International Journal of Electrical and Computer Engineering (IJECE)
Vol. 7, No. 3, June 2017, pp. 1568~1573
ISSN: 2088-8708, DOI: 10.11591/ijece.v7i3.pp1568-1573

Dynamic Modelling of Aerobic Granular Sludge Artificial Neural Networks

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Article Info

Article history:

Received Feb 13, 2017
Revised Apr 18, 2017
Accepted May 2, 2017

Keyword:

Aerobic Granular Sludge
Dynamic
Feedforward
Neural Network
Sequencing Batch Reactor

ABSTRACT

Aerobic Granular Sludge (AGS) technology is a promising development in the field of aerobic wastewater treatment system. Aerobic granulation usually happened in sequencing batch reactors (SBRs) system. Most available models for the system are structurally complex with the nonlinearity and uncertainty of the system makes it hard to predict. A reliable model of AGS is essential in order to provide a tool for predicting its performance. This paper proposes a dynamic neural network approach to predict the dynamic behavior of aerobic granular sludge SBRs. The developed model will be applied to predict the performance of AGS in terms of the removal of Chemical Oxygen Demand (COD). The simulation uses the experimental data obtained from the sequencing batch reactor under three different conditions of temperature (30˚C, 40˚C and 50˚C). The overall results indicated that the dynamic of aerobic granular sludge SBR can be successfully estimated using dynamic neural network model, particularly at high temperature.

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1. INTRODUCTION

Domestic wastewater treatment in urban areas is one of the crucial elements to be considered in the development of a country in order to sustain individual’s health and welfare. Untreated wastewater can cause spreading of disease in the form of several types of endemic and epidemic illnesses [1]. There are various kind of wastewater treatment applications nowadays ranging from modest, low priced, and less efficient processes to very advanced, highly efficient and pricey operations. Aerobic granular sludge (AGS) technology is a promising development in biological wastewater treatment [2],[3]. Aerobic granules have a regular and compact physical structure, good settle ability, high biomass retention, have the ability to withstand shock load of toxic compounds compared with activated sludge. Aerobic granulation usually happened in sequencing batch reactors (SBRs). Many researchers (refer to [3]-[5]) have extensively investigated the fundamentals of aerobic granular sludge SBRs.

The main challenge of modelling and control of an aerobic granular sludge system is it involved complex physical, biological and chemical processes which include internal interactions among process variables and sludge characteristics. Most of the available models for the system are complex (mathematical model). Therefore, this paper proposes artificial neural networks (ANN) modelling which using dynamic neural network and feed-forward neural network (FFNN) approach to model aerobic granular sludge SBRs. Chemical Oxygen Demand (COD) effluent is selected as the output of the model as it is one of the critical parameters that has been monitored and reveals the efficient of the plant. The objectives of this paper are to develop a dynamic neural network model and a feed-forward neural network model of AGS for prediction of COD effluent in wastewater treatment plant (WWTP). The performance of dynamic network and feed-forward network were compared in order to assess the effectiveness of the methods in predicting the dynamic behaviour of aerobic granular sludge SBRs particularly at high temperature.

2. RESEARCH METHOD

Aerobic granular sludge (AGS) using SBR system is chosen as the case study. AGS is a dense cluster of symbiotic organisms with excellent efficiency in mass transfer and good biological activity performance. The input-output of the experimental data of the system were used in developing dynamic neural network model and FFNN model. The training data set is 60% and another 40% is used for testing data set. The performances of the models were evaluated using coefficient of determination (R^2), mean square error (MSE) and root mean square error (RMSE). High value of R^2 and low values of MSE and RMSE indicate the most accurate prediction of the model.

Previous research on AGS using SBR system have been conducted at ambient temperature. There were some studies on AGS that have been conducted at high temperature, further knowledge on the effect of high temperature on aerobic granulation is still confined [6].

2.1. Experimental Setup

The experiment was been conducted in Madinah city, Saudi Arabia. The purpose of the experiment is to investigate the granulation process, stability, density and performances of aerobic granules at high temperature 30˚C, 40˚C, and 50˚C. Sludge collected from the wastewater treatment plant in Madinah city, Saudi Arabia as seed sludge was used to cultivate aerobic granulation in SBR. During summer time, the temperature desert in Madinah due to the climate is reaching close to 50˚C.

