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Excess Sludge Minimization in Conventional Activated Sludge Pilot Plant by Three Chemical Matters

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ABSTRACT: The excess sludge treatment and sludge disposal are major factors to the over-all economy of wastewater treatment plants (WWTP). The ideal solution to the problem of sludge disposal is to combine sludge minimization with contamination removal at the source. In this study, the effect of ozonation, chlorination and 3,3,4,5–tetrachlorosalicylanilide (TCS) to treat part of the return activated sludge flow with the intention of reducing the overall plant yield in a conventional activated sludge pilot, were investigated in a side-stream pilot reactor. It was found that in the case of ozonation 8% g O_3/g MLSS, and in the case of chlorination 2% g Cl_2/g MLSS produce the best results. In the utilization of TCS method, the excess sludge production was reduced by 80% per day at a TCS dose of 1% g TCS/g MLSS. In all the above experiments a reduction in the volume of the excess sludge was achieved, while the efficiency of removal chemical oxygen demand (COD) from the reactor without the use of those methods was not significantly different.

Key words: Biological Treatment, Chlorination, Ozonation, 3, 3, 4, 5–Tetrachlorosalicylanilide (TCS)

INTRODUCTION

The most widely used biological treatment process for domestic and industrial wastewaters is the conventional activated sludge (CAS) process; however, the disadvantage of this process is high sludge production. The cost of handling, treatment and disposal of the excess sludge is about 40-60% of the costs of wastewater treatment (Tchobanoglous *et al.*, 2003).

A noticeable increase in excess sludge production has been resulted from an increase for wastewater and in the treatment rate worldwide. In the EU countries, after utilizing the Urban Wastewater Treatment Directive 91/27/EEC that demands more extensive wastewater treatment and an end to sea disposal of sewage sludge, a 40% increase in wastewater treatment plants (WWTP) was expected between 1998 and 2005, making approximately 9.4 million tons of dry weight a year; whereas, in 2010 this figure is expected to exceed 10 million tons (Pérez -Elvira *et al.*, 2006). It is believed that approximately 10 million dry tons of sewage sludge is made in the United States (Bandosz and Block, 2006). Recent valid rules concerning sludge treatment and disposal along with social and environmental concerns have concluded remarkable impetus to put forward strategies to minimize excess sludge production. New sludge disintegration processes that involve all the biological, chemical, thermal and mechanical methods are now developed to minimize excess sludge production. It is worth mentioning that these methods are now highly used on a commercial basis (Yan *et al.*, 2009). Many researches on sludge reduction including lyses-cryptic growth, uncoupling metabolism and micro-fauna predation have been done (Li *et al.*, 2008). Chemical oxidation techniques like ozonation and chlorination (Yasui *et al.*, 1996) and the feasibility of applying metabolic uncouplers like TCS (Chen *et al.*, 1999;) to minimize excessive sludge production from the wastewater biological treatment process have been used in order to minimize sludge production in the activated sludge process.

One of the practical methods for the excess sludge reduction is ozonation which submits a degree of disintegration at a large scale (Müller, 2000). In the

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activated sludge process, the production of excess sludge can be reduced greatly by the ozonation of the part of the returned sludge (Ramakrishna and Viraraghavan, 2005; Sakai *et al.*, 1997; Yasui and Shibata, 1994). In addition, the settling properties of the sludge are improved by ozonation as well as bulking and scumming reduction (Caravelli *et al.*, 2006; Kamiya and Hirotsuji, 1998). Some EU countries and Japan are in favor of using the ozonation method to reduce the excess sludge (Sievers *et al.*, 2004; Yasui *et al.*, 1996).

The chlorination-combined activated sludge method had been developed for reducing the excess sludge as an alternative resolution of sludge minimization. This process is similar to the ozonation activated sludge method. Both chlorination and ozonation of sludge are based on lysis-cryptic growth. The two steps in cryptic growth are lysis and biodegradation and the rate-limiting stage is the lysis step. In order to differentiate growth on the original organic substances, the biomass growth on the lysates is named cryptic growth. Microbial cells undergo lysis or death during which cell contents (substrate and nutrients) are released, when disintegration methods are used. In microbial metabolism the organic, autochthonous is used again and a part of the carbon is released as respiration products, which causes a reduction in the overall biomass production (Low and Chase, 1999).

