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Performance evaluation of upflow anaerobic sludge blanket reactor process for dairy wastewater treatment

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Abstract

Investigation on dairy wastewater treatment was undertaken at ambient temperature in 11 l effective volume of laboratory – scale upflow anaerobic sludge blanket reactor receiving an average influent chemical oxygen demand of 2100 mg l^{-1} for 3 months of 24 hours, hydraulic retention time. The feeds of the synthetic dairy wastewater operated with HRT of 12 hrs, 16 hrs, 20 hrs and 24 hrs was equivalent to organic loading rates of 1.20 kg COD m^{-3} d - 7.20 kg COD m^{-3} d, 0.9 kg COD m^{-3} d - 5.40 kg COD m^{-3} d, 0.72 kg COD m^{-3} d - 4.32 kg COD m^{-3} d and 0.60 kg COD m^{-3} d - 3.60 kg COD m^{-3} d respectively. After steady state condition was reached, which took about 2 months, the effluent quality parameter were sampled and analysed to quantify treatment efficiencies. The following removal efficiency observed were 73 - 94.33% COD; 50.04 - 56.66% total solids; 45.55 - 70.63% total dissolved solids; 66 - 86.67% total nitrogen and 72 - 94% total phosphorous. Maximum biogas production rate was 383 l kg^{-1} COD removed with 260 l of methane gas. Estimation of biogas production was analysed using artificial neural network software model, and the results predicted coincided well with the experimental results.

Key words

Biogas, Chemical oxygen demand, Dairy wastewater, Hydraulic retention time, Organic loading rate

Introduction

India is the largest producer of milk and dairy products in the world with growth more than 15% and poised to cross 150 million tonnes per annum (Kothapalli and Vengalapati, 2010). Most of the dairy plants in the country do not have proper wastewater and nutrient removal system, particularly small-scale dairy plants. Wastewater is a significant problem for dairy plant operation since large quantity of water is used for product addition and utensil cleaning. In the processing of milk in India 6 liters of water are used per liter of milk processed (Saseetharan and Jeyanti, 2007). In India, milk production is about 150 million tonnes per annum throughout. Thus, some 900 million tonnes of water is used annually from Indian dairy plants subsequently, approximately 80% of used water is discharged as wastewater, which contain large amount of nutrients and milk constituents such as caseins, lactose, fat and others. All these contribute towards high concentration of biochemical oxygen demand (BOD) and nutrients in dairy wastewater. Dairy wastewater is due to the usage of nitric acid and phosphoric acid in cleaning of utensil. Most of dairy plants in India, particularly small - scale ones, discharge wastewater directly into nearby areas such as waste land or natural receiving water body. The discharged volume of wastewater depends on the size of plant and their activities.

Hence, an attempt to improve and clarify some of the uncertain queries would be worthwhile research exercise in the field of wastewater treatment. Especially, enhanced biological phosphorous removal can be cost effective than chemical precipitation strategies (Reardon, 1994). Therefore, it is important for dairy industry to evaluate enhanced biological phosphorous removal, combined with nitrification and denitrification to remove nitrogen, as treatment option for nutrient removal. Rodriguez - Matinez *et al.* (2002) reported 88.8% of removal efficiency UASB treating slaughterhouse wastewater. Removal efficiency for phosphate, total suspended solids, nitrogen and nitrates were 39, 90.3, 71.8 and 78.1 %, respectively

In view of the above, in the present study performance of Upflow Anaerobic Sludge Blanket (UASB) reactor for treatment of dairy wastewater under different organic loading rates (OLRs) at hydraulic retention time (HRT) of 12 hr to 24 hr was investigated. The HRT, OLR and feed concentration (FC) of UASB treating dairy wastewater can be used as model input. The developed model, by using Artificial Neural Network (ANN) could be used further design pilot scale or actual plant design for predicting biogas formation. The new approach involves modeling of UASB using ANN because now-a-days everything seems to be customized. Because, tailor-made products are mostly in demand and are available very easily. Automated output is our choice. The pattern of thinking and the horizons of thinking have gone tremendous change. In a nutshell, sophistication has swept our life-style. All this has become possible due to the emergence of customized application software in various fields. Sinha *et al.* (2002) used neural network for simulation of upflow anaerobic sludge blanket (UASB) reactor performance treating high strength (unrefined sugar based) wastewater.

