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Anaerobic Digestion in a Tapered Fluidized Bed Reactor and Modeling Using Radial Basis Function Neural Network

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Abstract: A study of the anaerobic digestion of synthetic wastewater derived from the processing of sago from tubers of tapioca was carried out in a laboratory-scale, mesophilic (35°C) Anaerobic Tapered Fluidized-Bed Reactor (ATFBR) with mesoporous Granulated Activated Carbon (GAC) as bacterial support. Soluble COD removal efficiencies in the range of 90-92% were achieved when subjected to a steady-state operation over a range of Hydraulic Retention Time (HRT) from 26 to 2 h and Organic Loading Rate (OLR) up to 85.44 kg COD m^{-3} day^{-1} in the reactor. Also an Artificial Neural Network (ANN) model using Radial Basis Function (RBF) has been developed to predict the measured output parameters. To model the above, a system of two input variables viz., influent OLR (combination of three parameters viz., flow rate, influent COD concentration and HRT) and influent pH and two output dependent variables viz., organic loading removal rate and biogas have been taken. For the training of the input-output data, the experimental values obtained have been used. The output parameters predicted with the help of developed ANN models for respective inputs have been found to be very much closer to the corresponding experimental ones (Goal of 0.02). The model was validated for 30% of the untrained data. The Mean Square Error (MSE) was found to be 0.026 for organic loading removal rate and 0.99 for biogas, which is very much encouraging for further research in this area.

Key words: Anaerobic digestion, tapered fluidized bed reactor, organic loading rate, % COD removal, sago effluent, radial basis function

INTRODUCTION

Anaerobic Fluidized Bed Reactors (AFBR) are currently utilized to achieve several biological wastewater treatment goals. AFBR were originally a chemical engineering tool used to perform phase transformations, reactions and diffusions of various chemicals existing in solid, liquid and vapor phases. With the concept of maximum diffusion and maximum chemical reaction within a minimum volume in mind, AFBR have been adapted to perform biological wastewater treatment and are utilized in several process configurations. In AFBR treatment, the presence of high biomass concentrations upon a carrier material allows for faster utilization of COD per unit volume than many other types of biological treatment. Several process configurations of this reactor are available in literature (Perez *et al*., 1977, 1999; Chen *et al*., 1988; Barascud *et al*., 1992; Anderson *et al*., 1990; Iza, 1991; Seckler *et al*., 1996; Fox *et al*., 1990; Matsumoto and Noike, 1991; Converti *et al*., 1993; Suidan *et al*., 1996; Breitenbucher *et al*., 1990; Sreekrishnan *et al*., 1991; Saravanane *et al*., 2001).

The conventional AFBR has a severe drawback due to its uniform velocity. Wash-out of bio-particles occurs frequently if the operating superficial velocity exceeds the defined range. To overcome this drawback, Scott and Hancher (1976) modified the geometrical circular fluidized bed configuration along its length to a tapered form. If the entry cross section is sufficiently small and the expansion is gradual (an angle of few degrees), the flow is expected to be relatively stable throughout the reactor. As there is a natural gradient of up flow velocity, it results in the lowering of superficial velocity which allows a perfect segregation of the particles along the vertical axis and tends to stabilize the bed for a wider range operating conditions. However, the efficiency in the removal of COD in fluidized bed reactors is limited by the taper angle. The experimental substrate removal efficiencies for taper angles of 5° and 10° were nearly the same. The COD removal efficiencies for taper angles of 5° and 10° tended

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to be higher than at a taper angle of 2.5° (Boening and Larsen, 1982; Denac and Dunn, 1988; Wu and Huang, 1995, 1996).

This study reports a laboratory investigation for the treatment of sago industrial waste water. Processing of tapioca produces 20,000 to 30,000 L of effluent per ton of Sago, which is highly organic, foul smelling and acidic (Murthy and Patel, 1961; Sastry and Mohan, 1963). According to Hien *et al.* (1999) a tapioca processing factory discharges the wastewater containing 11,000-13,500 mg O_2 L^{-1} in terms of COD, 4,200-7,600 mg suspended solids L^{-1} and pH 4.5-5.0. Studies by Mai *et al.* (2004) and Oanh *et al.* (2001) on large-scale tapioca processing companies give similar tapioca wastewater characteristics, with a total COD in the range of 7,000-41,406 mg L^{-1}, a BOD_5 of 6,200-23,077 mg L^{-1}. The performance of anaerobic fluidized bed treatment of corn starch wastewater was studied by Chen *et al.* (1988) to demonstrate the effect of operating variables on biomass activity. Various anaerobic technologies have been attempted to treat Sago industry wastewater (Sastry *et al.*, 1964; Tongkasane, 1970; Saroja and Sastry, 1972; Pescod and Thanh, 1977), high rate anaerobic treatment such as Anaerobic Filter (Khageshan and Govindan, 1995), Hybrid UASB (Rajesh Banu *et al.*, 2006) and Fluidized Bed (Saravanane *et al.*, 2001). We have chosen to study ATFBR due to its advantages as explained earlier.

