Improvement and prediction of OSA system performance in sludge reduction through integration with thermal and mechanical treatment

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ABSTRACT

The oxic–settling–anoxic (OSA) process is one of the sludge production reduction methods in the activated sludge process. In this method, sludge is stored in an anaerobic tank within the sludge return line before entrance into an aeration tank. Due to this method’s flexibility in application to operating treatment plants and not being energy-consuming, its application is developing. In this research, the improvement of the OSA process is investigated via thermal and mechanical treatment in a sequencing batch reactor (SBR). A pilot-scale reactor and domestic wastewater are used. Sludge was subjected to high temperature in an anaerobic tank using a heat transformer and it was subjected to mechanical shear through mechanical mixing in the anaerobic tank. Different temperatures and voltages were tested. The OSA process reduced sludge production by 24% while the chemical oxygen demand (COD) removal rate decreased from 90% to 86%. Thermal treatment combined with the OSA process caused a maximum of 46% sludge production reduction. However temperatures above 90 °C are not recommended due to a high level of decrease in COD removal. Mechanical mixing in combination with the OSA process led to 34% sludge production reduction. The effluent quality is not affected by the OSA process itself but is slightly reduced by thermal treatment and mechanical mixing. Therefore, for reaching the maximum sludge reduction in OSA plus thermal and mechanical treatment it would be necessary to evaluate the effect of different sets of parameters on effluent quality beside the sludge reduction. For this purpose multi-layer perceptron artificial neural network models are developed to predict the effluent total suspended solids and COD removal efficiency as well as sludge production rate. The models perform well and would be useful tools in determining the optimal set of system operation parameters.

Key words | mechanical shear, oxic-settling-anoxic, sequencing batch reactor, sludge reduction, thermal treatment

INTRODUCTION

Different types of activated sludge process have an irreplaceable role in domestic wastewater treatment plants (WWTPs). However, waste activated sludge is the unpleasant by-product of this process because of its large volume, offensive odor (Guo et al. 2015) and being a cause of health problems. Treatment and disposal of excess sludge generated by the activated sludge process is an economic, legislative and sanitary issue for WWTPs. The costs associated with sludge management account for up to 65% of the total operating costs of a typical WWTP (Wei et al. 2005). A reason for more attention being given to OSA system application for sludge reduction in recent years, is that it could be easily applied to existing WWTPs with minimum cost. It is sufficient just to add an anaerobic tank to the return sludge line. Based on Salsabil et al. (2010), the resulting benefits from less sludge production by an oxic–settling–anoxic (OSA) system application would be much less than the cost of its application to the WWTP. Therefore, looking for excess sludge production reduction methods is prevalent. To achieve this goal, different methods have been investigated in the literature. A technique that is used for sludge reduction in the activated sludge process is the OSA process.
The main mechanisms of sludge production reduction can be identified as follows: cell lysis and cryptic growth (mechanical, thermal, electrical treatment); uncoupled metabolism (chemical uncouplers, OSA process); maintenance metabolism; microbial predation and hydrothermal oxidation (Low & Howard 1998; Wei et al. 2003; Ramesh et al. 2006; Novak et al. 2007; Riedel 2009; Mohammadi et al. 2011). Among the variety of methods developed based on these mechanisms, the OSA process is an efficient method due to its low application and operation costs and high compatibility with current WWTPs. The OSA process modifies the conventional activated sludge process by inserting an anaerobic sludge tank in the recycling bypass of the sludge. It has been confirmed to reduce excess sludge production by 25% to 58%, while improving effluent quality and settleability of the activated sludge (Wang et al. 2008).

Ye et al. (2008) evaluated the effect of OSA system application on chemical oxygen demand (COD) removal rate and the effluent nitrogen content. They concluded that the COD removal rate is not affected by OSA application and total phosphorus removal rate is increased. Datta et al. (2009) also investigated the simultaneous effect of OSA application on sludge reduction and nutrient removal. Their results showed a net 63% sludge reduction while there was 90% phosphorus and 100% NH₃ removal.