In the method of using uncouplers such as TCS, Chen et al. (2001) indicated that the use of metabolic uncouplers reduces the production of excess sludge, because they disassociate the energy coupling between catabolism and anabolism, by means of that certain portions of energy through futile cycles is dissipated (Cook *et al.*, 1994). The energy which is dissipated will not be accessible for anabolism, thus the growth of sludge can be limited. Catabolism is coupled tightly with the anabolism under normal conditions so that energy uncoupling does not appear, but sludge growth can be reduced effectively in some abnormal conditions such as nutrients limitation, high temperature and the presence of metabolic uncouplers that energy uncoupling can be accomplished (Cook *et al.*, 1994).

This paper presents the results of the effectiveness of ozone, chlorine and TCS dose to treat part of the return activated sludge flow on volume reduction of waste conventional activated sludge in a laboratory scale system.

MATERIALS & METHODS

The pilot-scale which has been used in this study consisted of two cubic Plexiglass conventional activated sludge reactors (CAS) with the continuous-flow regime, equipped with diffused air, sedimentation tank, and a line of return waste activated sludge which their characteristics are presented in Table 1. Fig. 1 is the schematic diagram of each reactor illustrates ozone, chlorine and TCS which is used in side-stream recycle. The reactors were fed with a synthetic wastewater which was provided through mixing of 100 L of urban treated water with other materials as presented in Table 2, which provided the wastewater that its characteristics are presented in Table 3.

Table 1. The characteristics of the applied reactors

Reactor	
Number (unit)	2
Shape of aeration basin reactors	Cubic
Material	Plexiglas
Volume (L)	96
Aeration dimension (cm)	40×40×60
Net aeration volume (L)	80
Settling area (cm^2)	40×20
Sludge holding tank dimension (cm)	28×18×22

Table 2. The compounds used in wastewater

Characteristic	rector-1	reactor-2
Milk powder (mg)	800	800
Sugar (mg)	400	400
Urea (mg)	320	320
Phosphorus (mg)	30	30

Table 3. Average of main characteristics of synthetic wastewater

Characteristic	rector-1	reactor-2
COD (mg/lit)	600	600
BOD_5 (mg/lit)	300	300
Nitrogen (as TKN)(mg/lit)	30.7	30.7
Phosphorus (mg/lit)	10.5	10.5

The seed was chosen from the return activated sludge line in activated sludge system of the largest residential complex in Tehran, Iran, Ekbatan Complex (a local municipal) wastewater treatment plant in which any problem such as bulking and similar failures are not observed. The sample bulk was stored at 4°C to prevent from changing the characteristics. To operate the system about 30 L of the aforementioned sludge was used for a CAS reactor with capacity of 96 L. Next, the synthetic wastewater was added to the reactor. Two weeks aeration and reaction was performed to establish the flocs. During this reaction process, synthetic wastewater was added to the reactor by a feeder pump continuously. The parameters of COD, suspended solids (SS) and pH of wastewater were tested and compared with previous data. 15 days are considered as the cell retention time and consequently