Three double-walled cylindrical column bioreactors (internal diameter of 6.5 cm and total height of 100 cm) were used in the experiment. The working temperatures for the bioreactors were controlled using a thermostat and water bath sleeves without controlling the pH level and oxygen at 30, 40 and 50 ± 1 °C.

2.2. Data Collection

The inputs variables in constructing the models are Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Total Phosphorus (TP), Total Nitrogen (TN), Ammonia Nitrogen (AN) and Mixed Liquor Suspended Solid (MLSS). These inputs are the influents for the plant and the concentration of COD effluent is selected as the output for the model.

The measurement for influents and effluent for 6 parameters been recorded. The effluent reading has been recorded from the day 1 of the operation until day 60 at interval of 3 days (total 21 samples). The total 21 samples are utilized to develop the model for aerobic granular sludge under three different temperature of sequencing batch reactor.

2.3. Dynamic Neural Network Model of Aerobic Granular Sludge

The real experimental data from the SBR for three different temperatures are utilized to develop the models. The normalization of the measured data is done by using equation (1). The data values have been scaled between zero (0) and one (1).

$$Y_i = \frac{(y_i - x_{min})}{(x_{max} - x_{min})} \tag{1}$$

where Y_i is the normalized data point, y_i is the data sample, x_{min} is the minimum values among the data samples and x_{max} is the maximum value among the data sample. The data normalization for neural network is vital in minimizing the chances of getting stuck in local minima and faster convergence. The normalized data is divided into 60% for training and 40% for testing sets. In this case, the selection of training and testing data sets have been done statistically as suggested in [7].

The main challenge in developing neural network models is for determining structure of the network. In this work, the network structure was selected after several trials considering the relationship proposed by [8]. It consists of three layers which are input layer that containing six inputs variables and a feedback which made a total of seven inputs connected to hidden layer (hidden neurons) and connected to the output layer.

In determining the range of the hidden neurons, [9] proposed that there exist an upper bound for the number of hidden neurons in order to achieve an accurate neural network approximation.

$$N\alpha \leq 2N\beta + 1 \quad (2)$$

where Nα is the number of hidden neuron and Nβ is the number of inputs.

The simulation started with one hidden neuron followed by 2, 4, 6 (increment by 2) until 16 as it is the upper boundary proposed in [9]. The following range is decided based on the Equation (2) and it is able to see the variation faster by increment of two instead of starting from one hidden neuron until sixteen (16).

The tangent-sigmoid (tansig) transfer function is applied for the hidden layer and purelin (purelin) for the output layer as it is widely used with dynamic neural network and FFNN. The Levenberg-Marquardt algorithm (trainlm) and back-propagation was used to train the model. The accuracy of prediction ability of the developed model is based on the performance criteria using R^2, MSE and RMSE. The de-normalization process is done to scale back the values to its original scale. The formula is expressed in Equation (3).

$$Y_d = Y_i(x_{max} - x_{min}) + x_{min} \quad (3)$$

where Y_d is denormalized data sample, Y_i is normalized data sample, x_{min} is the minimum value among the data samples and x_{max} is the maximum value among the data sample.

The same experimental data were used which is 60% used for training set and 40% for testing to develop FFNN models. Also, similar procedure of data normalization to the de-normalization applied into the dynamic neural network modelling were repeated in FFNN model.

3. RESULTS AND ANALYSIS

The real experimental data of the aerobic granular sludge SBR system is used for modeling of COD effluent using dynamic neural network model. The simulation of COD model for reactor with temperature of 30˚C started with one hidden neurons until 16 neurons. The best model for each neuron number is determined using three parameters which are coefficient of determination (R^2), mean square error (MSE) and root mean square error (RMSE). Figure 1 shows the measured and predicted models of COD at the temperature of 30˚C for training stage while for testing stage as depicted in Figure 2. From Figure 1, the prediction performance of R^2 and MSE for training give 77.98% and 0.0094, respectively. For testing, the dynamic model demonstrated better prediction with R^2 of 91.17% and MSE of 0.0014.

