Simulation Model to Predict the Performance of UASB Reactor

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ABSTRACT---- ***This paper explored the applicability of multiple linear regression model to predict the performance of an Up-flow Anaerobic Sludge Blanket Reactor (UASBR) for treating effluents of sugar, sago and dairy. UASBR was run at continuous mode with different combinations of influent COD and influent flow rate. The flow rates were maintained at 4.8, 12.0, 14.4, 18.0 and 24.0 l/day corresponding to Hydraulic Retention Time (HRT) of 5.21, 2.08, 1.39 and 1.04 respectively. The resulted upward velocity varied from 0.0064 to 0.031 m/hr. The experiment was run for continuous observations for COD, Volatile Suspended Solids (VSS) and biogas generation. Data obtained on HRT, Volumetric Loading Rate (VLR), Organic Loading Rate (OLR) and VSS for treating sugar, sago and dairy effluents were used as independent parameters. Based on the data, regression equation was proposed for percentage removal efficiency of COD for each effluent. The proposed regression equations were proved to closely predict the performance of UASBR.***

Keywords--- Anaerobic, biogas, chemical oxygen demand, multi linear regression, UASB Reactor

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1. INTRODUCTION

An Up-flow Anaerobic Sludge Blanket Reactor (UASBR) is an exclusive suspended growth system that can retain more amount biomass (30-60 kg VSS/m^3) so that it can offer up to 80% reduction in COD even under high rates of organic loading [4]. Review on anaerobic–aerobic systems employed in the treatment of industrial and municipal wastewater and highlighted the merits of several bio-reactors [1]. There are four types of bio-reactors: integrated bioreactors with physical separation of anaerobic–aerobic zone, integrated bioreactors without physical separation of anaerobic–aerobic zone, anaerobic–aerobic Sequencing Batch Reactors (SBR), and combined anaerobic–aerobic culture system. Among these, the integrated bioreactor with stacked arrangement in treating high strength industrial wastewaters is beneficial due to minimal space requirements, low capital cost and excellent COD removal efficiencies in excess of 83%. While investigating the removal of Tetrachloro ethylene at 35^{o}C for over 200 days in UASB reactor, [9] have reported that 94% of total soluble COD removed is converted to methane and the removal efficiencies of 94% COS and 90% TCE are achieved at OLR of 160 mg TCE/l day. While investigating the anaerobic biological treatment of volatile fatty acids and sucrose based wastewaters, The COD removal efficiency of 95% and 80% at OLR of 20 kg COD/m^3.day for both volatile fatty acids and sucrose fed reactors respectively[3]. The possibility of using an up-flow anaerobic sludge blanket reactor (UASBR) followed by activated sludge system for the treatment of wastewater discharged from dairy factory was explored [10]. According to the authors, The UASB reactor is proved to be a competent technique for the treatment of effluent of dairy at an average wastewater temperature of 20^{o}C with HRT of 24 hours. The percentage removal efficiency of 69% of COD removal, 79% of BOD and 72% of TSS has been achieved.

An Artificial Neural Network (ANN) based regression model to evaluate the performance of wastewater treatment plant using MATLAB software [2]. A comparative study on Regression model and Artificial Neural Network model to predict the percentage volume of diamond deposition in Ni-diamond composition coating[8]. Regression model by means of fuzzy inference system to improve neural network for predicting hospital wastewater treatment plant effluent[6]. Regression model for anaerobic digestion of wastewater treatment by employing Multi layer perception neural network to predict the biogas yield and pH_{out}[7]. The independent variables considered are COD_{in}, hydraulic retention time and flow rate. The author has concluded that the proposed regression model using 2 layered feed forward neural network model yields excellent correlation with R value nearer to 1 for all training, testing and validation datasets.