Materials and Methods

Laboratory bench scale experiments were carried out in 11 l UASB reactor used for this investigation. Sewage sludge from sludge digestion tank was used as seeding material for this investigation and the same was obtained from the municipal sewage treatment works, Karaikudi, Tamil Nadu, India. Raw dairy wastewater for investigation was collected from Avin Milk Thiruchirappalli district co - operative milk producers union Ltd., Pudukkottai road, Kottappattu, Thiruchirappalli-620 023, Tamil Nadu State, India. Laboratory analysis were carried out for chemical oxygen demand (COD), pH, temperature, total solids (TS), dissolved solids (DS), suspended solids (SS), volatile solids (VS), volatile suspended solids (VSS), volatile fatty acids (VFA), total nitrogen (TN) and total phosphorous (TP) for both influent and effluent. The startup of experiment was performed continuously by running the UASB reactor at 35 ºC. The feed solution was fed into the reactor seeded with 5 l of previously sieved sewage sludge. The direction of flow was up through the reactor vessel and into GLS separator. The feed flow rate was maintained as 0.46 l h^{-1} and the organic loading rate (OLR) ranged between 0.6 - 3.6 kg COD m^{-3}-d with hydraulic retention time of 24 hrs was maintained till pseudo steady state was reached. The steady state was assumed to reach when COD of the effluent and biogas production remained the same for three consecutive days. The characteristics of dairy wastewater and sludge seed is shown in Table 1.

Synthetic milk wastewater, equivalent to the characteristics and composition of mixed effluent from different processing units of dairy wastewater characteristics, was prepared in laboratory using Nestle Everyday milk powder. The composition of 100g milk powder, as mentioned by the manufacturer, has 17.4 g protein, 53.1 g carbohydrates, 22.6 g sugar and 18 g fat as approximate values. Thus, Synthetic wastewater was fed into the reactor as a substrate to grow biomass in the reactor. Synthetic milk wastewater of different organic loading was prepared using different weight of milk powder. Furthermore, the actual COD, TN, TP values were verified each time before initiation of every experimental work. The feed of synthetic dairy wastewater were operated with HRTs of 12 hrs, 16 hrs, 20 hrs and 24 hrs equivalent to OLRs of 1.20 kg COD m^{-3} d - 7.20 kg COD m^{-3} d, 0.9 kg COD m^{-3} d - 5.40 kg COD m^{-3} d, 0.72 kg COD m^{-3} d - 4.32 kg COD m^{-3} d and 0.60 kg COD m^{-3} d - 3.60 kg COD m^{-3} d respectively in continuous mode of influent in the UASB reactor. In total 10 samples were taken for each HRT. Gas production is one of the key parameters indicating performance of the reactor. An anaerobic digestion treats wastes by converting all organic material into carbon dioxide and methane gas. The biological transformation by which organic matter is degraded to methane and carbon dioxide is commonly called methanogenesis. The main product of methanogenesis was mixture of carbon di oxide and methane usually called as biogas. Biogas evolved during the process was collected through biogas capturing ports available at the top of the reactor. This was measured using gas-liquid displacement method. In order to know the percentage of methane and biogas production, the same was collected and analysed using Gas Chromatograph. Microbiological study was performed using Scanning Electron Microscope available in the laboratory (Model no: S 3000 N).

Table 1 : Characteristics of dairy wastewater and sludge seed

Parameters	Raw dairy waste water range	Sludge seed range
pH	6.8 - 7.4	6.9 - 7.3
COD (mg l^{-1})	2850 - 3550	35000 - 42000
Temperature (ºC)	28 - 32ºC	-
Total solids (mg l^{-1})	1900 - 3100	42000 - 48000
Dissolved solids (mg l^{-1})	400 - 550	6000 - 8000
Suspended solids (mg l^{-1})	1500 - 2550	36000 - 40000
Volatile solids mg l^{-1})	1200 - 2100	-
Volatile suspended solids (mg l^{-1})	400 - 1500	25000 - 28000
Total nitrogen (mg l^{-1})	150 - 170	-
Total phosphorus (mg l^{-1})	30 - 34	-

Start–up regime for the reactor : The reactor was fed with solution of raw dairy wastewater and Nestle Everyday milk powder dissolved (50% each) in tap water as a substrate to grow biomass in the reactor. In the present study, micronutrients like nitrogen and phosphorous were not added because sufficient nutrients was available in the substrate itself to maintain the ratio of COD: N: P (300:5:1) which was suggested by Berg *et al.* (1980). Schematic diagram of UASB experimental set up is shown in Fig. 1.