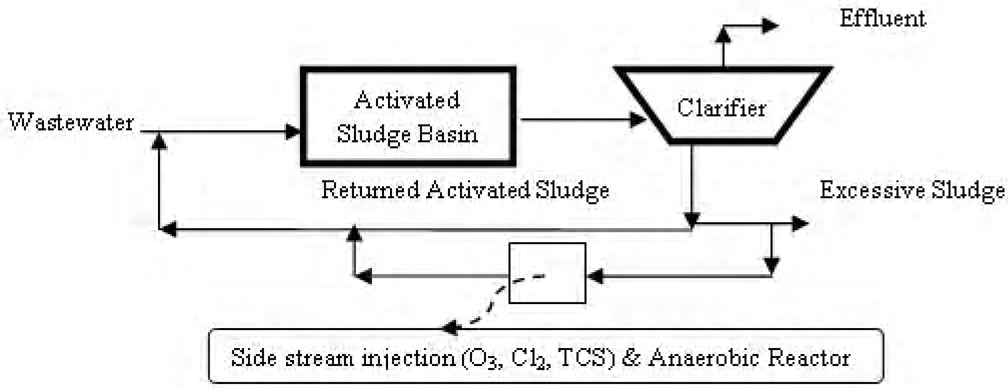

Fig. 1. Reactor with O_3, Cl_2 & TCS Process Flow Diagram

the disposal sludge was 1000 mL. After 1 month of pilot run, the effluent COD data were close to each other, demonstrating the start up ending.

To find the best dosage of ozone, chlorine and TCS with the intention of minimizing sludge yield in the activated sludge process, a part of returned activated sludge (1 L) in each experiment was subjected to different doses of ozone, chlorine and TCS with different volumes of disposed sludge from the sample reactor (the reactor with attached mentioned methods) separately, and the mixed liquor was then returned to the aeration tank. The parameters of COD, mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solid (MLVSS) and sludge volume index (SVI) were tested during 8 months. All these measurements were carried out on samples, according to APHA, (2005). It should be mentioned that due to the changes in the sludge age, Ozone, Chlorine and TCS concentration were considered for the system to be adopted with the new situation for at least 2 weeks. Then, data was gathered after stable condition after each new experiment. The MLSS in CAS reactor and effluent wastewater COD, were considered as factors of the stability condition. Each experiment was done 3 times, and the mean of the results was registered.

RESULTS & DISCUSSION

Ozone has been investigated as a side-stream process attached to the return activated sludge line to treat a percentage of the return activated sludge with the intention of minimizing sludge yield in the activated sludge process (Ahn *et al*,. 2002, Boehler and Siegrist 2006, Lee *et al*,. 2005, Yeom *et al*,. 2002). 15 days were considered as the cell retention time and consequently the disposal sludge was 1000 mL. To find the best dosage of ozone, an experiment was designed as follows:

1-The volumes of disposed sludge from the sample reactor (the reactor with attached ozonation process) were 1000, 800, 600, 400, 200 and 0 mL respectively in different experiments.

2-The ozonation is done with the constant weight ratio of the ozone to MLSS equal to 1%, 1.5%, 2%, 4% and 8% at intervals of almost 15 days, changing the amount of sludge disposal in each experiment.

Fig. 2 (a) is the comparison between the different dosages of ozone with a simultaneous reduction of sludge disposal simultaneously. It demonstrates that ozonation and reduction of sludge disposal at the same time will improve the COD removal efficiency in most cases. According to Fig. 2 (b), ozonation in the first case (g O_3/g MLSS= 1%), removing 1000 mL sludge, the amount of MLSS reduced, but when the bacteria adapted to the new environment, the concentration of MLSS increased. Reducing disposal sludge (800 ml), MLSS decreased, but over time when microorganisms adapted with the new environment and the amount of sludge disposal was reduced at the same time, MLSS increased. However, the effect of ozonation on reduction of the overall MLSS over time, MLSS decreased to less of its initial amount, without any sludge disposal at final stage. In this dose of ozonation, the best conditions will be obtained, when 200 ml of sludge is removed. In the second case, ozonation (g O_3/g MLSS= 1.5), removing 1000 mL sludge, the amount of MLSS reduced at first, but after a while the bacteria adapted with the new environment, the amount of MLSS increased. By reducing disposal sludge (800 ml), MLSS still decreased, so that it seems the effect of ozone exceeded the microorganisms able to adapt to at this stage fully, and less sludge should be removed, in order that the concentration of MLSS remains constant in aeration tank. By disposing less sludge, the concentration of the MLSS will be increased and finally it will reach to its initial value before ozonation, while the sludge disposal rate can even be zero. In the third case (g O_3/g MLSS= 2%), after adaptation to the new environment in condition of reducing the sludge removal (reaching 200 mL or even zero), microorganisms could be resistant to the increase in dosage of ozone, however a small decrease is seen in COD removal efficiency. In case IV (g O_3/g MLSS= 4%), the concentration of microorganisms were reduced by ozonation over time. This reduction will be compensated by disposing less sludge to the amounts of 200 mL. Increased to fifth case (g O_3/g MLSS= 8%), ozonation affected the concentration of the microorganisms very much so that the amount of removal sludge will be reduced even without substantial reduction of MLSS, but this reduction couldn't affect on COD removal efficiency.

