Comparative Study of Performance Evaluation of Upflow Anaerobic Sludge Blanket Reactor for Treating Tannery Effluent in Psychrophilic and Mesophilic Temperature

Dr.R. Sivakumar, R. Jayasankar, R. Elliss Yogesh and R. Krishnapriya

Abstract--- *The present study evaluated the performance of UASBR through a laboratory model (25 liters of total volume) for treating the synthetic tannery effluent with maintained ambient psychrophilic temperature (20-28ºC) at phase I and mesophilic temperature (30-40ºC) at phase II. This model was studied its treatment efficiency in terms of COD reduction. In the phase I, the average varying influent COD applied over the model are 6520, 7083, 7515, 8113 and 8561 mg/l with flow rates for each average influent COD are 4.80, 9.60, 14.40, 19.20 and 24.00 l/d. It was found to be successful with COD removal of 80.54% for the operating conditions of OLR at 0.096kgCOD/kg VSS day, VLR at 1.45kgCOD/m3day and HRT at 5.21 days. In the phase II the average varying influent COD of 6515, 7027, 7571, 8104 and 8514 mg/l were applied with same flow rates. The experimental work on UASBR model is found successful with 82.60 % COD removal under the operating conditions of OLR at 0.091 kg COD/kg VSS day, VLR at 1.46 kg COD/m3day and HRT at 5.21 days. The reactor achieved BOD, TSS, TDS, N and P removal efficiency was observed at phase I and II are 82.8 %, 75.6 %, 77.2 %, 33 % & 56 % and 84.8 %, 76 %, 79.5 %, 35 % & 55 % respectively. The ratio of VFA to alkalinity was varied between 0.17-0.34 during the treatment.*

Keywords--- *Tannery, UASBR, Wastewater Treatment, Anaerobic Treatment, COD.*

I. INTRODUCTION

Industrialization has become a matter of major concern due to its deteriorating activity on environment [1]. The discharge of the polluted water from industries is a serious concern. The manufacturing of leather can be divided into two parts; beam house operations and tanning process. In beam house operations, the removal of dirt and blood by washing is the first step after which the hides are then soaked in water for softening and removal of salts. After the removal of salts, fatty tissue is removed by fleshing.

Tanning is the chemical process that converts animal hides and skin into leather and related products. The transformation of hides into leather is usually done by means of tanning agents and the process generates highly turbid, colored and foul smelling wastewater. The major components of the effluent include sulfide, chromium, volatile organic compounds, large quantities of solid waste, suspended solids like animal hair and rimming [1]. For every kilogram of hides processed, 30 litres of effluent is generated and the total quantity of effluent discharged by

Dr.R. Sivakumar, Professor, Department of Civil, E.G.S. Pillay Engineering College, Nagapattinam.
R. Jayasankar, Associate Professor, A.V.C. College of Engineering, Mannampandal.
R. Elliss Yogesh, Associate Professor, A.V.C. College of Engineering, Mannampandal.
R. Krishnapriya, Assistant Professor, Department of Civil, E.G.S. Pillay Engineering College, Nagapattinam.

Indian industries is about 50,000 m^3 /day [2]. Wastewater discharged from tannery industries is highly complex, concentrated, and toxic hence there is a need for highly efficient treatment processes that are simple to operate and have low/reasonable construction and operation costs [3]. During the tanning process, about 300 kg chemicals are added per ton of hides [4]. Based on the tanning agents, tanning operations are further divided into vegetable tanning and chrome tanning. Vegetable tanning is usually done in series of vats by using natural organic substances.

Therefore, it is necessary to adopt appropriate treatment method to meet the effluent standards for disposal. Biological treatments either by anaerobic or aerobic is the natural choice for biodegradable wastes. Anaerobic treatment technology is the most attractive practice in which the pollution reduction and energy recovery. Hence in the recent years, the anaerobic treatment process has increased considerably due to energy considerations and environmental concerns.