Problem formulation of artificial neural network model : For constructing a neural network model, UASB reactor is looked upon as a system that, under the influence of varying sets of inputs, will respond by producing different sets of outputs. Such a model presupposes no prior knowledge about the structure of relationship that exists between input and output variables of the system. Neural networks comprise of number of interconnected entities, similar in many ways to biological neurons. The choice of the architecture of the network depends on the task to be performed. For modeling of physical systems, a feed-forward layered network is normally used Wasserman (1989). It consists of a layer of input neurons, a layer of output neurons, and one or more hidden layers. The number of neurons in the input layers is three .The two hidden layers consist of neurons each. A neural network as defined above was trained such that application of a set of inputs produces the desired set of outputs. For modeling the UASB reactor, the input vector consisted of a set of three variables, Hydraulic Retention Time (HRT), Organic Loading Rate (OLR), and Feed Concentration (FC), whereas the output could be the reactor variable of bio gas production. Training was accomplished by sequentially applying input vectors, while adjusting network weights according to a predetermined procedure Zurada (1992). During training the network weights converge to values such that each input vector produces the desired output. The most versatile learning algorithm for the feed forward layered network described above is back propagation. This method back propagates the output errors to the network by appropriately modifying the weight matrices. The trained network was subsequently tested with independent sets of data, and then used for UASB reactor simulation studies because neural network solutions should be kept as simple as possible. A computer program incorporating the salient features described above was written in 'C' language for this purpose.

Results and Discussion

Chemical oxygen demand removal for 12 hr to 24 hr HRT ranged from 78.40 to 94.33%. The COD removal efficiency of 20 hr HRT was slightly higher than 24 hr HRT, and slightly decreased at 16 hr HRT. It was observed that COD removal clearly dropped at 12 hr HRT as illustrated in Fig. 3. Comparing the result of the present work with Rajeswari *et al.* (2000), a treatment efficiency of 90% was achieved with maximum OLR of 6.5 kg COD m^{-3} d for treatment of dairy wastewater with COD of 2.05 g l^{-1}, using 10.7 m^3 UASB reactor. The removal efficiency of COD, as mentioned above, was different from the present investigation. In addition, results showed that variation of HRT (16 hr to 24 hr) had little effect on COD removal efficiency. This was consistent with previous the results recorded by Fang *et al.* (2000) on the effect of HRT on mesophilic acidogenesis of dairy wastewater. Apostolos Vlyssides *et al.* (2012) used UASB reactor for treating cheese dairy wastewater. The anaerobic digester performance was considered satisfactory, since COD reduction was greater than 90%. The concentration of VFA for 12 hr to 24 hr HRT was 332 mg l^{-1},336 mg l^{-1},330 mg l^{-1} and 329 mg l^{-1}, respectively.

Total nitrogen removal at 12 hr to 24 hr HRT ranged from 74 to 86.67%. Maximum removal of TN was achieved at 20 hr HRT. Total nitrogen removal efficiency of 20 hr HRT was slightly higher than 24 hr HRT, and slightly decreased at 16 hr HRT. It was observed that total nitrogen removal clearly dropped at 12 hr HRT. This result indicated that HRT did not affect the removal efficiency of total nitrogen from HRT of 16 hr to 24 hr. Arrojo *et al.* (2004) treated of dairy wastewater using SBR with total nitrogen of 50-200 mg l^{-1}, operating NLR of 0.7 gN l^{-1} d, obtained removal efficiency of 80%.

Total phosphorous removal at 12 hr to 24 hr HRT ranged from 88 to 94 %. It was clearly observed that maximum total phosphorous removal obtained (greater than 80.00%) was 0.0072 g P m^{-3} d and maximum removal was achieved at 20 hr HRT. Total phosphorous removal efficiency of 20 hr HRT was slightly higher than 24 hr HRT, and removal efficiency slightly decreased at 16 hr HRT. It was observed that total phosphorous removal was lower at 12 hr HRT. Kundu *et al.* (2013) investigated the treatment of slaughterhouse wastewater using SBR with TP of 144 mg l^{-1}, with removal efficiency of 97.30%. The removal efficiency of COD, TN and TP at various HRTs' during treatment phase is shown in Fig. 2a.