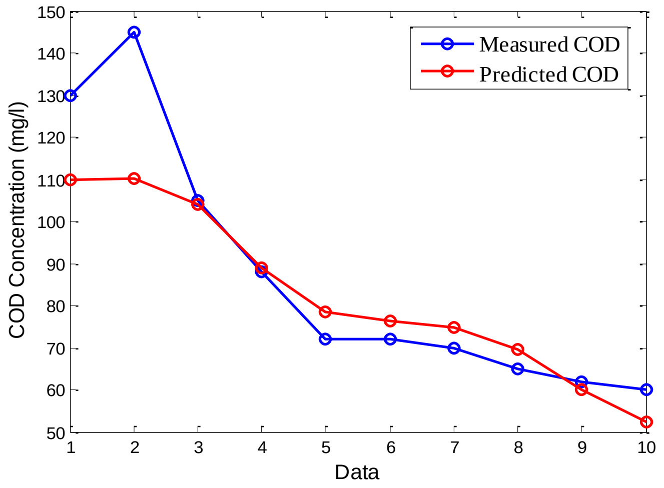

Figure 1. Model prediction during training for reactor 30˚C

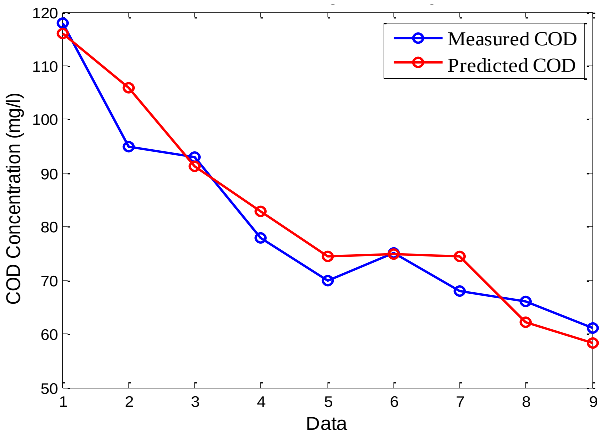

Figure 2. Model prediction during testing for reactor at 30˚C

For reactor 40˚C, the model predicted for COD during training stage give R^2 of 94.2% and the MSE of 0.004 as illustrated in Figure 3. In the testing model, the performance of R^2 is 91.14% with the value of MSE of 0.0062 as shown in Figure 4.

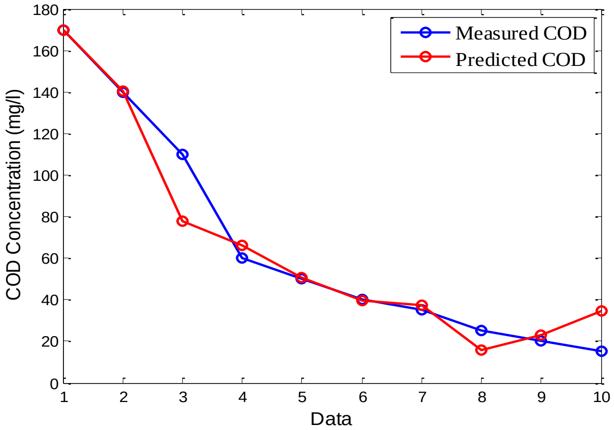

Figure 3. Model prediction during training for reactor at 40˚C

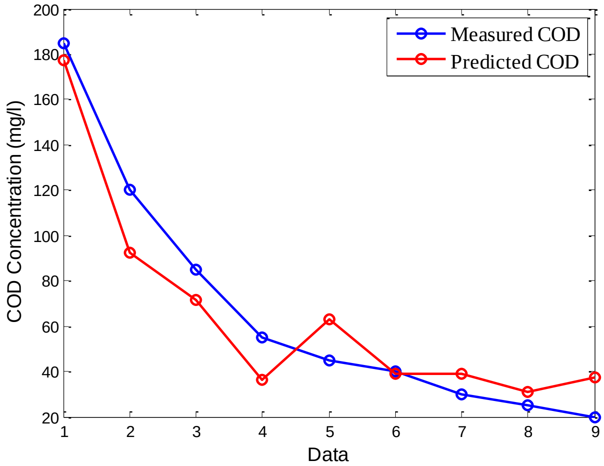

Figure 4. Model prediction during testing for reactor at 40˚C

For reactor 50˚C, the prediction give R^2 of 74.62% and MSE of 0.0255 during training while in testing, the R^2 of 89.64% and MSE of 0.0077 were achieved as depicted in Figures 5 and 6, respectively.