The possible mechanism of sludge reduction in the OSA process is that sludge decay is accelerated effectively under a low oxidation reduction potential (ORP) in the anaerobic tank. Such an increase in the sludge decay coefficient induced by a low ORP is able to explain a low production rate of the excess sludge in the OSA system (Ye & Li 2010). The main advantages of the OSA process are that there is no need for extra-chemical or physical addition, better sedimentation capability, capability of treating complex components or high-strength organic pollutants, flexibility in operation and easy melioration and economic efficiency and environmental friendliness.

Wang et al. (2008) reported up to 67% sludge reduction using the OSA process. According to their research, microbial death in the anaerobic tank is responsible for 7% of sludge reduction. Also, anaerobic reactions in the sludge anaerobic tank have lower sludge production than in aerobic oxidation when equivalent soluble COD is consumed, which may lead to approximately 25% of sludge reduction in the OSA process. Ye & Li (2010) investigated the effect of sludge retention time in a sludge holding tank on excess sludge production in an OSA activated sludge process. Four pilot-scale activated sludge systems were employed, one of which was a conventional activated sludge process, as the control system. The other three were OSA systems operated with different sludge retention times (5.5 h, 7.6 h, and 11.5 h) in the sludge holding tank. Compared to the control process, COD removal efficiency was not significantly influenced and results suggested that a 6–7 h sludge retention time would be optimal.

Coma et al. (2013) evaluated the application of an anoxic side-stream reactor in the sludge return line of a conventional activated sludge system for sludge reduction. The applied sludge loading rate was modified by changing the percentage of return sludge treated in this reactor and a maximum reduction of 18.3% of the observed yield was obtained by treating the whole sludge return line. Chon et al. (2011) investigated the mechanism of sludge reduction in the anaerobic side-stream reactor (SSR) process, with five different sludge reduction schemes. These are activated sludge with (1) aerobic SSR, (2) anaerobic SSR (OSA), (3) aerobic digester, (4) anaerobic digester, and (5) no sludge wastage. Results showed that the anaerobic SSR led to the highest sludge reduction rate and it was the only system that showed stable sludge settling and effluent quality.

Other methods such as thermal and mechanical sludge treatment mechanisms have also been effectively used for sludge volume reduction in the literature. Mohammadi et al. (2012) studied and compared the efficiency of some methods based on lysis and cryptic growth processes in pilot-scale, using a sequencing batch reactor (SBR). These methods included: lysis using ultrasonic waves, intermittent ozonation, thermal lysis, and loading reduction and dissolved oxygen (DO) increase. The results showed that the disintegration of 50% of the sludge of a reactor using ultrasonic waves can reduce bio-sludge yield by as much as 78% whereas ozonation of 30% of the sludge of the system can result in 63% reduction of biological sludge and thermal lysis of 30% of the system sludge can reduce the biological sludge yield up to 49%. Also a low rate of loading in the presence of high concentrations of oxygen can reduce the excess sludge production by 37%.

Laurent et al. (2011) used a continuous laboratory-scale activated sludge process coupling thermal (90 °C) sludge disintegration of a part of the return sludge in order to investigate both operational and more fundamental aspects. The results revealed that thermal disintegration effectively decreased sludge production by 50%, however the process affected the overall treatment performances. COD and total suspended solids (TSS) removal efficiencies were decreased by 15%. Graja et al. (2009) investigated anaerobic sludge treatment coupled with thermal pretreatment. They heated sludge up to 175 °C for 40 minutes and then it...
remained in an anaerobic situation. The results showed 65% sludge reduction overall.

Mechanical disintegration methods have been used for quick sludge disintegration and immediate depletion of cell energy. Mechanical pretreatment can be divided into two categories. One category of mechanical shear typically utilizes violent shearing methods to try to achieve cell lysis and includes such devices as stirred-ball mills, high-pressure homogenizers, blenders and other devices that exert high stresses on the sludge. Sonication is the other category of mechanical shear and could be considered as a more refined and less abusive method. All these methods aim to decrease the sludge flocs’ size so that they can be disintegrated more easily and sooner. Strünkmann et al. (2006) investigated the usability of mechanical disintegration techniques for the reduction of excess sludge production in the activated sludge process. Using three different disintegration devices (ultrasonic homogenizer, stirred media mill, high-pressure homogenizer) and different operational parameters for the disintegration, the effect of mechanical disintegration on the excess sludge production and on effluent quality was studied. Depending on the operational conditions and the disintegration device used, a reduction of excess sludge production of up to 70% was achieved. It was revealed that the disintegration has no, or only minor, negative effect on the soluble effluent COD and on the COD-removal capacity of the activated sludge process.