Tannery wastewaters are generally treated using biological methods such as activated sludge process, aerated lagoons, trickling filters, sequencing batch reactor (SBR), anaerobic sludge blanket (UASB) reactor, anaerobic filters, etc., Among which the high rate anaerobic treatment system such as "up flow anaerobic sludge blanket reactor" (UASBR) is a logical alternative to treat the wastewater. The UASB reactor process has been investigated since 1971 [5]. Anaerobic treatment converts the waste water organic pollutants into small amount of sludge and large amount of energy as gas [6]. The up flow anaerobic sludge blanket (UASB) reactor is by far the most widely used high rate anaerobic treatment system for variety of waste water [7]. The wide application of the UASB reactor is due to its high efficiency of organic material removal, its low construction cost and land requirement and its extremely simple operation. The suspend growth systems have sludge that is considered to be granular sludge co exist in a reactor. Temperature plays an important role on the anaerobic process in UASB technology, to enhance the microorganism ability to produce biogas from digestion. The temperature and upward velocity effect sludge granulation substantially and investigated the formation of sludge granulation at ambient temperature (19-28℃) and upward velocity of 0.478 m/h [8]. The rate of degradation of organics is enhanced at elevated temperature of mesophilic condition and UASB reactor displays better efficiency at lower rate [9] and around 78% decreases in gas production rate when the temperature lowered from 27℃ to 10℃ [10] also there is an increase in methane production with a gradual increase in temperature [11]. The suitable temperature provides the microorganisms with less viscosity and good degradation [12] and the rate of degradation of organics is enhanced at mesophilic temperature (30-40℃) and a decline in UASB efficiency at low temperature (psychrophilic) can be explained due to decreases in microbial activity [13].

The present study aims at the performance evaluation of UASBR for treatment of tannery wastewater in ambient psychrophilic temperature (20-28°C) and mesophilic temperature (30-40℃) with respect to various parameters of tannery waste water like COD, BOD, pH, TSS, TDS, P and N.

II. MATERIALS AND METHODS

Sample Collection and characterization: The real time waste water was collected for both phases from A.K.M. Tannery industry Thiruchirappalli, Tamilnadu. The samples were collected in a clean sterile plastic container and stored at a cool place until the analysis was carried out. It was characterized as : COD, 6456 mg/l ; BOD, 2160 mg/l ; pH, 8.2; TSS, 2580 mg/l; TDS 8350 mg/l; Nitrogen (as N), 178 mg/l; Phosphorus (as P), 31.5 mg/l. Present research study was conducted for the period of 8 months for both phase I and II. The performance of reactor was also evaluated and the quality of reclaimed waste was compared with disposal standards.

Experimental Setup: A laboratory model of the up flow anaerobic sludge blanket reactor with necessary mixing cum equalization tank, having capacity of 25 liters was fabricated with 5mm thick acrylic sheet of 200 mm internal diameter and effective height of 600 mm used for this study (fig. 1). The reactor was provided inlet at the bottom and gas outlet at the top and another at a distance of 40mm from the top of the reactor as the outlet for the treated effluent, at the same level a gas liquid solid separator (GLSS) was provided. Baffle arrangement was also made to guide the gas bubbles into the separator to capture the evolved gas. As per the guidelines given by Lettinga and Hulshoff Pol [14] three phase separator was also provided with 3 sampling ports at a distance of 300mm c/c along the reactor. A check valve was fixed at the bottom for sludge withdrawal. Miclins peristaltic pump of model PP 20 was used to maintain the flow rate and upward velocity of the feed. The table 1 shows the dimensions of the laboratory model UASBR used.