Several applications of ANNs for modeling of nonlinear process system and subsequent control have been reported by Parthiban *et al.* (2007), Wasserman, (1989), Chitra (1984), Bhat and McAvoy (1990), Singh and Mohanty (2002), Kumar and Roy (2004), Boskovic and Narendra (1995) and Costello *et al.* (1991). In the present case, a software package for ANN using RBF has been developed and used using MATLAB 7 environment. A typical three layers, namely (i) the input layer (ii) the hidden layer and (iii) the output layer, neural network with four input nodes, hidden layer and six output node, respectively has been developed is shown in Fig. 1.

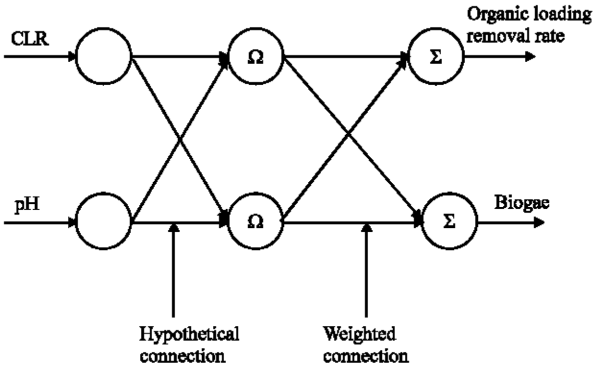

Fig. 1: Architecture of radial basis function network

MATERIALS AND METHODS

Experimental set up: The ATFBR consists of conical shaped acrylic column of 5° taper angle with a total volume of 7.8 L and the volume of tapered section is 1.5 L. The reactor column had a height 290 mm with a progressive increase in diameter from 46.6 mm at the base to 91.5 mm at the top. An upper settling section was attached to it, which was 1.073 m high and 91.5 mm diameter. A static bed volume of 500 cc of mesoporous GAC were used a biomass carrier (Fig. 2).

The effluent was recycled from the top to the bottom of the reactor using a magnetic driven polypropylene centrifugal pump. Complete fluidization of the GAC is achieved by operating at a constant rate. The settlement zone of the reactor contained a conical gas liquid separator to allow venting of the biogas produced. Sampling ports were provided along the column length to obtain bed samples. Influent was pumped in continuously at the bottom of the reactor by means of a peristaltic pump for low flow rates and for higher flow rates it was pumped using a magnetic driven polypropylene centrifugal pump. The effluent discharge output port is located in the cylindrical section at a point below 55 mm from the top of the column. Biogas produced from the reactor was collected by a 20 L displacement jar which contains 10% NaOH solution. When the gas flow rate exceeds 16 L per day it was measured using a wet gas meter.

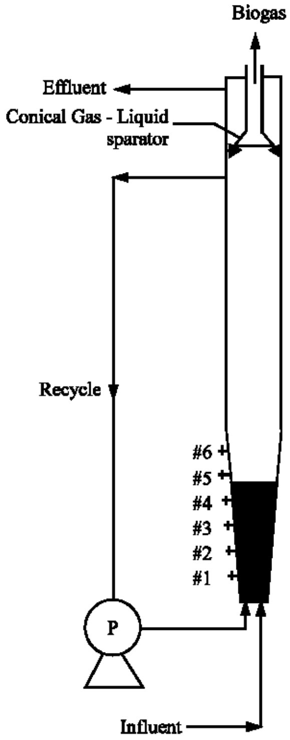

Fig. 2: An anaerobic tapered fluidized bed reactor and the gas liquid separator

Waste water: The waste water used throughout the study was a simulated sago industry effluent with the required feed COD concentration between 1100 to 7000 mg L^{-1}. It is analyzed as per the Standard Methods (APHA, AWWA, WEF, 2005). The characteristics are presented in Table 1.

Support material: GAC of 600 μm particles were used as a growth support material because of its ability to readily attach methanogenic bacteria. It has been proved that the application of activated carbon to anaerobic process enables better degradation of inhibitory waste water (Hanaki *et al*., 1997) besides serving a role in the storage and releasing of the generated methane gas (Najibi *et al*., 2007). The main characteristics of this carrier were given in Table 2.

Start-up of the anaerobic fluidized-bed reactor: The reactor was initially filled with 500cc of mesoporous GAC, then 7 L of supernatant liquid of the UASB reactor from Central Leather Research Institute, Chennai which was treating the municipal wastewater and the remaining volume with the sago feed of 1100 mg L^{-1}. Then the reactor was operated in a total recycle fashion with initial bed expansion maintained at 30%. Sodium bicarbonate was added if necessary to maintain the reactor pH in the range of 6.8-7.2. Diluted synthetic waste water was added to the reactor each day to promote and sustain the growth of biofilm on the carbon particles. The reactor operation resulted in 90% of COD removal after 45 days which ensures a complete adaptation to the wastewater used.

Sampling and Analysis: During the operation of the fluidized bed reactor the parameters such as temperature, influent and effluent pH and COD concentrations, biogas production rate, effluent total VFA, alkalinity concentration, ORP were monitored daily. All analytical determinations were performed according to Standard Methods (APHA, AWWA, WEF, 2005).