The COD removal efficiency decreased slightly with an increase in OLR from 2.88 to 3.60 kg COD m^{-3} d with 94.33 to 92.98%, whereas removal efficiency of COD at OLR of 4.32 kg COD m^{-3} d sharply decreased to 92% as shown in Fig. 3a. In a similar investigation reported by Rajeswari *et al.* (2000), COD reduction of 90% dropped to 70 - 80% with increase in OLR from 6.5 kg COD m^{-}_{3} d to 45 kg COD m^{-3} day for treatment of dairy wastewater with COD of 2.05 g l^{-3}, using 10.7 m^3 UASB reactor. Can increasing the influent COD concentration from 37 g l^{-1} or equivalent to OLR of 6.2 g COD l^{-1} d to 42 g l^{-1} or 7.5 g COD l^{-1} d of OLR, low efficiency of COD removal was noted. Thenmozhi and Uma (2012) conducted treatability studies of dairy wastewater by upflow anaerobic sludge blanket reactor. The UASB reactor was fabricated using plexi glass pipe of 100 mm diameter and 61 cm height having an effective volume of 4.32 l. The reactor study showed about 78% COD removal, when influent COD rate was 2.5 g l^{-1} day^{-1}. Thus, the removal efficiency of COD, observed by various researchers as mentioned above, were different from the present investigation. A common problem encountered with cheese, whey or dairy wastewater is that when the substrate loading is increased, the acidogenic region extends into the methanogenic resulting poor efficiency in methanogenic phase of acidified wastewater due to failure of the reactor. This indicates that COD removal is related to OLR. The removal efficiency of COD at various OLRs during treatment phase of 20 hr HRT was shown in Fig. 3a.

Maximum removal efficiency was achieved at 24 hr HRT. This result indicates that increased upflow velocity or shorter HRT caused solid loss from the reactor or decreased removal efficiency. Regarding suspended solids, the proportion of maximum suspended solids to total solids removal was 43.76 -

56.66 % and minimum suspended solids to total solids removal was 13.61 - 22.56 %, respectively. The portion of volatile suspended solids removal was 22.99 - 49.77 %. Gotmare *et al.* (2011) treated dairy wastewater using UASB reactor and reported 56.54% total suspended solids removal and this efficiency was not much different from the present investigation. It was observed that dairy wastewater mainly composed of dissolved organic matter. Since, the proportion of dissolved solids was high (65.84 %), the results obtained from this study indicated that removal efficiency of solid for 16 hr, 20 hr and 24 hr HRT was not significantly different, and dropped at 12 hr HRT. Solids discharged in terms of total solids, volatile suspended solids and total dissolved solids were affected by OLR and HRT variation. Initially, the washout of sludge was higher due to poor settleability of seed sludge. During the end of the operation, sludge remained in the reactor stratified with the larger ones settling down in the lower part of reactor and the smaller ones expanded or suspended in the upper part of sludge - bed due to increased upflow velocity. The removal efficiency of total solids at various HRT during treatment phase is shown in Fig. 2b.

The volumetric biogas production rate increased linearly with COD loading rate, until it reached maximum (9.6 l d^{-1}) at OLR of 4.32 kg COD m^{-3} d. Increased upflow velocity was not only caused due to increase biogas formation but also due to increase of suspending of smaller size of sludge to the upper part. This result is in Ramasamy and Abbasi (2000). Regarding biogas composition, that of methane ranged from 60 - 80% with average value of 68%. As mentioned above, 383 l of biogas was generated from 1kg COD resulting in production 260 l of methane from that amount of COD utilized. This value was slightly inferior to the stoichiometric theoretical of 0.35 m^3CH_4 kg^{-1} COD, and similar to the result investigated by Perez *et al.*(2001), Yan and Tay (1996) also showed similar methane production of 300 l CH_4 kg^{-1} COD removal, based on the continuous operation using UASB reactor treating brewery wastewater. Rajeshwari *et al.* (2000) reported methane composition pH for treatment of cheese whey wastewater by anaerobic degradation ranged from 70.8 to 71%. Buntner *et al.* (2013) treated of dairy wastewater using combined UASB and MBR systems with OLR of 4.85 kg COD m^{-3} day, obtaining 73% of methane. Biogas and methane production rate at various OLRs during treatment phase of 20 hr HRT is shown in Fig. 3b.