There are three potential methods for sludge ozonation. First of all, ozone, which was driven by the pressure/concentration mass, passes into the cell wall of microorganisms, detriments the cell membrane, reacts with proteins and DNA, and distributes the cytoplasm and intracellular matters into water. Secondly, ozone damages the zoogloea buildings by oxidizing the EPS and bridging matters, and finally ozone reacts with dissolved organics at third stage (Zhang *et al.*, 2009). Cellular contents, including COD are permeated as lysis materials in each case, which are then turned back to the aeration tank, and there, the bacteria in the aeration basin feed on the permeated COD. Consequently, when the COD from the lysis materials is bio-consumed, an effective decrease in excess sludge is occurred.

The effects of different chlorine dosages on the volume of sludge disposal are shown in Fig. 3, respectively. According to Fig. 3(a), adding amounts of chlorine (g Cl_2/g MLSS= 1&2%) to the part of

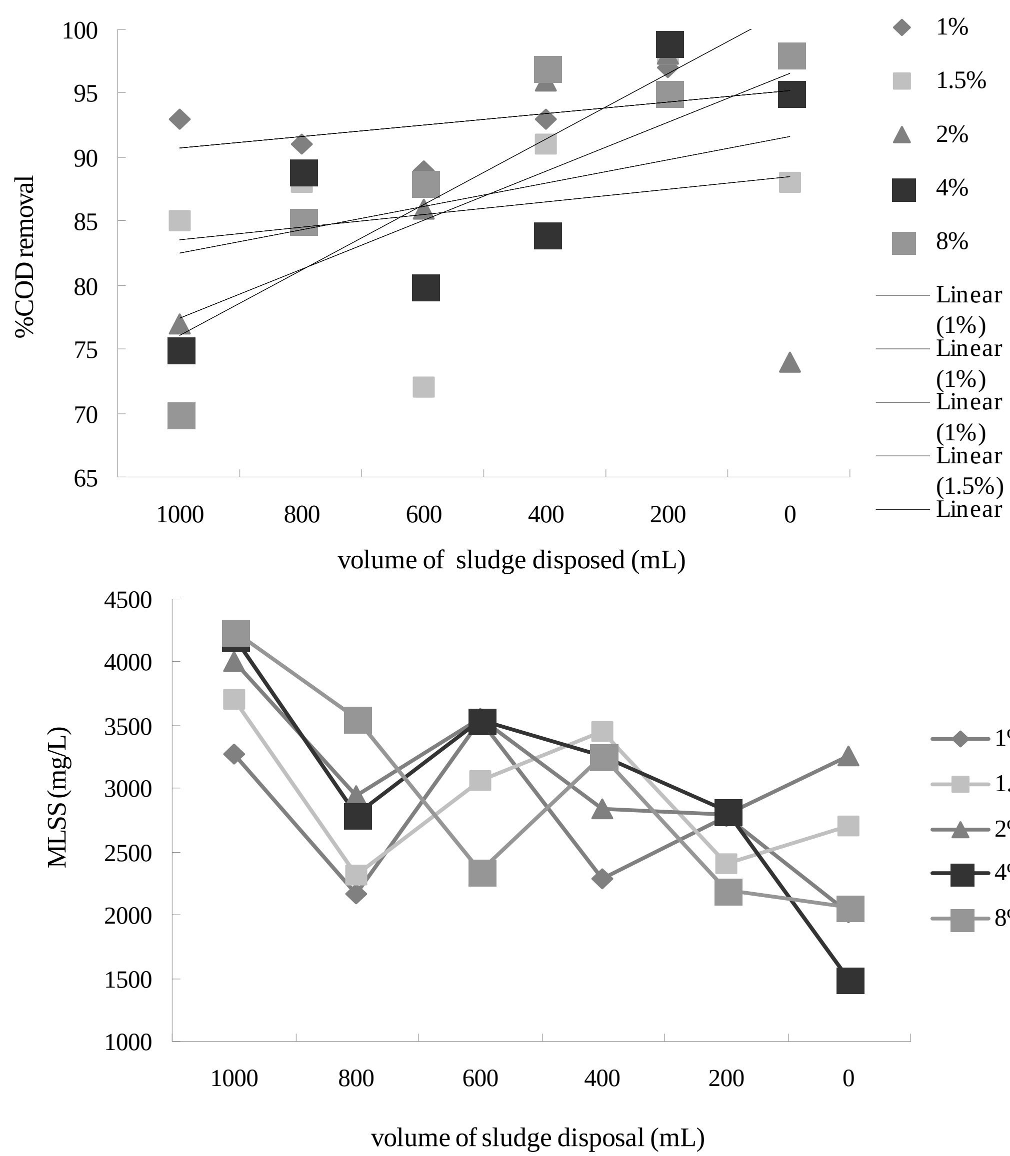

Fig. 2. Comparison between different dosages of ozone with reduction of sludge disposal simultaneously and effects on the COD removal efficiency (a) and the MLSS (b)

returned activated sludge caused the volume of disposal sludge became zero while COD removal efficiency was about 99%. By increasing the chlorine dosages (g Cl_2/g MLSS=4%), and with disposing of sludge, no significant changes were created to rate of 400 mL but more than of it reduced the COD removal efficiency. According to Fig. 3 (b), increasing