Scanning electron microscopy: Batch culture (500 mL) was centrifuged at 10000 rpm for 15 min. The resulting pellet was added to 1 mL of sodium cacodylate buffer and centrifuged at 8000 rpm for 10 min. Pellet obtained was added with 1 mL of glutaraldehyde and centrifuged at 8000 rpm for 10 min and placed overnight. To this mixture, 1 mL of osmium tetra oxide was added and centrifuged at 8000 rpm for 10 min. The obtained pellets was then washed with series of 10 to 100% acetone and centrifuged for 15 min and air dried. The air dried sample was placed on brass stubs (1 cm in diameter) using a double sided adhesive carbon tape and coated with platinum for about 3 to 4 min using JEOL-JFC-1600 Auto Fine Coater to render the surface of the specimens conductive for scanning. The samples were scanned and micrographs were taken using JEOL-JSM 6360 Scanning Electron Microscope.

Table 1: Composition and features of the wastewater

Parameters	Value
pH	6.5-7.5
COD (mg L^{-1})	1100-7500
BOD_5 (mg L^{-1})	690-5960
Alkalinity ($CaCO_3$, mg L^{-1})	350-970
Total solids (mg L^{-1})	4100-8400
Total dissolved solids (mg L^{-1})	2500-6300
Total suspended solids (mg L^{-1})	1600-2100
Volatile suspended solids (mg L^{-1})	900-1500
Total Phosphorus (P mg L^{-1})	50-100
Kjeldahl Nitrogen (N, mg L^{-1})	5-20

Table 2: Characteristics of the GAC support material

Parameters	Value
Surface area (BET) (m^2 g^{-1})	438.900
Micropore surface area (m^2 g^{-1})	214.600
Mesopore surface area (m^2 g^{-1})	224.300
Micropore volume (V_{micro}) (cm^3 g^{-1})	0.118
Mesopore volume (V_{meso}) (cm^3 g^{-1})	0.268
Total pore volume(V_{total}) (cm^3 g^{-1})	0.387
V_{micro}/V_{total} (%)	69.330
Average pore diameter (μm)	3.528
Ash content (%)	59.080
Bulk density (g cc^{-1})	0.560

Reactor operation: The experimental protocol was designed to examine the effect of the OLR on the efficiency of the ATFBR. The reactor was subjected to an operation of 535 days over a range of HRT of 26.74 to 1.97 h. Initially it is operated for an OLR of 1 kg m^{-3} day^{-1} and gradually increased to 85.44 kg m^{-3} day^{-1} with the optimum superficial velocity (2.5 U_{mf}) which gives the maximum COD removal. The COD concentrations were varied from 1100 to 7000 mg L^{-1}. The start up period of the reactor was found to be 45 days. The attainment of the steady state was verified after an initial period.

Development of RBF-ANN-models: RBF networks have a static Gaussian function as the nonlinearity for the hidden layer processing elements. The Gaussian function responds only to a small region of the input space where the Gaussian is centered. The key to a successful implementation of these networks is to find suitable centers for the Gaussian functions. The transfer function for a radial basis neuron $\text{radbas}(n) = e^{-n^2}$ is and the corresponding plot is shown in Fig. 3. The radial basis function has a maximum of 1 when its input is 0. A radial

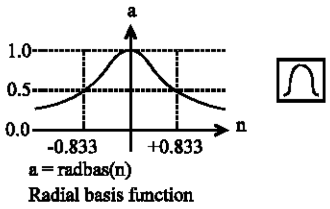

Fig. 3: Plot of radial basis function

basis network is designed with the function newrbe or newrb. These functions produce a network with zero error on training vectors. Newrbe is called in the following way.

net = newrbe (P, T, SPREAD)

The function newrbe takes matrices of input vectors P and target vectors T and a spread constant SPREAD for the radial basis layer and returns a network with weights and biases such that the outputs are exactly T when the inputs are P. The function newrb which is used for this model iteratively creates a radial basis network one neuron at a time. Neurons are added to the network until the sum-squared error falls beneath an error goal or a maximum number of neurons has been reached. The call for this function is:

net = newrb (P, T, Goal, SPREAD, MN, DF)

where:
P = R x Q matrix of Q input vectors.
T = S x Q matrix of Q target class vectors.
GOAL = Mean squared error goal, default = 0.0.
SPREAD = Spread of radial basis functions, default = 1.0.
MN = Maximum number of neurons, default is Q.
DF = No. of neurons to add between displays, default = 25.
and it returns a new radial basis network.