The initial start up and process stabilization of the reactor model was seeded with domestic waste water of COD (250 – 370); BOD (180 – 260); pH 6.6; TSS 110; TDS 560 and stabilized sludge for a period of 60 days continuous run and the observations were noted for the COD removal. The COD removal is started with 46.8 and it rise up to a maximum of 84.2 % (fig.2) and process stabilization was observed after 60 days with average removal of 80 to 85 %. The synthetic waste water which simulates the typical characteristics of real time tannery waste water was prepared with necessary chemicals and nutrients (table 2) and feed with an initial COD of 2000 mg/l and HRT of 48 hrs [15], [16] was selected in order to allow the sludge acclimatize itself to the environment. Then the performance of UASBR could be found out with different average COD with different OLR, VLR and HRT at both temperatures.

The ratio of VFA to alkalinity exceeds 0.8, the inhibition of methanogens occurs and process failure is apparent, increase above 0.3 to 0.4 indicate system instability and a proper ratio is between 0.1 to 0.2 [17].

Then the experiment on the laboratory scale UASB model was conducted for different operating condition viz., varying influent flow rate (l/day), organic loading rates and hydraulic loading rates to achieve the higher % of COD removal. Based on the COD reduction, the optimum operating condition for UASBR in treating tannery effluent was identified. And also the observations were made for VSS and biogas generation. The laboratory analysis of the wastewater and treated effluent samples were carried out by the standard methods, standard analytical procedures for water analysis.

III. RESULTS AND DISCUSSION

The varying average COD of synthetic tannery influent applied over the model during phase I were 6520, 7083, 7515, 8113 and 8561 mg/l and during phase II are 6515, 7027, 7571, 8104 and 8514 mg/l. The flow rate applied for each average influent COD are 4.80, 9.60, 14.40, 19.20 and 24.00 l/d with a resulted upward velocity in the reactor varying from 0.0064 to 0.031 m/hr. The hydraulic retention time (HRT) was 5.21, 2.6, 1.74, 1.3 and 1.04 days. In the phase I, maintained psychrophilic temperature condition, the average varying influent COD applied over the model are 6520, 7083, 7515, 8113 and 8561 mg/l. The VLR varies from 1.24 to 8.28 kg COD/m^3day and the biomass values vary from 37060 to 50020 mg/l and the respective values of OLR are varying from 0.087 to 0.658 Kg COD/KgVSSday. It was found successful COD removal of 80.54% for the operating conditions of OLR at 0.096kgCOD/kgVSSday, VLR at 1.45kgCOD/m^3day and HRT at 5.21 days. The reactor achieved BOD, TSS, TDS, N and P removal efficiency was observed are 82.8 %, 75.6 %, 77.2 %, 33 % & 56 % respectively.

In the phase II, maintained mesophilic temperature condition the average varying influent COD applied over the model are 6515, 7027, 7571, 8104 and 8514 mg/l. The VLR varies from 1.23 to 8.17 kg COD/m^3day and the biomass values vary from 38460 to 51720 mg/l and the respective values of OLR are varying from 0.076 to 0.512 Kg COD/KgVSSday. The experimental work on UASBR model was found successful with 82.60 % COD removal under the operating conditions of OLR at 0.091 kg COD/kg VSS day, VLR at 1.46 kg COD/m^3day and HRT at 5.21 days. The reactor achieved BOD, TSS, TDS, N and P removal efficiency was observed are 84.8 %, 76 %, 79.5 %, 35 % & 55 % respectively.

The maximum concentration of VSS in the Sludge Blanket of the model was observed at 51720 mg/l. The maximum gas conversion ratio was assessed at 0.29 m^3 of gas/kg of COD removal. The variations of VFA and alkalinity during the study period are 131-156 mg/l & 728-458 mg/l. The ratio of VFA to alkalinity was varied between 0.17-0.34 during the treatment. The optimum ratio of VFA to alkalinity should be less than 0.3 or 0.4 [18], [19].

The Figure 3 and 4 shows the performance of the model as % COD removal and varying organic loading rates OLR, 0.020 to 0.242 kg COD/kg VSS day and identified that the maximum COD reduction at 0.039 kg COD/kg VSS day at phase I and OLR, 0.025 to 0.283 kg COD/kg VSS day and identified that the maximum COD reduction at 0.037 kg COD/kg VSS day at phase II respectively.