the amount of chlorine (g Cl_2/g MLSS= 8%), had adverse effect on the microorganisms so that the reducing of the amount of sludge over time also could not compensate for this effect so that COD removal efficiency decreased over time. This problem in addition to the amount of chlorine (g Cl_2/g MLSS=16%), was more intensity. Since chlorine kills many heterotrophic microorganisms and oxidizes part of the biomass, the soluble COD, SCOD rate increased in the effluent. As it can be seen in Fig. 3(b) microorganisms were generally tolerated up to (g Cl_2/g MLSS = 8%) increase in chlorine tolerated and more than it had adverse effect on microorganisms. Also, the twentieth day after, reducing the MLSS in the system was created in all cases. Although still in the states of chlorine adding in (g Cl_2/g MLSS=1&2%), the amount of changes in removal COD efficiency was minimum.

Chlorine has the role of oxidation and disinfection, hence killing many microorganisms and bacteria in the reactor by attacking the lipids in the cell walls and demolishing the enzymes and structures inside the cell, making them oxidized and harmless, except for special slime microorganisms which can resist (Liu, 2003).

In order to reduce excess sludge volume, the application of TCS has been investigated as a side-stream process attached to the return activated sludge line to treat a percentage of the RAS with the intention of minimizing sludge yield in the activated sludge process. 15 days were considered as the cell retention time and consequently, the disposal sludge was 1000