Treated effluent from each OLR were subjected to microbiological investigation. Sludge samples were taken from, the reactor and examined in Scanning Electron Microscope. The surface of the microbial granules is clearly shown in the image. The active methanosaeta - like bacteria were fully dominant and covered the reactor. OLR and feed type influence the mathanogen population in the reactor. OLR in the ranges of 0.72 - 2.16 kg COD m^{-}_{3} d, the microbial population fluctuated for each OLR. SEM images of suspended biomass, acquired from UASB reactor, showed image of predominantly fusiform (spindle shape) bacterial groups along with few number of bacilli (rod shape). Approximate, length varied from 15–50 µm with occasional

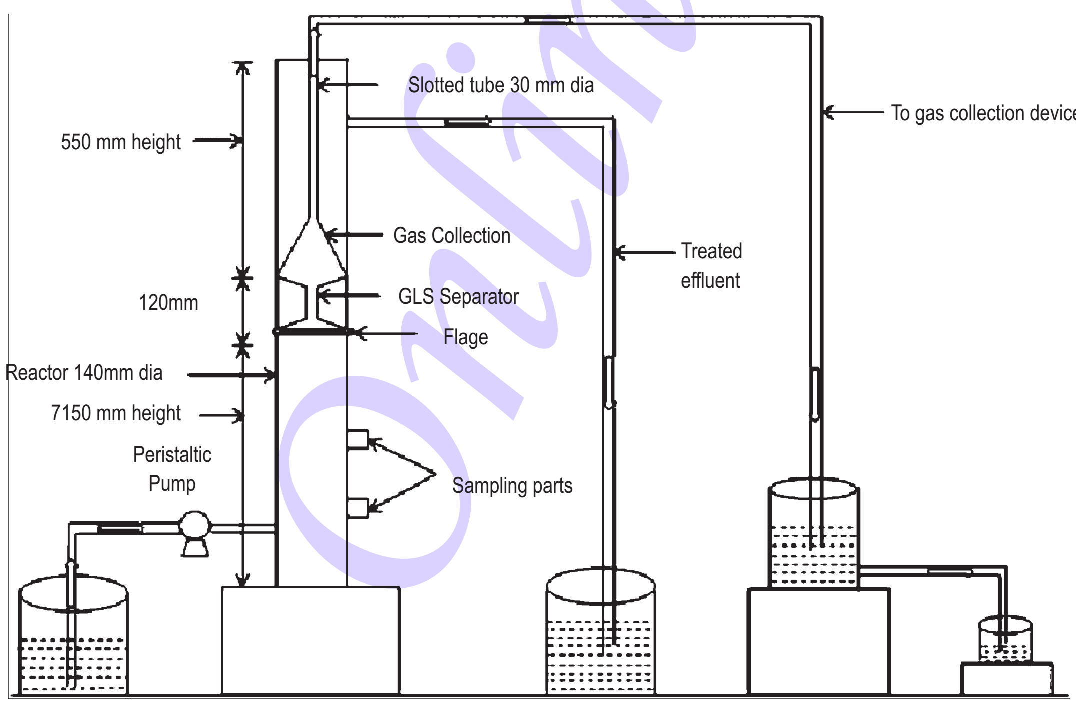

Fig. 1 : Schematic diagram of upflow anaerobic sludge blanket experimental setup used in the study

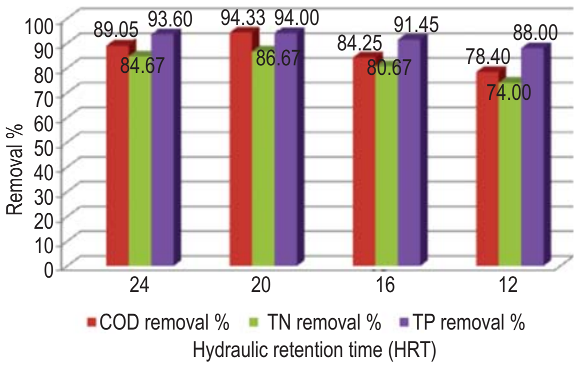

Fig. 2 (a) : Removal efficiency of chemical oxygen demand, total nitrogen and total phosphorous during treatment phase