It can be concluded that OSA, thermal treatment and mechanical disintegration methods can effectively reduce excess sludge production. The aim of this study is to investigate how the combination of these methods could increase the efficiency of the reduction of excess sludge. The effect of system operation variables on sludge reduction percentage is also investigated. This would help in identification of the optimal architecture of the system for minimum excess sludge production.

Due to the huge number of tests needed to evaluate all of the cases, application of simulation models would be beneficial. Artificial neural networks (ANNs) have successfully been used for interpolation of system results in different cases, but there are limited cases in which ANNs have been used for determining treatment process results in different situations based on limited experimental results. As an example, Nasr et al. (2012) addressed the problem of how to capture the complex relationships that exist between process variables and to diagnose the dynamic behavior of EL-AGAMY WWTP by applying an ANN model. They concluded that ANN provides an effective analyzing and diagnosing tool for understanding and simulating the non-linear behavior of the plant, and is used as a valuable performance assessment tool for plant operators and decision makers.

Therefore, in this study we aim to evaluate the effect of thermal and mechanical treatment in OSA system performance. In this study the effect of OSA with thermal and mechanical treatment is investigated on a system based on just C removal. Of course the OSA is applicable to systems that include nutrient removal, however this is not considered in this study. For this purpose, a laboratory pilot of SBR plus OSA is developed. Different combinations of variables controlling the performance of sludge reduction such as temperature, voltage and mixing time are included in this study. The experimental results are used as an ANN model input to train it for simulation of other cases not experimentally tested. This can be an effective tool to test the system performance variability in different conditions of input wastewater characteristics and operation situation. It can also effectively be used for determining the optimal operation condition in real cases.

METHODS AND MATERIALS

In this study the effect of a combined application of thermal and/or mechanical treatment with OSA on excess sludge production in a conventional SBR is investigated. Regarding the considerable number of parameters that affect the process, ANN models are developed to predict the sludge reduction when different sets of operation variables are used. The main steps of the study are shown in Figure 1 and described in the following paragraphs.

Setting up the conventional SBR system

In the first step, the SBR system is set up and the optimal detention time in the aerobic tank based on COD removal rate and sludge production is determined. For this purpose, different detention times are considered. Before evaluation of system performance, the system should be stabilized and this requires at least 14 days. As one of the basic objectives of wastewater treatment is to reduce the COD load, the COD removal rate is selected as the criterion by which to determine the optimal detention time.

Adaptation of the SBR system to the OSA system

The SBR system is adapted to OSA by adding an anaerobic tank in the sludge return line. The sludge anaerobic tank in
the OSA process is different from the anaerobic zones in other processes in different aspects, including few external organic substrates, high sludge concentration, and long sludge-retention time. These characteristics result in microorganism death and endogenous oxidation, and therefore reduce the sludge volume. The optimal detention time in the anoxic tank is determined considering different times and regarding the effluent COD and percentage of sludge reduction.

**Thermal treatment of return sludge in combination with the OSA system**

In this step, the sludge is subjected to a high-temperature environment during the detention time in the anaerobic tank. The high temperature is provided using a thermal transformer attached to the anaerobic tank. The tested temperatures are 50, 70, and 90 °C and the duration of heating is 2 hours. By thermal treatment, sludge flocs are broken into smaller flocs. The thermal treatment affects sludge characteristics including solubilization of organic compounds because of cell lysis and desorption of sludge compounds, modification of surface properties, evolution of the fate of heavy metals, changes in bacterial community structure and finally anaerobic/aerobic biodegradability improvement (Laurent et al. 2014).