The larger that SPREAD is the smoother the function approximation will be. Too large a spread means lot of neurons will be required to fit a fast changing function. Too small a spread means many neurons will be required to fit a smooth function and the network may not generalize well. As newrb creates neurons one at a time, at each iteration the input vector that results in lowering the network error the most, is used to create a radbas neuron. The error of the new network is checked and if low enough, newrb is finished. Otherwise the next neuron is added. This procedure is repeated until the error goal is met, or the maximum number of neurons is reached. As with newrbe, it is important that the spread parameter be large enough that the radbas neurons respond to overlapping regions of the input space, but not so large that all the neurons respond in essentially the same manner (Bose and Liang, 1998; Fu, 1994). The important aspect of the radial basis network is the usage of activation function for computing the output. Radial basis function uses Gaussian activation function. The response of such function is non-negative for all value of x. The function is defined as:

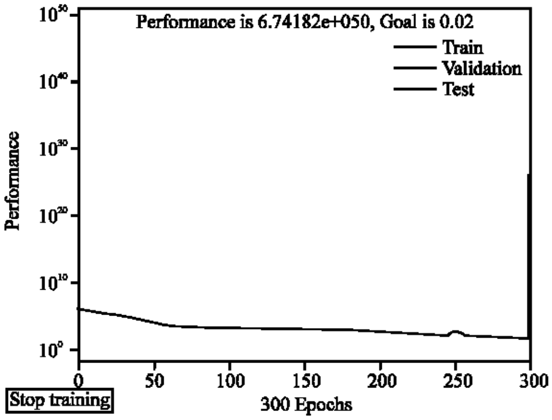

Fig. 4: Training and performance curve

$$f(x) = \exp(-x^2)$$

Its derivative is given by:

$$f'(x) = -2x \exp(-x^2) = -2xf(x)$$

A training algorithm has been developed and we have trained the RBF network with input-output measured parameters. It was found that the error between the actual and trained output for a goal of 0.02 error and plotted its performance as in Fig. 4.

RESULTS AND DISCUSSION

The results obtained in this investigation by operating the reactor for a maximum of 535 days. Figure 5 shows the results of the total influent and effluent OLR represented as kg m^{-3} day^{-1} of the reactor. The reactor was started with an OLR of 1 kg m^{-3} day^{-1} and the maximum efficiency was observed around 48 days as evident from Fig. 6. Hsu *et al.* (1993) also reported that COD values were found to decrease with increase in time of operation during the start-up of the reactor.

Very low OLR was preferred to prevent the washout of inoculated biomass (Hickey *et al.*, 1991). Initially the