The Figure 5 and 6 was drawn for % COD removal under varying volumetric loading rates VLR, 0.331 to 4.33 kg COD/m^3day and the maximum was found at 0.63 kg COD/m^3day at phase I and VLR, 0.427 to 4.24 kg COD/m^3day and the maximum was found at 0.63 kg COD/m^3day at phase II respectively.

The Figure 7 and 8was drawn on the performance of the model in terms of % COD removal under varying hydraulic retention time HRT, 5.21, 2.6, 1.74, 1.3 and 1.04 days and the maximum was found at 5.21 days on both phases.

The optimum condition for higher % COD removal of each average influent COD was identified from the results and given in table 3 & 4. Maximum efficiency of COD reduction, concentration of VSS in sludge blanket and gas conversion ratio were 80.54 & 82.60%, 50020 & 51520 mg/l and 0.28 & 0.29 m^3 per kg COD removal respectively. The influent & effluent characteristics at maximum COD removal are presented in table 5.

The experiments was run on continual basis under each conditions of model operation, influent COD, effluent COD, concentration of volatile solids in the sludge blanket zone and amount of gas per kg COD removal were observed through suitable samples drawn and using standard methods of analysis.

IV. CONCLUSION

1) The startup of an UASB reactor can be achieved within 60 days with domestic waste and stabilized sludge and the model was run with synthetic tannery industry waste water as substrate.
2) During psichrophilic temperature range the reactor achieved COD removal efficiency of 80.54% at OLR at 0.096 kgCOD / kgVSSday, VLR at 1.45 kgCOD/m^3day and HRT at 5.21 days. The reactor achieved BOD, TSS, TDS, N and P removal efficiency was observed are 82.8 %, 75.6 %, 77.2 %, 33 % & 56 % respectively.
3) During mesophilic temperature range the reactor achieved COD removal efficiency of 82.60 % at OLR at 0.091 kg COD/kg VSS day, VLR at 1.46 kg COD/m^3day and HRT at 5.21 days. The reactor achieved BOD, TSS, TDS, N and P removal efficiency was observed are 84.8 %, 76 %, 79.5 %, 35 % & 55 % respectively.
4) Biogas can be produced at max rate of 0.29m^3/kg of COD removal. The model was observed to retain a concentration of biomass as VSS as high as 50020 mg/l at lower temperature and 51520 mg/l at higher in the sludge blanket zone. To meet the standards for disposal of treated effluent, UASBR required downstream aerobic system to reduce COD further.
5) The performance observed for high strength wastewater has better only at suitable influent COD and overall performance only below the influent COD of 6000mg/l.

Table 1: UASBR Dimension Details- Experimental Model

Total volume of the Reactor, lit	25
Height of the Reactor, cm	69
Effective height of the Reactor, cm	60
Effective diameter of the Reactor, cm	20
Diameter of the Reactor at Top, cm	36
Diameter of the GLSS as Top, cm	7.2
Diameter of the GLSS at Bottom, cm	17
Total height of the GLSS, cm	9
Diameter of the Influent & Effluent Pipes, cm	1
Width of the Launder, cm	2.5
Peristaltic Pump [Miclin's make]	PP-20 Model

Table 2: Chemical Composition of the Synthetic Tannery Wastewater [20]

Glucose, g/l	3.64
$(NH_4)_2SO_4$, g/l	0.91
$MgSO_4,7H_2O$, g/l	0.025
$FeSO_4,7H_2O$, g/l	0.02
KH_2PO_4, g/l	0.088
K_2HPO_4, g/l	0.09
Na_2CO_3, g/l	0.066
$NaHCO_3$, g/l	0.105
$CaCl_2$, g/l	0.03
$KCrO_4$, g/l	1.86