**Applying shear stress method in combination with the OSA system**

The application of shear stress leads to smaller sludge flocs that the bacteria can consume more easily and faster. Commonly in this method violent shearing methods are used for the purpose of cell lysis (Riedel 2009). Cell lysis will release cell contents into the medium, providing an autochthonous substrate that contributes to the organic loading. This organic autochthonous substrate is reused in microbial metabolism and a portion of the carbon is liberated as a product of respiration, and then results in a reduced overall biomass production.

There are several common equations that are used for estimation of energy produced through mechanical shear. In this study the specific energy is used:

\[ E_s = \frac{P \cdot t}{V \cdot x \cdot 1 \cdot 000} \]
where $E_s$ is specific energy (kJ/kgTS), $P$ is the applied power (W), $t$ is the time of treatment (s), $V$ is the volume of treated sludge (m$^3$), and $x$ is the concentration of the sludge (kgTS/m$^3$). The applied power is defined as follows:

$$P = V \cdot I$$

(2)

where $V$ is voltage (V), and $I$ is current (A). Therefore the time and voltage of the treatment are the variables that should be determined as mechanical treatment decision variables.

**Applying thermal treatment and mechanical shear simultaneously to the OSA system**

In this step, based on the previous results, the three methods are combined. To investigate the interaction between thermal treatment and mechanical treatment, different combinations of operation variables determined as the optimal values in the previous steps are considered.

In order to investigate the efficiency of different methods and compare their performance, regarding the measurement limitations, a few variables were measured such as pH, DO, COD, volatile suspended solids (VSS), and temperature. Sludge production rate was measured through the yield coefficient ($Y$) which is calculated as given in Equation (3):

$$Y = \frac{\text{VSS}_{\text{out}} - \text{VSS}_{\text{in}}}{\text{COD}_{\text{in}} - \text{COD}_{\text{out}}}$$

(3)

where VSS$_{\text{in}}$ and VSS$_{\text{out}}$ are the VSS concentrations in the influent and effluent (mg/l), and COD$_{\text{in}}$ and COD$_{\text{out}}$ are the COD concentrations in the influent and effluent (mg/l). COD, total solids (TS), TSS, VSS, pH, and DO are measured according to Standard Methods for the Examination of Water and Wastewater (APHA 1992).

**Development of ANN models for sludge reduction prediction**

Based on the experiment’s results, ANNs are developed for prediction of sludge volume changes under different operational conditions. These models can be used to forecast sludge reduction percentage based on available information such as thermal treatment temperature and mechanical treatment duration and voltage. In this work, MATLAB™ was employed for ANN modeling. The main advantage of ANNs over physically based models is that they are data-driven. The ANN modeling approach does not require a description of how the processes occur in either the micro or macro environments, but only the knowledge of important factors that govern the process. This situation makes the ANN modeling approach a rational choice for process modeling and control in wastewater treatment (Badalians Gholikandi et al. 2014).

A supervised neural network of multilayer perceptron composed of one input layer, one output layer, and one hidden layer is used in this study. In these types of ANN models, neurons in the input layer represent the network inputs and have no computational activities, while the output layer contains one or more processing units that produce the network outputs. Layers between the input and output layer are called hidden layers and may contain a large number of hidden processing units (Tashaouie et al. 2012). For more information on ANNs please see Hagan et al. (1996). The model is trained using the experiment’s results. In this research, 80% of data are used for training and 20% for testing the developed ANN models. The input variables are influent COD and TSS, temperature and duration of thermal treatment, and voltage and duration of mechanical treatment. The effluent COD and TSS as well as the yield coefficient are considered as the output variables.

To achieve proper ANN model configuration, the number of neurons in the hidden layer are changed from four to eight and for the hidden layer’s activation function the hyperbolic tangent (tansig) is selected. The performance function of the mean square error (MSE) is used in this study (Equation (4)). MSE is one of the most common measures used to evaluate accuracy. It is an average of the squares of the difference between the actual observations and those predicted. Smaller values of MSE show that the model results are more accurate:

$$\text{MSE} = \frac{1}{n} \sum_{i=1}^{n} (y_{\text{est}} - y_{\text{obs}})^2$$

(4)

where $y_{\text{obs}}$ is the observed or measured value, $y_{\text{est}}$ is the estimated value which is the model’s output, and $n$ is the number of values or data.