The agro-based industries such as sago, sugar, dairy *etc*., require significant amount of water for their processing unit, facing serious problem in ensuring acceptable level of effluent treatment [5]. In this regard, the present work was undertaken to evaluate the performance of UASBR through a laboratory model having 25 litres of effective volume for treating effluents of sago, sugar and dairy to focus on treatment efficiency in terms of COD reduction, independently.

2. MATERIALS AND RESEARCH METHOD

2.1 Experimental Set-up

The experimental set-up of UASB reactor was made of acrylic material with a cylindrical portion with a height of 60 cm and a diameter of 20 cm and the top widened to accommodate a gas liquid solid separator as shown in Fig.1.

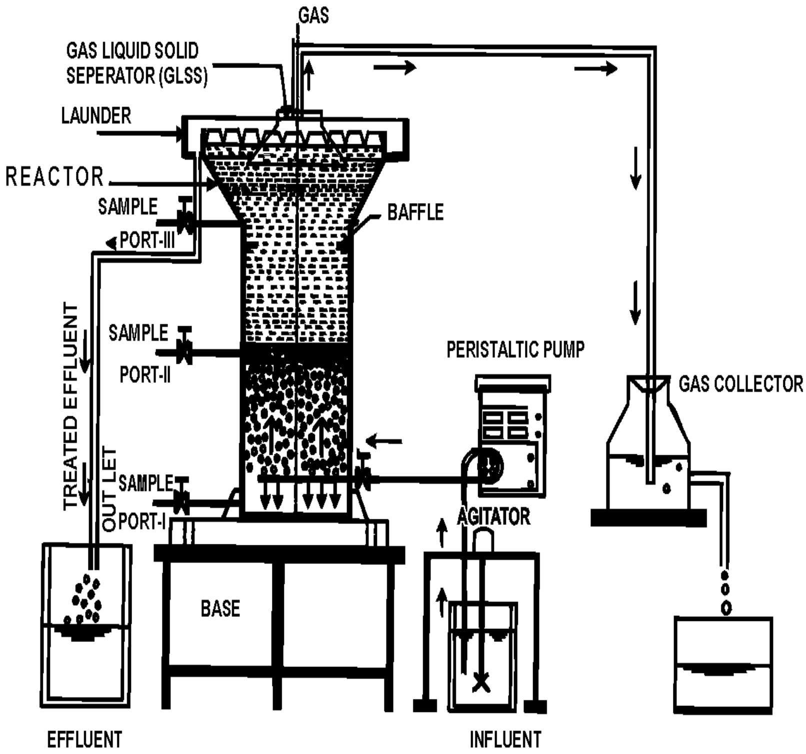

Fig.1 UASBR Experimental Set-up

The physical dimensions of the reactor model were assessed using empirical approach for an effective volume of 19 litres with an overall volume of 25litres. The reactor was fed from the influent tank by means of peristaltic pump. The influent to the reactor was at its bottom and the reactants moved from the bottom to the gas liquid solid separator at the top where the gas got separated and collected in a gas collector. The reactor was provided with sampling ports at zones viz, hydrolysis, acidogenesis and methanogenesis in the reactor. The influent tank was provided with an agitator to ensure proper mixing of the wastewater. The treated effluent from the top of the reactor was obtained by overflow through the launder provided at the top of the reactor.

2.2 Operating Parameters

The experiment was carried out on two major operating parameters: influent flow rate and influent COD. The dependent variables of the operating parameters were hydraulic retention time and organic loading rate. The observations were made on operating the model on continuous mode for influent COD, effluent COD, VSS in the sludge blanket and volume of gas collection. The operating conditions and observations were correlated and interpretations such as VLR, OLR and biogas generation were made to study the performance of the model.

3. REGRESSION MODELING

Regression analysis is a time tested method for relating given input parameters and resulting parameters by assuming a suitable form of relationship such as polynomial, logarithmic, exponential etc. The type of relationship assumed reflects the perceived form of relationship between the inputs and results.