Table 3: Optimum COD Removal of Each Average COD in Psichrophilic Temperature

Average Influent COD mg/l	*Flow Rate m^3/day*	*HRT days*	*VLR Kg COD/ m^3·day*	*OLR Kg COD/ kg VSS day*	*Concentration of volatile solids in sludge blanket zone mg/l*	*Effluent COD mg/l*	*% of COD removal mg/l*	*Gas conversion m^3/kg COD removal*
6458	0.0048	5.21	1.24	0.087	45920	1448	77.58	0.26
6980	0.0048	5.21	1.34	0.100	43350	1485	78.72	0.28
7550	0.0048	5.21	1.45	0.096	48880	1469	80.54	0.28
8124	0.0048	5.21	0.76	0.102	49560	1721	78.81	0.28
8468	0.0048	5.21	1.62	0.105	50020	2240	73.54	0.28

Table 4: Optimum COD Removal of Each Average COD in Mesophilic Temperature

Average Influent COD mg/l	*Flow Rate m^3/day*	*HRT days*	*VLR Kg COD/ m^3·day*	*OLR Kg COD/ kg VSS day*	*Concentration of volatile solids in sludge blanket zone mg/l*	*Effluent COD mg/l*	*% of COD removal mg/l*	*Gas conversion m^3/kg COD removal*
6426	0.0048	5.21	1.23	0.076	48420	1378	78.55	0.26
7054	0.0048	5.21	1.35	0.087	46610	1382	80.4	0.26
7618	0.0048	5.21	1.46	0.091	47880	1325	82.60	0.29
8015	0.0048	5.21	1.54	0.09	49450	1426	82.20	0.26
8640	0.0048	5.21	1.66	0.096	51520	1676	80.60	0.27

Table 5: Influent & Effluent Characteristics at Maximum COD Removal

Parameters	*psychrophilic range*			*mesophilic range*		
	Influent	*effluent*	*% removal*	*Influent*	*effluent*	*% removal*
pH	8.4	6.7	-	8.2	6.7	-
BOD, mg/l	3420	588	82.8	3530	536	84.8
TSS, mg/l	1826	455	75.6	1788	430	76
TDS, mg/l	3728	850	77.2	3560	730	79.5
N, mg/l	148	99	33	152	99	35
P, mg/l	24.5	10.8	56	25.2	11.3	55