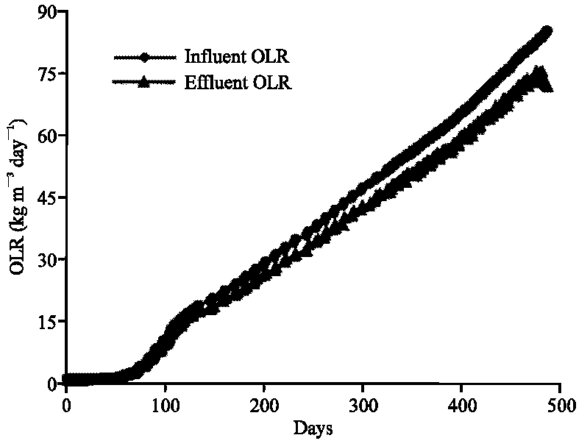

Fig. 5: OLR and removal rate vs. days

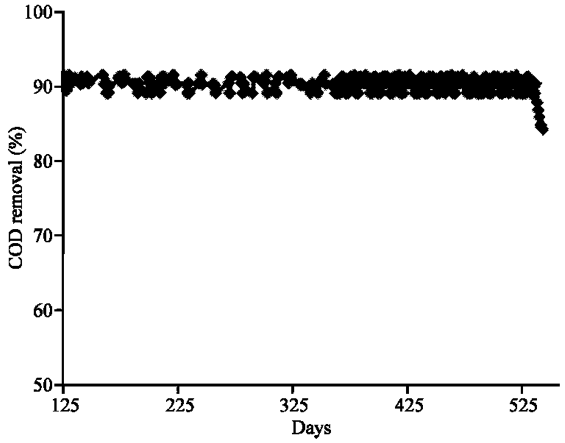

Fig. 7: Variation in the COD removal efficiency

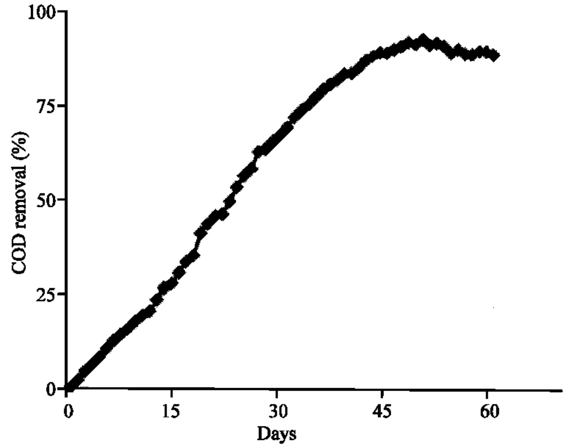

Fig. 6: Variation of % COD removal during start up

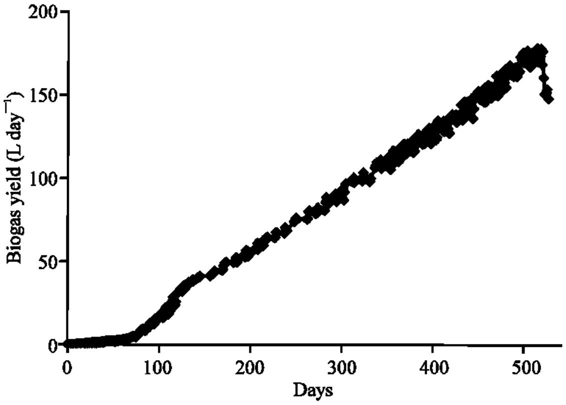

Fig. 8: Volumetric biogas formation

study was carried out between flow rates of 7-16 L day^{-1}. The COD concentrations of the influent were varied between 1100 to 7000 mg L^{-1} up to 124 days. (OLR of 14.4 kg m^{-3} day^{-1}). After this period, the influent COD concentration was kept constant and the flow rate was increased gradually by varying the HRT. The increment between two successive OLR was about 1 kg m^{-3} day^{-1} and kept constant for three days in order to get steady state condition of the reactor. When ever there is a change in OLR, the system gets disturbed resulting in a reduction of the COD removal efficiency. The removal efficiency reaches a maximum value, when the reactor is operated at a constant OLR for 2-3 days.

It is evident from the Fig. 7 that the COD removal was maximum (92%) for an OLR up to 83.7 kg m^{-3} day^{-1} which indicates that the ATFBR is highly effective. This was in general agreement with investigations of Chen *et al.* (1988) and Saravanane *et al.* (2001) on continuous fluidized bed reactor fed with corn starch wastewater and Sreekrishnan *et al.* (1991) synthetic glucose as substrates respectively. Saravanane *et al.* (2001) have reported an efficiency of 82-85% of COD removal for the same treatment of synthetic Sago wastewater using a columnar AFBR for an OLR upto 52.8 kg m^{-3} day^{-1}. The ATFBR can give a higher efficiency of minimum 5-7% more than the columnar FBR and the operating OLR can be significantly increased upto 83.7 kg m^{-3} day^{-1}. When the OLR was increased beyond 83.7 kg m^{-3} day^{-1}, the COD removal efficiency drops from 92%. All the biomass in the anaerobic reactor is retained in biofilms grown on the fluidized particles; the possibility of biomass wash-out at higher hydraulic and/or organic loadings is dramatically reduced due to the tapering effect in the column.

Methane production is a direct result of COD reduction within the methanogenic system i.e., it is a.function of the biodegradable TCOD concentration in the effluent of the reactor (Rincon *et al.*, 2006). The biogas production increased gradually during the start up period as evident from Fig. 8. The production of biogas after the start up period for an OLR of 1 kg m^{-3} day^{-1} was found to be 0.3125 m^3 m^{-3} of reactor day^{-1}. The gas production increases as the OLR is increased, reaching a maximum 25.36 m^3 m^{-3} reactor day^{-1} at an OLR of 83.7 kg COD m^{-3} day^{-1}. Beyond this loading, the gas production decreased with increase in OLR. Bio gas generation was found to be in the range of 0.330 to 0.345 L g COD removal^{-1}. Theoretically, 0.35 L of methane is produced per gram of COD removed, when the starting compound is glucose (Lawrence and McCarty, 1969)

The results are significant, especially in the context of wastewater treatment in tropical developing countries, where reactor design with low HRT and high OLR would be a technologically viable and economically affordable option. Further the nitrogen enriched digested sludge was recommended as manure for agriculture use.

SEM gives detailed images of the support surface and the biofilm. In Fig. 9a the microphoto shows the surface aspect of the carbon. The exo-polysaccharide producing bacteria is immobilized in the pores of mesopores activated carbon. Some of the areas have not been immobilized. In this photo the great superficial porosity that confers it a high specific surface, of this substratum is visible. The Fig. 9b shows the different degree of colonization of the bioparticles. Microphotos show images of the diverse morphotypes found in the surface of the colonized support, with the predominant

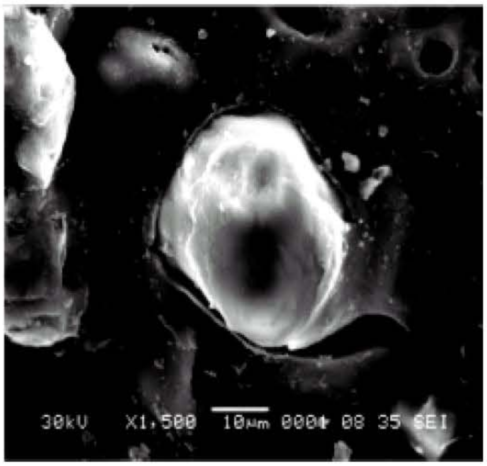

Fig. 9a: SEM microphotographs showing: the mesoporous and macroporous of the activated carbon