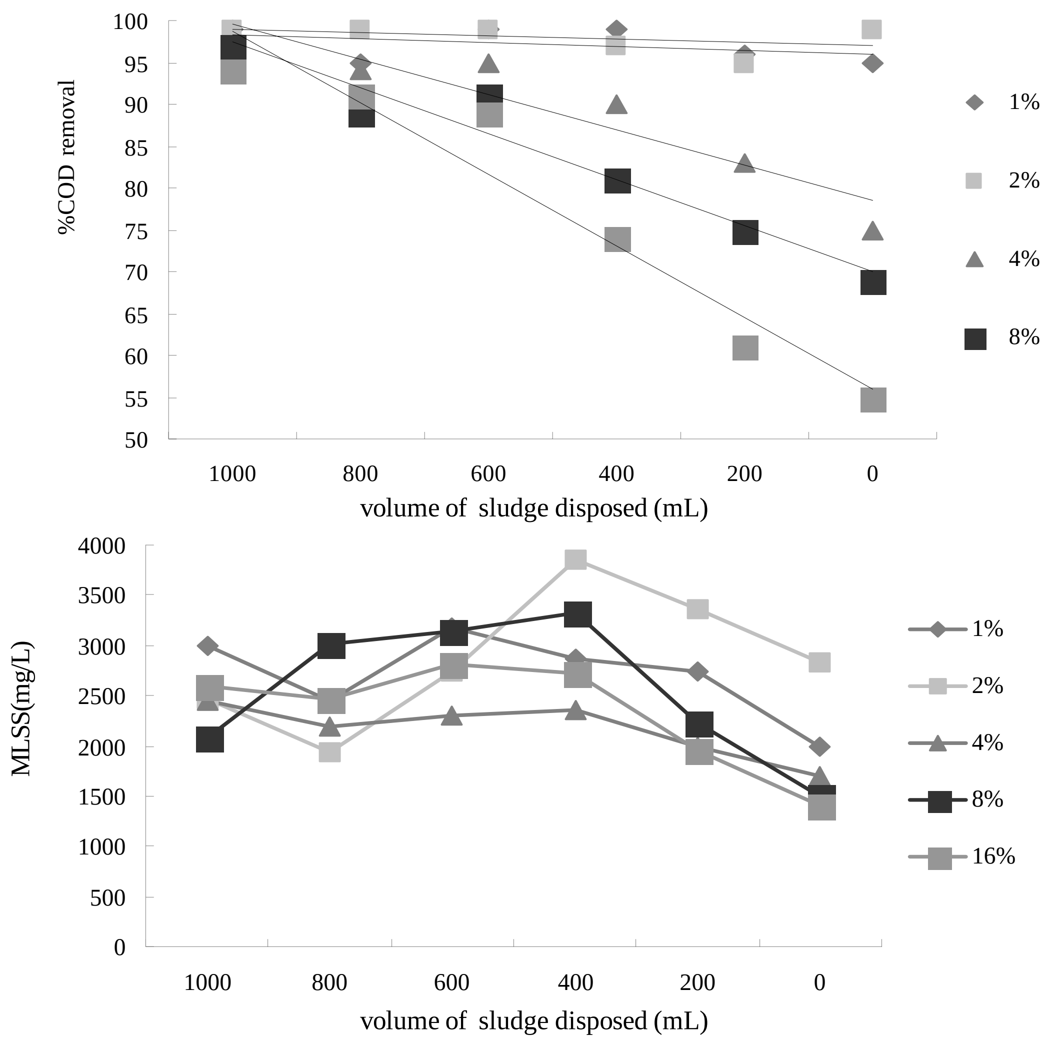

Fig. 3. Comparison between different dosages of chlorine with reduction of sludge disposal simultaneously and effects on the COD removal efficiency (a) and the MLSS (b)

mL. To find the best dosage of TCS, an experiment was designed as follows:

1-The volumes of disposed sludge from the sample reactor (the reactor with attached TCS process) was 1000, 800, 600, 400, 200 and 0 mL respectively in different experiments.

2-The TCS doses is added with the constant weight ratio of the TCS to MLSS equal to 1%, 2%, 4%, 8%, 15% and 20% at intervals of almost 10 days, changing the amount of sludge disposal in each experiment.