The developed models can be used to determine the optimum operational conditions of the OSA system regarding the characteristics of the influent wastewater in a way that produces the minimum sludge with the maximum effluent quality.

**LABORATORY PILOT SET-UP**

In the present study, a cubic SBR reactor is used as the pilot with dimensions of 20 cm and a useful volume of 6 L (Figure 2). An aerator with capacity of 15 L/min and output power of 20 W is employed for supplying the
required air flow. For ensuring uniform air distribution, especially at lower aeration rates, and for providing necessary mixing energy, a mixer with an engine with a speed of 110 rpm is installed in the reactor. The DO is checked during the process to be more than 5 mg/l. The reactor is fed by municipal wastewater sampled instantly from Qheytaye WWTP. Characteristics of the influent raw wastewater used in this research are summarized in Table 1. Wastewater is kept in a refrigerated (4°C) tank for a maximum of 24 hr so that its physical, chemical, and microbiological characteristics are kept almost fixed. The pilot needs 14 days to reach a stable condition. Meanwhile, the DO of raw wastewater is measured in all steps. The F/M ratio based on COD and MLSS is 0.35 and the surface organic loading rate is $10.5 \times 10^3$ mg COD/d·m$^2$.

The anaerobic tank of the OSA is fed by 250 ml of the SBR sludge content after settling. The remaining sludge is disposed of. The bottle, used as the anaerobic tank, is kept in a dark place at ambient temperature. The anaerobic condition is ensured by tightening its cap to avoid air entering and keeping it in a dark place and the DO condition is also checked to be less than 1.5 mg/l. Thermal treatment is applied using a heater in the sludge return line. Thermal treatment temperatures are fixed at 50, 70, and 90°C as these temperatures are feasible to use in real cases. The shear stress is produced by a four-bladed turbine attached to an electric engine. The turbine’s rotation speed is adjusted using different voltages. The mechanical shear reactor consists of an electric engine, blades, a glass bottle, and a concrete pod.

It is noted that the experiments use the following instruments:

- portable DO meter made by Lutron
- DR 5000 UV/VIS spectrophotometer made by the HACH company
- laboratory furnaces with temperature range of 50–500°C
- laboratory scale with an accuracy of 0.0001 g
- laboratory oven with temperature range of 0–250°C.

## RESULTS AND DISCUSSION

### Conventional SBR system

At first, the optimal detention time in the SBR process is determined based on the COD removal rate. The maximum COD removal rate occurs at a detention time of 6 hours. In a 6-hour aeration, the COD removal rate varies between 87% and 90% with an average of 89%. Therefore, the SBR system is operated in 8-hour cycles. Each cycle includes 6 hours of aeration, 1.5 hours for sludge settling and 0.5 hours for effluent discharge. The SBR is stabilized after three cycles and the samples used for different parts of study are taken after system stabilization.

### OSA system

After adding the anaerobic tank to the SBR system to form the OSA, it is necessary to determine the detention time in the anaerobic tank. In order to determine the optimal detention time in the anaerobic tank, COD removal rates for the anaerobic tank in the OSA system are considered. The considered detention times are 4, 6, 8, 10, 12 and 15 hours and the highest COD removal rate is obtained when a 10-hour detention time in the anaerobic tank is considered. The removal rates for these detention times range from 5% to 13% due to the anaerobic conditions.