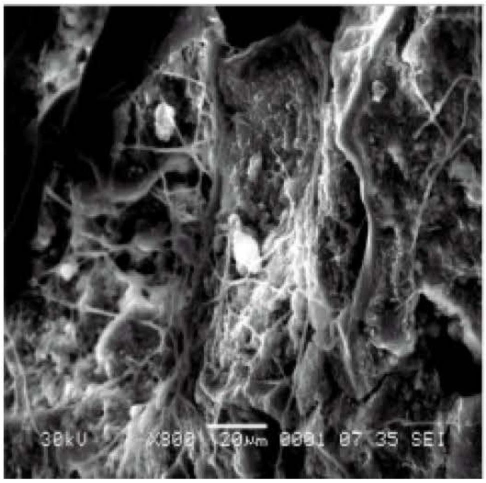

Fig. 9b: SEM microphotographs showing the accumulation of microorganisms inside the crevices of the activated carbon

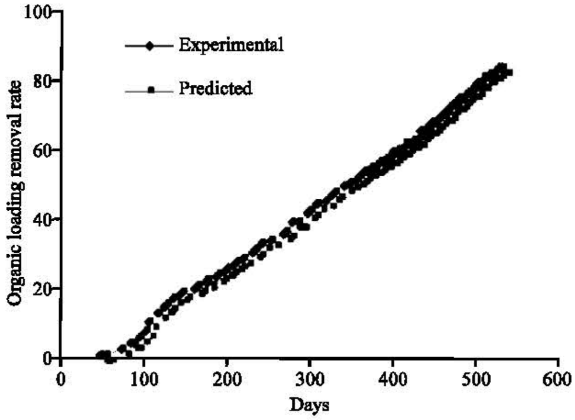

Fig. 10a: Validation of the untrained data for the organic loading removal rate output (experimental and predicted)

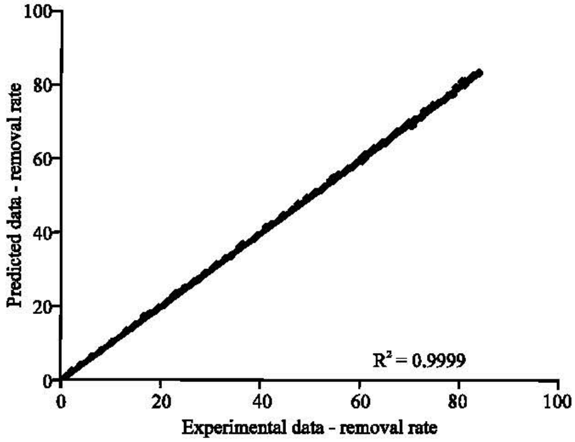

Fig. 10b: Validation of the untrained data for the organic loading removal rate output in terms of correlation coefficient

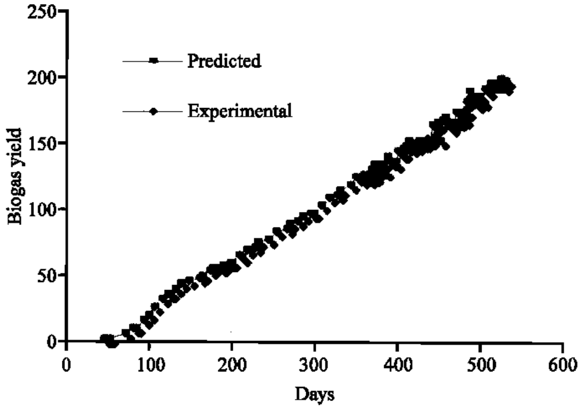

Fig. 11a: Validation of the untrained data for the output, biogas yield (experimental and predicted)

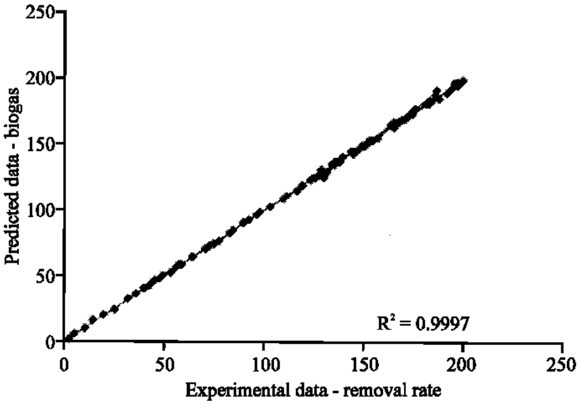

Fig. 11b: Validation of the untrained data for the biogas yield output in terms of correlation coefficient

presence of filamentous methanogenic forms, closely resembling to Methanosaeta (Methanotrix), rod-like morphologies, that could correspond to Methanobacterium and Methanobrevibacter (Koorneef *et al.*, 1990; Mussati *et al.*, 2005) and small coccoid bacterias. The abundant presence of extracellular material is observed in micrograph.

A new model using ANN with RBF has been developed using the 70% of the measured experimental values. It is validated for the output using the remaining 30% of the untrained data in the ANN. The error is very less for the untrained data. The Fig. 10 and 11 shows the difference of error between the experimental and simulated values. The Mean square error was found to be 0.026 for organic loading removal rate and 0.99 for biogas. The correlation coefficient was found to the 0.9999 for organic loading removal rate and 0.9997 for biogas which validates the proposed model.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the management of Sri Venkateswara College of Engineering for providing the necessary infrastructure facilities to carry out this research.