The essence of regression is to evaluate the unknown coefficients in the regression equation. Regression having more than one independent variable, for which the solution is not so direct then it is called as multi-variate regression. But, proper formulation of the basic relationships would help to develop equations and solution procedures for multiple regression problems. The fundamental formulation for multivariate linear regression is as given below.

$$\sum_{i=1}^{K}\begin{bmatrix} 1 & x_{1i} & x_{2i} & x_{3i} & \cdots & x_{ni} \\ x_{1i} & x_{1i}^2 & x_{1i}x_{2i} & x_{1i}x_{3i} & \cdots & x_{1i}x_{ni} \\ x_{2i} & x_{2i}x_{1i} & x_{2i}^2 & x_{2i}x_{3i} & \cdots & x_{2i}x_{ni} \\ x_{3i} & x_{3i}x_{1i} & x_{3i}x_{2i} & x_{3i}^2 & \cdots & x_{3i}x_{ni} \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ x_{ni} & x_{ni}x_{1i} & x_{ni}x_{2i} & x_{ni}x_{3i} & \cdots & x_{ni}x_{ni} \end{bmatrix}\begin{Bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_n \end{Bmatrix} = \sum_{i=1}^{K}\begin{Bmatrix} P_i \\ P_1P_i \\ P_2P_i \\ P_3P_i \\ \vdots \\ P_nP_i \end{Bmatrix}$$

(Eq.1)

where, $a_0 \ldots a_n$ are the coefficients to be established, $x_{1 \ldots} x_n$ are the independent variables, P is the dependent variable for the set of i^{th} input data and K is the number data sets available for multivariate regression. The above equation can be solved by summing up the values of independent and dependent variables after carrying out the required operations.

The regression equations proposed in the present work provide an easy means of computing the performance characteristics with reasonable accuracy, where high computational power is not available. The proposed equations estimate the experimental percentage removal efficiency of COD for each effluent. Consequently, the use of the regression equations proposed in this study to predict the performance of an Up-flow Anaerobic Sludge Blanket Reactor in treatment of industrial effluent.

The performance of UASBR evolved as its capability of removing COD. The UASBR treatment process depended on OLR, VLR, HRT and VSS in the sludge blanket. The multivariate regression model is constructed using these parameters of process, influence with substrate (COD) removal efficiency with partial coefficients. The proposed regression equations projected with percentage removal efficiency of COD as dependent variable and OLR, VLR, HRT and VSS as independent variables. Both the dependent variable and independent variables of experimental data used for the multivariate regression analysis are presented in Table 1 and the proposed regression equations for various effluent streams are presented in Table 2.

