum pH for the removal of phosphorous through lime is reported to be 11 (Metcalf and Eddy, 2003). In practical this is difficult to achieve as it require addition of alkali to raise the pH of the solution to near 11. In the present study, usage of lime can be possible because the solution pH falls within the optimum range of lime-phosphorous precipitation. There will not be any need to adjust the pH of the solution to 11. TP concentration in the digested supernatant of control experiment was found to be 104.5 mg l^{-1}. It is evident from the figure that the added lime acted as a precipitant and removed TP from the digested supernatant. The TP concentration in the supernatant decreased with increase in lime dosage. For instance, in the case of lowest lime dosage used (0.3 g l^{-1}), the TP concentration in the supernatant was found to be 74.5 mg l^{-1} and the corresponding TP removal was 29%. Whereas, for the sludge pretreatment experiment with highest lime dosage (1.6 mg l^{-1}), the TP concentration in the supernatant was found to be 6.5 mg l^{-1} and the corresponding TP removal was 94%. The TP removal percentage for lime dosage 0.7g l^{-1} was found to be 61%.

The CST test determines rate of water release from sludge, it provides a quantitative measure, reported in seconds, of how readily sludge releases its water. The results can be used to assist in sludge dewatering process, to evaluate sludge conditioning aids and dosages. The CST test has been used as a relative indicator to characterize the performance of most dewatering processes. The sludge is having low CST can be managed better than the sludge having high CST. The filtration time as determined from CST measurement was showed in the Fig. 5. The CST value for the sludge treated with NaOH alone was found to be 1360 sec. The presently observed high CST value for NaOH pretreatment was comparable to the report of Bruus *et al.* (1992) and Nowak (2006). They revealed that, excess sodium in activated sludge system has been shown to result in the deterioration of settling and dewatering properties of activated sludge. It was reported that, the poor settling and dewatering that, occurred with sodium concentrations was a result of ion-exchange processes in which, divalent cations were displaced from within the floc by sodium (Nowak, 2006). After the introduction of lime in the experiment, the CST values for the digested sludge start to decrease. The CST values for the digested sludge at lime dosage 0.3 g l^{-1} were found to be 650 sec. Even at the low applied dosage, lime decreases the CST value of the digested sludge sharply from 1360 sec. The sharp decrease in CST by lime is due to the fact that the added calcium ions decreased the bound water content of the activated sludge, which would increase the floc density and cake solids (Bruus *et al.,* 1992). Further increase in lime dosage decreases the CST value and it stabilised to a value of 350 sec at the dosage of 0.7 g l^{-1} filtration. The CST value for the highest applied lime dosage was found to be 250 sec.

The sludge solubilisation efficiency of NaOH was found to better than the lime. The sludge pretreatment using the combination of NaOH and lime was found to be a better option than doing it alone.

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