### Adding the OSA system to the SBR system

After determining the optimal detention time for aeration and the anaerobic tanks, it is necessary to evaluate the

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Raw wastewater</th>
<th>Sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/l)</td>
<td>253</td>
<td>153</td>
</tr>
<tr>
<td>BOD (mg/l)</td>
<td>176</td>
<td></td>
</tr>
<tr>
<td>TS (mg/l)</td>
<td>660</td>
<td>13,560</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>451</td>
<td>10,750</td>
</tr>
<tr>
<td>VSS (mg/l)</td>
<td>396</td>
<td>5,180</td>
</tr>
<tr>
<td>pH</td>
<td>8.1</td>
<td>7.6</td>
</tr>
</tbody>
</table>
performance of OSA in sludge production reduction as well as COD removal in comparison with the SBR system. Table 2 compares sludge production in the SBR and the OSA system as well as the COD removal rate. As is shown, the average yield coefficient in the SBR process is 0.35, while it is 0.27 in the OSA process, which shows 24% sludge production reduction in the OSA process. It is also observed that the COD removal rate would decrease by about 4% in the OSA process, which would be acceptable because of the high amount of sludge reduction.

Thermal treatment in the OSA process

In this step, thermal treatment is also included in the OSA process. For this purpose, the sludge in the anaerobic tank is heated up to 50, 70, and 90 °C for 2 hours. The results are given in Table 3 and as is shown, the yield coefficient is on average 0.25, 0.21 and 0.19 for 50, 70 and 90 °C, respectively. These results show that thermal disintegration effectively decreases sludge production by 29%, 40%, and 46% for 50, 70 and 90 °C, respectively in comparison with the common SBR system. The maximum reduction of sludge production is observed at 90 °C which is about 46%. The sludge reduction at 50 °C is not much increased in comparison with simple OSA (7%) but it would be considerable in 70 and 90 °C which reach 22% and 30% reduction in sludge production, respectively. The COD removal efficiency is determined as 87%, 85%, and 85% at 50, 70 and 90 °C, respectively. This shows that thermal treatment in OSA does not affect the COD removal efficiency, which is of high importance. However, at a temperature of 90 °C, the results obtained for COD removal show high variability and high uncertainty. It can be concluded that the COD removal efficiency will decrease severely at higher temperatures. It should be mentioned that the tests are repeated for six cycles or 3 days to maintain the results and only the average values are shown in Table 3.

Mechanical treatment in OSA

In the next step, shear stress is applied to the OSA system. The sludge detention time in the mechanical shear reactor is fixed at 10 s and voltages of 80, 120, 150, and 220 V are applied to the system. As is shown in Table 4, at a voltage of 220 V the sludge production is reduced to Y of 0.14 but the COD removal efficiency is decreased by up to 82%, which is less than the COD removal efficiency in the SBR system. At other voltages, Y varies between 0.22 and 0.27 (the average of three tests in each case) and the COD removal efficiency varies between 0.87 and 0.89, which is close to ordinary OSA results. Therefore, it seems that the maximum voltage that is applicable without reduction in effluent quality will be 150 V. It should be mentioned that the tests are repeated for six cycles or 3 days to maintain the results and only the average values are shown in Table 4.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Sludge production and COD removal comparison in SBR and SBR + OSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment number</td>
<td>1</td>
</tr>
<tr>
<td>SBR</td>
<td>TSS&lt;sub&gt;in&lt;/sub&gt; (mg/l)</td>
</tr>
<tr>
<td></td>
<td>COD&lt;sub&gt;in&lt;/sub&gt; (mg/l)</td>
</tr>
<tr>
<td></td>
<td>COD removal rate (%)</td>
</tr>
<tr>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>SBR + OSA</td>
<td>TSS&lt;sub&gt;in&lt;/sub&gt; (mg/l)</td>
</tr>
<tr>
<td></td>
<td>COD&lt;sub&gt;in&lt;/sub&gt; (mg/l)</td>
</tr>
<tr>
<td></td>
<td>COD removal rate (%)</td>
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<tr>
<td></td>
<td>Y</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Evaluation of the SBR system performance under thermal treatment on COD removal rate and sludge production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>Y</td>
</tr>
<tr>
<td>50</td>
<td>0.25</td>
</tr>
<tr>
<td>70</td>
<td>0.21</td>
</tr>
<tr>
<td>90</td>
<td>0.19</td>
</tr>
</tbody>
</table>
Thermal and mechanical treatment in OSA