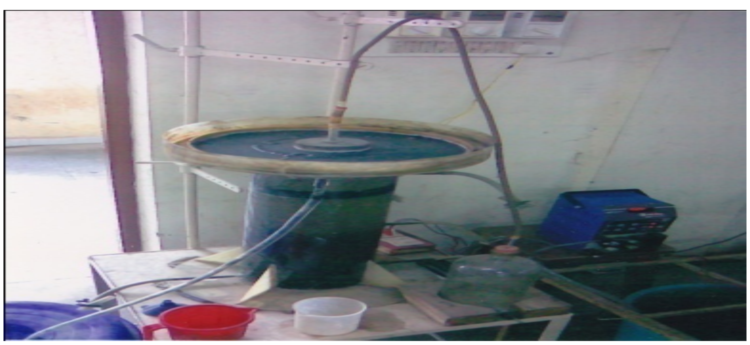

Figure 1: A laboratory Model of the Up Flow Anaerobic Sludge Blanket Reactor

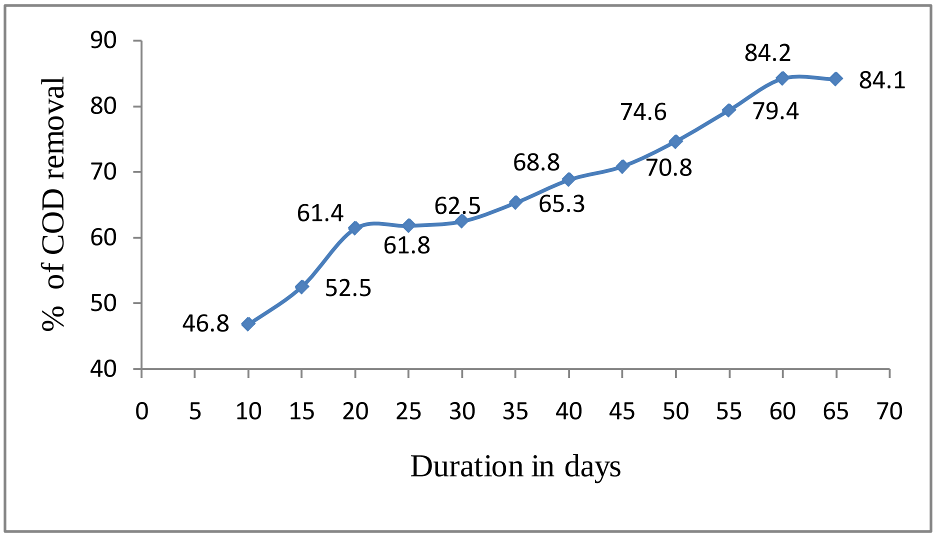

Figure 2: Startup and Process Stabilization

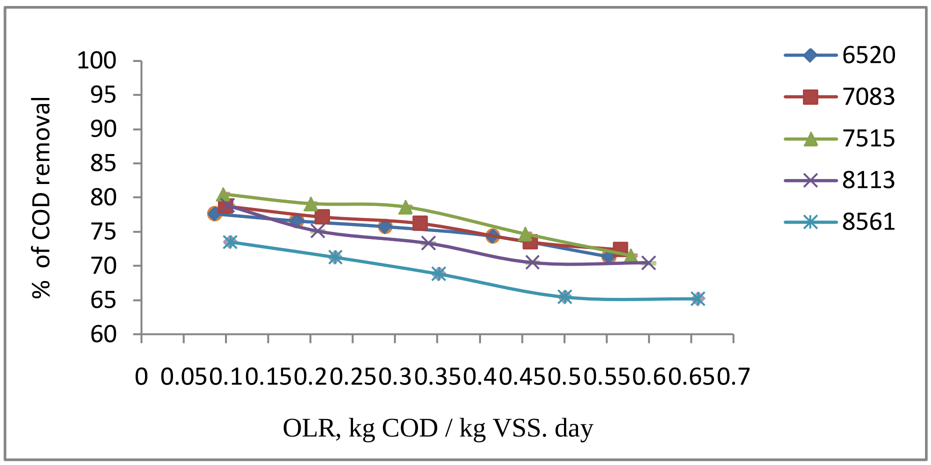

Figure 3: Organic Loading Rate (OLR) Vs COD Removal Percentage

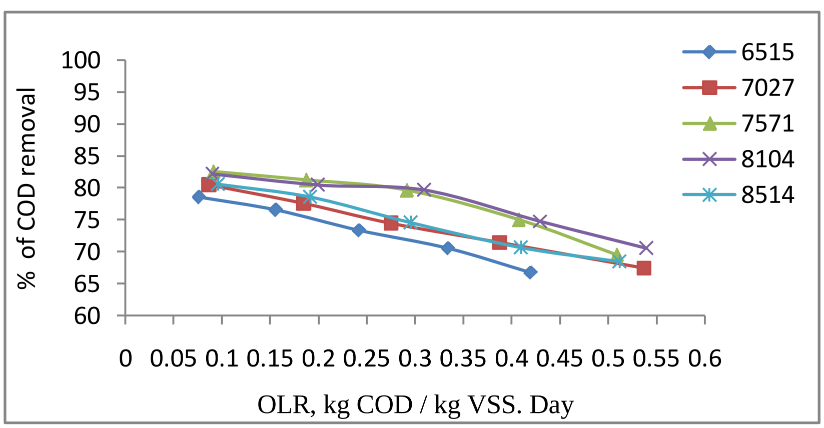

Figure 4: Organic Loading Rate (OLR) Vs COD Removal Percentage

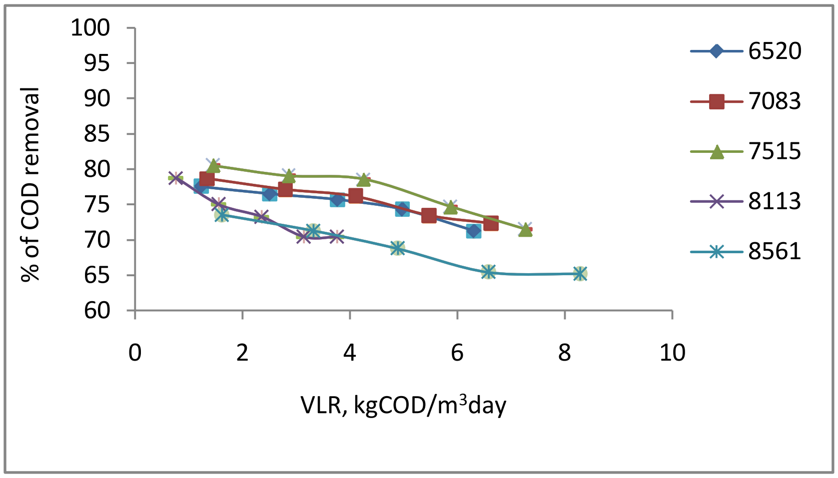

Figure 5: Volumetric Loading Rate (VLR) Vs COD Removal Percentage

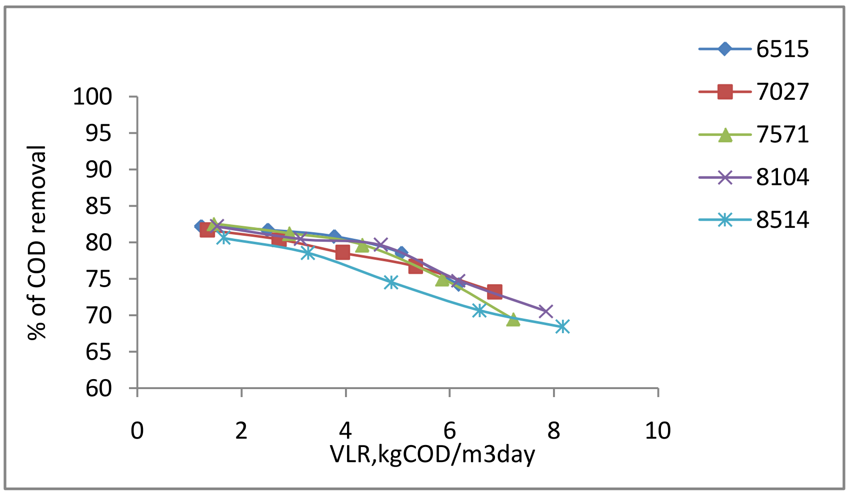

Figure 6: Volumetric Loading Rate (VLR) Vs COD Removal Percentage

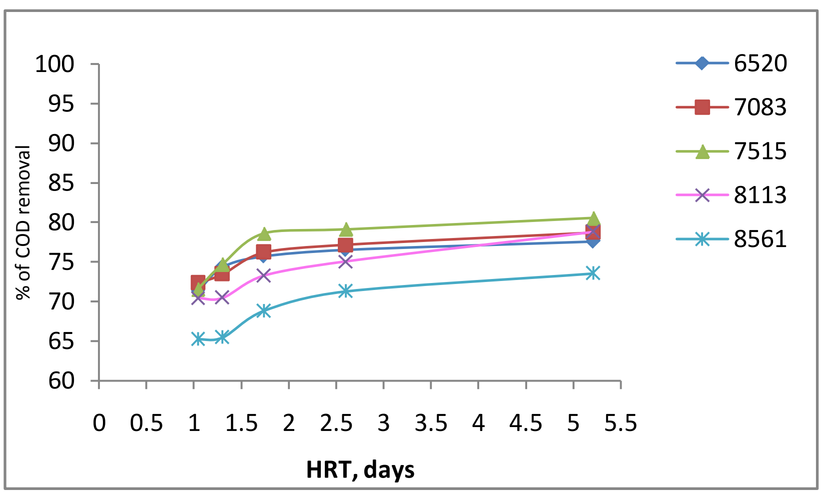

Figure 7: Hydraulic Retention Time (HRT) Vs COD Removal Percentage

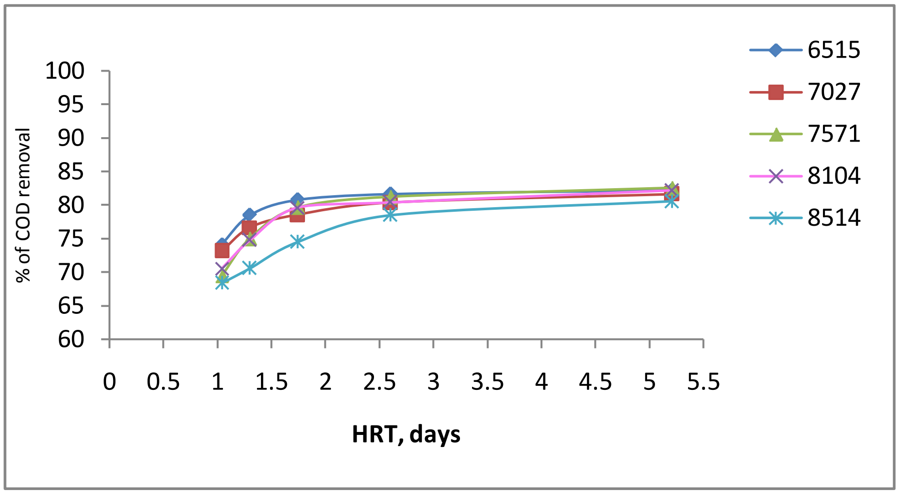