NOMENCLATURE

AFBR	:	Anaerobic fluidized bed reactor
ANN	:	Artificial neural network
ATFBR	:	Anaerobic Tapered fluidized bed reactor
BOD	:	Biological oxygen demand
COD	:	Chemical oxygen demand
GAC	:	Granular activated carbon
HRT	:	Hydraulic Retention time
MSE	:	Mean Square Error
OLR	:	Organic loading rate
RBF	:	Radial basis function
TCOD	:	Total chemical oxygen demand
UASB	:	Upflow Anaerobic Sludge Blanket Reactor
U_{mf}	:	Minimum fluidization velocity.

REFERENCES

Anderson, G.K., I. Ozturk and C.B. Saw, 1990. Pilot-scale experiences on anaerobic fluidized bed treatment of brewery wasters. Water Sci. Technol., 22: 157-166.

APHA, AWWA, WEF, 2005. Standard Methods for the examination of water and wastewater. 21st Edn., American Public Health Association, Washington DC.

Barascud, M.C., 1992. COD removal in a closed water circuit of a paper mill by an anaerobic fluidized bed reactor. Water Sci. Technol., 26: 445-454.

Bhat, N. and T.J. McAvoy, 1990. Use of neural nets for dynamic modeling and control of chemical process systems. Comput. Chem. Eng., 14: 573-580.

Boening, H. and V.F. Larsen, 1982. Anaerobic fluidized whey treatment. Biotechnol. Bioeng., 24: 2539-2556.

Bose, N.K. and P. Liang, 1998. Neural Network Fundamentals with Graphs, Algorithms and Applications. Tata McGraw-Hill Publishing Company Limited, New Delhi.

Boskovic, J.D. and K.S. Narendra, 1995. Comparison of linear, nonlinear and neural network based adaptive controllers for a class of batch-fed fermentation processes. Automatica, 31: 817-840.

Breitenbucher, K., M. Siegel, A. Knupfer and M. Radke, 1990. Open-pore sintered glass as a high-efficiency support medium in bioreactors: New results and long term experiences achieved in high-rate anaerobic digestion. Water Sci. Technol., 22: 25-32.

Chen, S.J., C.T. Li and W.K. Shieh, 1988. Anaerobic fluidized bed treatment of an industrial wastewater. J. Water Pollut. Cont. Fed., 60: 1826-1832.

Chitra, S.P., 1994. Use neural networks for problems solving. Chem. Eng. Prog., pp: 44-54.

Converti, A., D.M. Borghi and G. Ferraiolo, 1993. Influence of organic loading rate on the anaerobic treatment of high strength semisynthetic wastewater in a biological fluidized bed. Chem. Eng. J., 52: B21-B28.

Costello, D.J., P.F. Greenfield and P.L. Lee, 1991. Dynamic modeling of a single-stage high-rate anaerobic reactor. 1. Model derivation. Water Res., 25: 847-858.

Denac, M. and J.J. Dunn, 1988. Packed and fluidized bed biofilm reactor performance for anaerobic waste water treatment. Biotechnol. Bioeng., 32: 159-173.

Fox, P., M.T. Suidan and J.T. Bandy, 1990. A comparison of media types in acetate fed expanded-bed anaerobic reactors. Water Res., 24: 827-835.

Fu, L., 1994. Neural Networks and Computer Intelligence. McGraw Hill Inc., Singapore.

Hanaki, K., T. Saito and T. Matsuo, 1997. Anaerobic treatment utilizing the function of activated carbon. Water Sci. Techol., 35: 193-201.

Hickey, R.F., W.M. Wu, M.C. Veiga and R. Jones, 1991. Start-up, operation, monitoring and control of high rate anaerobic treatment systems. Water Sci. Technol., 24: 207-255.

Hien, P.G. *et al*., 1999. Closed wastewater system in the tapioca industry in Vietnam. Water Sci. Technol., 39: 89-96.

Hsu, Y. and W.K. Shieh, 1993. Start-up of anaerobic fluidized bed reactors with acetic acid as the substrate. Biotechnol. Bioeng., 41: 347-353.

Iza, J., 1991. Fluidized bed bioreactors for anaerobic wastewater treatment. Water Sci. Technol., 24: 109-132.

Khageshan, P. and V.S. Govindan, 1995. Anaerobic filter for treatment of Sago wastewater. 4th National Symposium on Environment, Chennai, India, Proceedings, pp: 248-252.

Koorneef, E., A.J.L. Macario, J.T.C. Grotenhuis and E.C. Demacario, 1990. Methanogens revealed immunologically in granules from five Upflow Anaerobic Sludge Blanket (UASB) bioreactors grown on different substrates. FEMS Microbiol. Ecol., 73: 225-230.

Kumar, A. and K. Roy, 2004. Artificial neural network-based prediction of bed expansion ratio in gas-solid fluidized beds with disk and blade promoters. J. Inst. Eng. (India), 85: 12-16.