In this step both the thermal and mechanical treatments are included in the OSA process. Different combinations of these variables based on results obtained in previous steps are considered for this purpose and results are provided in Table 5. As is shown in Table 5, the minimum yield coefficient is obtained at a voltage of 150 V and temperature of 90 °C but this condition results in a reduction of COD removal efficiency up to 73%, which is not acceptable. The combination of a voltage of 80 V and temperature of 90 °C not only will decrease the yield coefficient considerably, but also keeps the COD removal efficiency up to 88%, which is appropriate. The reduction of yield coefficient in this condition would be equal to 51% and 37% compared to the conventional SBR system and OSA system, respectively. The main advantage of this combination over the thermal treatment at 90 °C is that the COD removal rate is 4% more while the sludge production is about 10% less. In comparison with just the application of mechanical treatment at 80 V, this combination has resulted in almost the same COD removal efficiency while Y is decreased by up to 55%. Therefore, it can be considered as the best combination of thermal and mechanical treatment application in the OSA system. It should be mentioned that the tests are repeated for six cycles or 3 days to maintain the results and only the average values are shown in Table 5.

Development of ANN model for OSA system performance simulation

Based on the experiment’s results, ANNs are developed for simulation of OSA system performance from aspects of Y, COD removal efficiency and TSS changes. The tests done in this study resulted in a series of 97 data which are used for ANN model development. A series of 69 data (72%) are used as training data, a series of 14 (15%) are used as validation data, and the rest are used as testing data. The input variables are influent COD and TSS, temperature and duration of thermal treatment, and voltage and duration of mechanical treatment. The effluent COD and TSS as well as the yield coefficient are considered as the output variables. Due to data limitation, three separate ANNs with one hidden layer and four to 13 neurons in the hidden layer are developed to simulate each of the considered outputs. The maximum number of neurons in the hidden layer is determined based on the available data series in a way to prevent over-fitting. The training method used in this neural network is Levenberg Marquardt. The hidden layer’s transfer function is selected to be tansig and the output layer’s activation function is considered to be linear. The least MSE value in COD simulation is obtained using eight neurons in the hidden layer, and when 11 neurons are used in the hidden layer in simulation of Y the least error and the best results are obtained. The optimal number of neurons in the hidden layer for simulation of TSS is 17 as well. The data are normalized to be used for ANN development. The results of the simulation are given in Figure 3. Based on this figure, the developed models have well simulated the TSS, COD and Y based on the input data. Therefore, they can be used with high reliability to analyze different situations and determine the optimal situation.

CONCLUSION

This research has investigated how the performance of OSA in sludge production reduction can be improved. A pilot plant is developed and the OSA system, thermal treatment, shear stress, and their combinations are studied. The main conclusions are as follows:

1. OSA, thermal and mechanical methods are promising techniques in terms of sludge reduction. However, the
maximum reduction was achieved combining the three methods.

(2) High sludge reduction rate may lead to increasing the COD in the effluent; therefore, it is crucial to consider the COD removal rate while utilizing sludge reduction techniques.

(3) The sludge characteristics affect the optimal temperature in the thermal treatment and the voltage and duration of mechanical treatment; therefore, the optimal condition must be determined for different sludges by studying different combinations of techniques.

(4) The suggested modifications in this study to the OSA system would definitely increase the cost of OSA system application. However, the reduction in sludge treatment and disposal cost as a result of the 39% increase in OSA performance in sludge production reduction by application of the suggested modifications would be much more than the costs of the system’s application. It should also be mentioned that the energy needed for thermal treatment of sludge can be supplied from the methane gas that is produced in sludge digestion systems.

It is also emphasized that since WWTPs can be designed to remove nutrients beside the organic content, the effect of the proposed system on nutrient removal can also be investigated in future studies. Furthermore, an ANN model was developed to interpolate the results of this study for cases that are not experimentally tested. The operational conditions were considered as model inputs and three models were developed to simulate Y as well as effluent COD and TSS. The results show successful performance of the developed ANN models which can be used for further investigation purposes such as determining the optimal operation conditions regarding influent characteristics.

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