Table 1. Data Used for the Regression Analysis

Sago Effluent					Sugar Effluent					Dairy Effluent				
OLR	**VLR**	**HRT**	**VSS**	**% Eff.**	**OLR**	**VLR**	**HRT**	**VSS**	**% Eff.**	**OLR**	**VLR**	**HRT**	**VSS**	**% Eff.**
0.02	0.3	5.21	43620	79.78	0.03	0.3	5.21	24600	76.03	0.03	0.31	5.21	2360	74.08
0.04	0.77	2.08	42920	78.47	0.07	0.76	2.08	23910	75.09	0.07	0.74	2.08	2270	73.79
0.05	0.91	1.74	41800	75.00	0.09	0.86	1.74	21430	74.83	0.09	0.91	1.74	2184	73.16
0.07	1.15	1.39	39240	73.06	0.13	1.08	1.39	19440	73.66	0.13	1.14	1.39	1930	72.77
0.09	1.48	1.04	38320	72.79	0.19	1.49	1.04	17800	70.29	0.19	1.44	1.04	1760	71.33
0.03	0.51	5.21	45560	79.45	0.04	0.48	5.21	26330	77.00	0.04	0.50	5.21	2631	76.51
0.06	1.28	2.08	44900	78.54	0.11	1.2	2.08	24500	76.08	0.12	1.30	2.08	2411	72.85
0.08	1.54	1.74	43960	75.77	0.14	1.38	1.74	23120	75.00	0.14	1.43	1.74	2263	72.00
0.11	1.87	1.39	40690	74.42	0.19	1.81	1.39	21300	73.23	0.20	1.87	1.39	2096	71.08
0.14	2.4	1.04	39820	73.20	0.26	2.32	1.04	20480	72.00	0.29	2.31	1.04	1813	70.16
0.03	0.7	5.21	49120	79.95	0.06	0.7	5.21	27350	80.58	0.06	0.71	5.21	2790	77.68
0.08	1.73	2.08	46700	77.77	0.14	1.63	2.08	26400	79.85	0.15	1.74	2.08	2640	74.97
0.1	2.04	1.74	45900	76.22	0.19	2.06	1.74	25220	79.17	0.18	2.06	1.74	2552	73.09
0.13	2.51	1.39	44100	72.27	0.23	2.37	1.39	23850	74.73	0.23	2.56	1.39	2461	70.28
0.17	3.26	1.04	42370	71.66	0.32	3.3	1.04	23110	73.50	0.34	3.27	1.04	2160	68.59
0.03	0.8	5.21	52910	77.11	0.06	0.77	5.21	28720	81.36	0.06	0.78	5.21	2820	77.43
0.09	1.89	2.08	49100	76.54	0.16	1.94	2.08	27460	79.91	0.17	1.99	2.08	2671	76.47
0.11	2.34	1.74	47540	75.73	0.2	2.32	1.74	26200	79.27	0.21	2.32	1.74	2540	75.17
0.15	2.95	1.39	45630	75.62	0.26	2.88	1.39	25100	77.50	0.27	2.93	1.39	2410	72.24
0.19	3.75	1.04	44100	70.30	0.38	3.93	1.04	23640	76.43	0.37	3.75	1.04	2274	71.83
0.04	0.87	5.21	53100	76.00	0.07	0.86	5.21	28120	82.81	0.07	0.89	5.21	2873	76.12
0.09	2.14	2.08	52160	76.39	0.19	2.24	2.08	27200	81.16	0.18	2.18	2.08	2722	75.07
0.13	2.66	1.74	48300	74.34	0.22	2.58	1.74	26310	79.32	0.24	2.61	1.74	2506	74.57
0.17	3.43	1.39	46700	72.75	0.29	3.28	1.39	25400	76.76	0.32	3.36	1.39	2410	70.21
0.22	4.32	1.04	45440	68.44	0.41	4.23	1.04	23430	75.00	0.42	4.32	1.04	2358	69.78

Note: *OLR in kgCOD/kgVSS/day; VLR in kgCOD/m^3.day; HRT in days; VSS in mg/l; % Eff – percentage removal efficiency*

Table 2. Proposed Regression Equations

Sl. No.	Prediction Parameter	Equation	Fitness
1.	Percentage removal efficiency for Sago effluent	89.07-202.18OLR+8.38VLR+0.467HRT-0.00023VSS	0.793
2.	Percentage removal efficiency for Sugar effluent	47.76+12.19OLR-1.61VLR-0.356HRT+0.00125VSS	0.880
3.	Percentage removal efficiency for Dairy effluent	56.60+31.01OLR-4.49VLR-0.336HRT-0.00084VSS	0.898

The exclusive multivariate linear regression models simulate the experimental results and envisage as design equation, which can be used for designing UASBR for industrial effluent wastes. The proposed equation will help the operators of UASBR for optimising the operating parameters of the reactor to perform the maximum efficiency of COD removal.

4. CONCLUSIONS

The following conclusions are drawn based on the experimental results and proposed regression equations.

- UASBR is more versatile in offering anaerobic treatment of high COD industrial effluents.
- Sago effluent can be treated for maximum COD removal up to 79.95% and 82.81% and 77.68% for sugar and Dairy effluents respectively
  The multiple nonlinear regression models yield excellent correlation coefficient for the prediction of percentage removal efficiency of COD.

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