According to Fig. 4. adding amounts of TCS in the first case (g TCS/g MLSS= 1%), removing 1000 mL sludge, the amount of MLSS reduced, but after the bacteria adapted with the new environment, the concentration of MLSS increased. Reducing disposal sludge (800 ml), MLSS decreased, over time when microorganisms adapted with the new environment, the amount of sludge disposal was reduced at the same time, MLSS increased. However, after this stage, the effect of TCS on reduction the overall MLSS over the time can be seen, because the microorganisms were not able to adapt themselves, due to accumulation of TCS, so that, MLSS decreased to less of its initial amount, that its effect on the slight reduction of the COD removal efficiency, was indicated. By increasing the TCS doses (g TCS/g MLSS= 2%, 4% and 8%), the same process was used, so that, the volume of excessive sludge could be reached to zero, without significant effect on the COD removal efficiency by the increasing the TCS with a constant dose. There was not any specific changes in the effluent COD with adding the amount of TCS (g TCS/g MLSS= 15%) until the sludge removal rate at 400 ml, but after that, the system broke down because of the accumulation of TCS and sludge disposal reduction. The former effect was started after disposing sludge at 800 ml in the case of (g TCS/g MLSS= 20%). Finally, It seems that, the best doses of TCS to decrease the excessive sludge without any adverse effect on the COD removal efficiency was g TCS/g MLSS= 1%, which in this case, the excessive sludge rate could be reached to less than 20%.

Much research has been focused on the development of uncoupler-induced energy spilling process for minimization of excess sludge production (Mayhew and Stephenson, 1998). Among those uncouplers, TCS seems to be more environmentally sound (Budavari *et al.*, 1989). For most aerobic bacteria, eukaryotic cells in the form of ATP are generated by mitochondrial oxidative phosphorylation, in which process electrons are transported through a series of carrier molecules called the electron transport system (ETS) from nutrients such as glucose. Indeed a source of electrons at elevated energy levels called substrate to a final electron acceptor (oxygen). The molecules

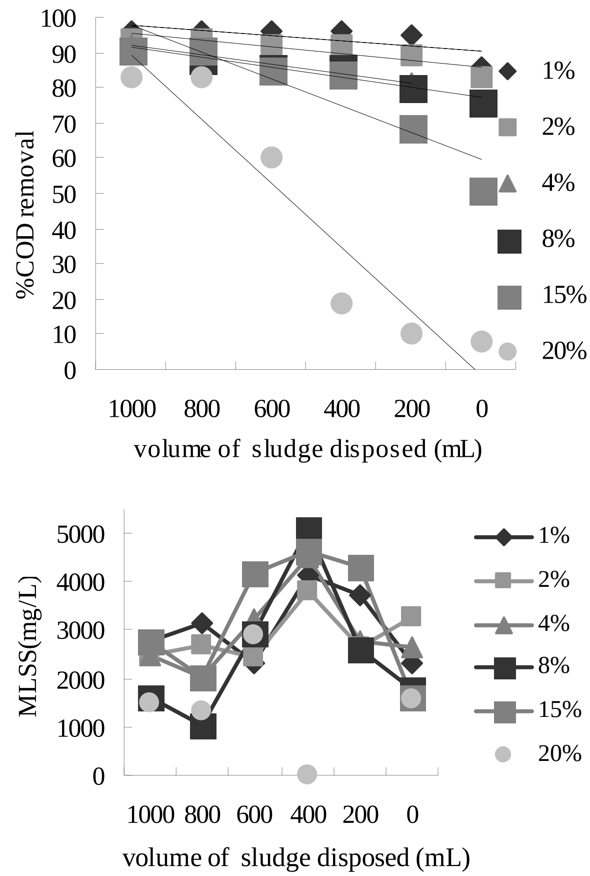

Fig. 4. Comparison between different dosages of TCS with reduction of sludge disposal simultaneously and effects on the COD removal efficiency (a) and the MLSS (b)

directly using the proton gradient developed by electron transport are proton-ATPase pumps that can be compelled to work reversibly (Mitchell, 1961). If working in forward direction, the pumps would use the energy that is released by ATP hydrolysis to push proton across a membrane, but in cellular organisms producing ATP, the pumps are operated in reverse by the magnitude of the proton gradient produced by electron transport.