Lawrence, A.W. and P.L. McCarty, 1969. Kinetics of methane fermentation in anaerobic treatment. J. Water Pollut. Cont. Fed., 41: Rl-R16.

Mai, H.N.P. *et al*., 2004. UASB treatment of tapioca processing wastewater in South Vietnam. In the Proceedings of the 10th World Congress-Anaerobic Digestion 2004, the International Conference, Canada, 4: 2420-2424

Matsumoto, A. and T. Noike, 1991. Effects of substrate composition and loading rate on methanogenic process in anaerobic fluidized bed systems. Water Sci. Technol., 23: 1311-1317.

Murthy, Y.S. and M.D. Patel, 1961. Treatment and disposal of Sago wastes. Report Submitted to the Central Public Health Engineering Research, Institute. India

Mussati, M., C. Thompson, M. Fuentes. P. Aquirre and N. Scenna, 2005. Characteristics of a methanogenic biofilm on sand particles in a fluidized bed reactor. Latin Am. Applied Res., 35: 265-272.

Najibi, H., A. Chapoy and B. Tohidi, 2007. Methane/natural gas storage and delivered capacity for activated carbons in dry and wet conditions. Fuel doi:10.1016/j.fuel.2007.03.044

Oanh, L.T.K. *et al*., 2001. Removing suspended solids from tapioca processing wastewater in upflow anaerobic filter. International Conference: Industry and Environment in Vietnam.

Parthiban, R., P.V.R. Iyer and G. Sekaran, 2007. ANFIS modeling for an anaerobic tapered fluidized bed reactor for industrial waste water treatment. J. Syst. Sci. Eng., 16 (In Press).

Perez, M., L.I. Romero and D. Sales, 1977. Steady state anaerobic thermophilic degradation of distillery wastewater in fluidized bed bioreactors. Biotechnol. Prog., 13: 33-38.

Perez, M., L.I. Romero and D. Sales, 1999. Anaerobic thermophilic fluidized bed treatment of industrial Wastewater: Effect of F:M relationship. Chemosphere, 38: 3443-3461.

Pescod, M.B. and N.C. Thanh, 1977. Treatment alternatives for wastewaters from the tapioca starch industry. Water Sci. Techol., 9: 63-574.

Rajesh Banu, J., S. Kaliappan and D. Beck, 2006. High rate anaerobic treatment of Sago wastewater using HUASB with PUF as carrier. Int. J. Environ. Sci. Technol., 3: 69-77.

Rincon, B., F. Raposo, J.R. Dominguez, F. Millan, A.M. Jimenez, A. Martin and R. Borja, 2006. Kinetic models of an anaerobic bioreactor for restoring wastewater generated by industrial chickpea protein production. Int. Biodeter. Biodegr., 57: 114-120.

Saravanane, R., D.V.S. Murthy and K. Krishnaiah, 2001. Anaerobic treatment and biogas recovery for Sago wastewater management using a fluidized bed reactor. Water Sci. Technol., 44: 141-147.

Saroja, K. and C.A. Sastry, 1972. Report on treatment of Sago wastes. National Environ. Eng. Res. Inst., India.

Sastry, C.A. and G.J. Mohan, 1963. Anaerobic digestion of industrial wastes. Indian J. Environ. Health, 5: 20-25.

Sastry, C.A., R. Murahari and K. Saroja, 1964. Studies on the treatment of Sago mill wastewater. In the Proceedings of the Seminar on Environ. Poll. Kerala, India, pp: 175-185.

Scott, C.D. and C.W. Hancher, 1976. Use of a tapered fluidized bed as a continuous bioreactor. Biotechnol. Bioeng., 18: 1393-1403.

Seckler, M.M., M.L.J. Van Leeuwen, S.L. Bruinsma and G.M. Van Rosmalen, 1996. Phospate removal in a fluidized bed. Process Optimiz. Water Res., 30: 1589-1596.

Singh, B.B. and B. Mohanty, 2002. Non-linear Constrained Optimization using Combine Approach of Neural Network-based Modelling and SQP Optimizer. J. Inst. Eng. (India), 82: 46-50.

Sreekrishnan, T.R., K.B. Ramachandran and P. Ghosh, 1991. Effect of operating variables on biofilm formation and performance of an anaerobic fluidized bed reactor. Biotechnol. Bioeng., 37: 557-566.

Suidan, M.T., J.R.V. Flora, T.K. Boyer, A.M. Wuellner and B. Narayanan, 1996. Anaerobic dechlorination using a fluidized-bed GAC reactor. Water Res., 30: 160-170.

Tongkasane, C., 1970. Anaerobic treatment of tapioca starch Wastewater. Water Waste Treat., 13: 392-398.

Wasserman, P.D., 1989. Neural Computing: Theory and Practice. Van Nostrand Reinhold, New York.

Wu, C.S. and J.S. Huang, 1995. Performance enhancement with tapered anaerobic fluidized-bed bioreactors. J. Chem. Technol. Biotechnol., 63: 353-360.

Wu, C.S. and J.S. Huang, 1996. Bioparticle characteristics of tapered anaerobic fluidized-bed bioreactors. Water Res., 30: 233-241.