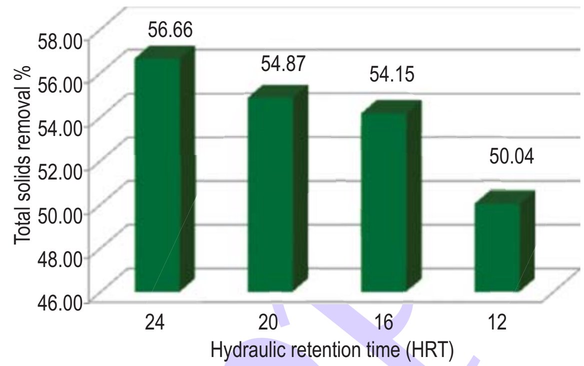

Fig. 2 (b) : Removal efficiency of total solid at various HRT during treatment phase

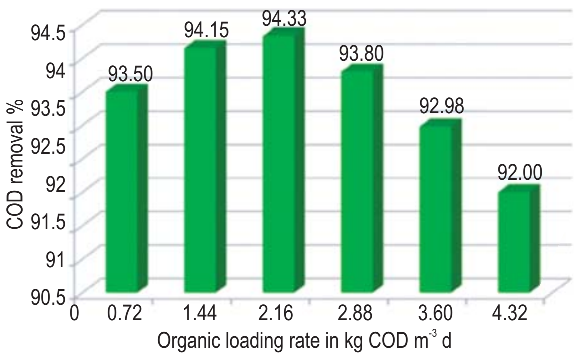

Fig. 3 (a) : Removal efficiency of chemical oxygen demand at various organic loading rates during treatment phase of 20 hr HRT

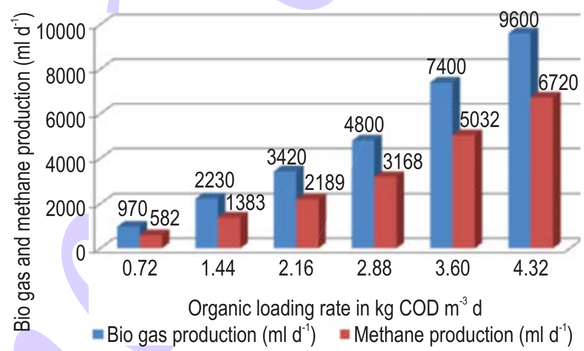

Fig. 3 (b) : Bio gas and methane production rate at various organic loading rates during treatment phase of 20 hr hydraulic retention time

Table 2 : Data generated from observation during the Hydraulic Retention Time of 12- h used for validation of developed Artificial Neural Network (ANN) model

Observation during the HRT of 12 hr	
Estimated biogas production (ml d^{-1})	**Actual biogas production (ml d^{-1})**
2430.624	2500
2744.256	2750
3051.072	3000
3330.144	3300
3571.776	3600
3783.264	3800
3991.2	4000
4697.472	4700
5462.784	5400
5957.184	6000
6632.64	6670

fluorescence and spore forming, rod shaped bacteria. Babu *et al.* (2006) reported *Bacillus, Pseudomonas, Micrococcus, Niesseria, Streptococcus* and *Lactobacillus* in dairy effluent.

Calibration of constructed UASB model performed for biogas production by ANN software, using obtained data generated from observation during HRT of 12 hr to 24 hr, indicated that ANN solutions were 0.25319, 0.28586, 0.31782, 0.34689, 0.37206, 0.39409, 0.41575, 0.48932, 0.56904, 0.62054 and 0.6909.

Sample taken from the observation during HRT of 12 hr was used for validation indicated that estimated values agreed with the monitoring values as shown in Table 2, with value of 0.999. Correlation value nearer to one indicated well working of UASB model.

Reactor produced optimal result HRT of 20 hrs and above it no improvement in efficiency was noted. The reactor was capable of treating dairy wastewater with high degree of consistency, even when the influent strength varied due to week flow variations, shock loads, etc. The estimation of biogas production using computer simulations of ANN software indicated that the estimated values agreed with the results obtained from laboratory using validation analysis

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