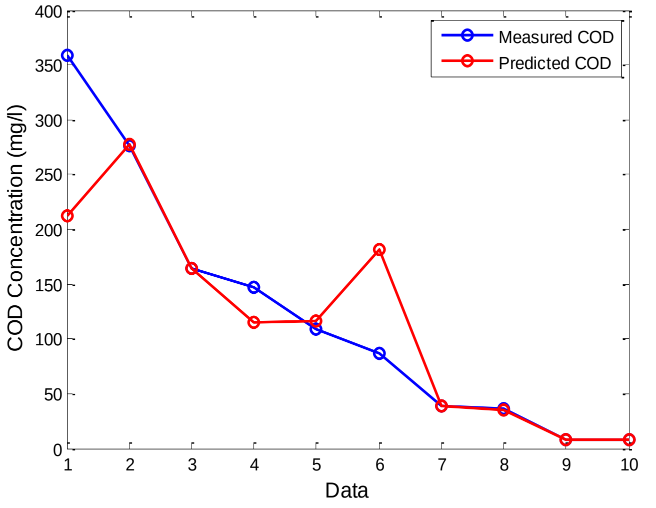

Figure 5. Model prediction during training for reactor at 50˚C

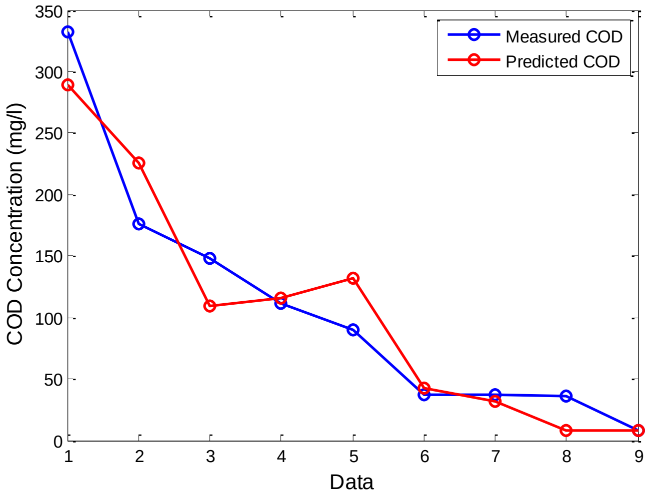

Figure 6. Model prediction during testing for reactor at 50˚C

Based on the result obtained, dynamic neural network is able to predict the dynamic behaviour of AGS at three different conditions of temperature. However, as the temperature goes higher, the accuracy of the prediction model showed some deteriorated slightly. It showed that the dynamic of AGS behave nonlinear as temperature increases. Moreover, the small amount of sample data used could be one of the reasons for model deterioration. The prediction performances of dynamic neural network for the three temperatures are summarized as shown in Table 1.

Table 1. Dynamic neural network prediction performances of COD effluent

Reactor	Training		Testing	
	R^2 (%)	MSE	R^2 (%)	MSE
30˚C	77.98	0.0094	91.17	0.0014
40˚C	94.20	0.0040	91.14	0.0062
50˚C	74.62	0.0255	89.64	0.0077

4. CONCLUSION

The dynamic neural network models are successfully predicted the aerobic granular sludge SBRs at different condition of high temperature. Due to the nonlinearity behaviour of AGS, the model prediction for COD showed minor deterioration especially during high temperature (50˚C). This can be improved by collecting more data for training and testing stages. The models for different temperature can be useful for prediction tools in wastewater treatment plant.

ACKNOWLEDGEMENTS

The authors would like to thank the Research University Grant (GUP) vote 13H70, Universiti Teknologi Malaysia for the financial support.

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