CONCLUSION

This study demonstrates that in the ozonation method in all cases, COD removal efficiency is reduced in small amounts but after a while when the bacteria adapt with the new environment, COD removal efficiency is increased. At the case (g O_3/g MLSS = 8%), COD removal efficiency is 99%, when the disposal sludge is zero (Fig. 2). In the chlorination method microorganisms, are generally tolerated up to (g chlorine/g MLSS= 8%), and more than it has adverse effect on microorganisms. Although still in adding chlorine adding in (g chlorine/g MLSS= 1&2%), the amount of changes in removal COD efficiency is minimum, and at case (g chlorine/g MLSS= 2%), no sludge is produced (Fig. 3). Also, the best dose of TCS to decrease the excessive sludge without any adverse effect on the COD removal efficiency, is (g TCS/g MLSS= 1%), which the excessive sludge rate can be reached to 200 mL, i.e. almost 20% initial amount (Fig. 4).In Table 4. the comparison of results of this study with other research performed in the field of reduction of excess sludge production by ozonation, chlorination and using TCS is presented.

Table 4.Literature data for reducing excess sludge production by ozonation, chlorination, using TCS, and inserting an anaerobic side stream reactor

Operation condition	Sludge reduction (%)	Effluent quality	References
Full scale: 550 kgBOD/d of industrial waste water, continuous ozonation at 0.05g O_3/gMLSS	100	Increase of COD	(Yasui et al., 1994)
Full scale: 450 m3 /d of municipal waste water, continuous ozonation at 0.02g O_3/gMLSS	100	Slightly Increase of BOD	(Sakai et al., 1997)
Lab scale, synthetic waste water, intermittent ozonation at 11g O_3/gMLSS(aeration tank)d	50	Nearly unaffected	(Kamiya et al., 1998)
Pilot plant scale, synthetic waste water, intermittent ozonation in SBR at: 16 mg O_3/gMLSS 20mg O_3/gMLSS 25mg O_3/gMLSS	43 52 100	Slightly Increase of COD	(Takdastan et al., 2009)
Full-scale application of ozonation from 0.03 to 0.05 g $O_{(3)}$/g TSS	appropriate	not significantly influence effluent quality	(Chu et al., 2009)
Pilot plant scale, synthetic wastewater, Ozonation in conventional activated system at 8% g O_3/g MLSS	100	not significantly influenced on COD	This study
Pilot study, chlorine dose of 0.066 g Cl_2/g MLSS	60	sacrificed sludge settleability	(Chen et al., 2001)
Bench scale in activated sludge, 20^{oC} synthetic wastewater Chlorination, 0.066 gCl_2/gMLSS	65	Significant increase of SCOD	(Saby et al., 2002)
Pilot plant scale, synthetic waste water, intermittent Chlorination in SBR at: 1- 5 mg Cl_2/gMLSS 2- 10mg Cl_2/gMLSS 3- 15mg Cl_2/gMLSS	17 38 48.3	Significant increase of SCOD	(Takdastan et al., 2009)
Pilot plant scale, synthetic wastewater, Chlorination in conventional activated system at 2% g Cl_2/g MLSS	100	not significantly influenced on COD	This study
The use of TCS at 0.8-ppm	45	increases the portion of active sludge microorganisms	(Chen et al., 2001)
The use of TCS at 0.8 mg/L	40	Not affected on substrate removal capability	(Chen et al., 2002)
lab-scale completely mixed activated sludge process,TCS = 40 mg/day	30	Not affected on substrate removal capability, increase of effluent nitrogen concentration	(Ye et al., 2005a)
Lab scale, TCS in SBR at 0.4 mg/lit	60	inhibitory effect on nitrification	(Sangchul et al., 2007)
The use of TCS in activated sludge at 0.8 mg/lit	30	Not affected on substrate removal capability	(Aragón et al., 2009)
The use of TCS in SBR at 1.2 mg/lit	48	low reduction of COD removal efficiency	(Dun et al., 2009)
Pilot plant scale, synthetic wastewater, Application of TCS in conventional activated system at 1% g TCS/g MLSS	80	not significantly influenced on COD	This study

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