Figure 8: Hydraulic Retention Time (HRT) Vs COD Removal Percentage

REFERENCES

[1] P.K. Tiwari, "An agenda for pollution control in dairy industry Indian dairyman", Vol. 46, Pp. 617-624, 1994.

[2] Varsha Midha and Apurba Dey, "Biological Treatment Of Tannery Wastewater For Sulfide Removal", Vol. 6, Pp. 472-486, 2008.

[3] M.A. El-Sheikh, H.I. Saleh, J.R. Flora and M.R. Abdul-Ghany, "Biological tannery wastewater treatment using two stage UASB reactors", Desalination, Vol. 276, Pp. 253–259, 2011.

[4] L.A.H.M. Verheijen, D. Weirsema, H. wshoffpol and J. Dewit, "Live Stock and the Environment: Finding a Balance Management of Waste from Animal Product Processing", International Agriculture Centre, Wageningen, The Netherlands, 1996.

[5] G. Lettinga, S.W. Hobma, L.W. Hulshoff Pol, W. De Zeeuw, P. De Jong, P. Grin and R. Roersma, "Design operation and economy of anaerobic treatment", Vol. 18, Pp. 99–108, 1984.

[6] B. Ayati and Ganjidoust, "Comparing the efficiency of UAFF and UASB with hybrid reactor in treating wood fiber wastewater", Iranian Journal of Environmental Health Science and Engineering, Vol. 3, 2006.

[7] A.C. Van Haandeland G. Lettinga, "Anaerobic Sewage Treatment: A practical guide for regions with a hot climate", John Wiley and Sons, New York, 1994.

[8] R.A. Barbosa and A.G.L. "Sant Treatment of raw domestic sewage in an UASB reactor", Vol. 23, 1989.

[9] A. Yasar, A. Bari Tabinda, "Anaerobic treatment of industrial wastewater by UASB reactor integrated with chemical oxidation processes an overview", Vol. 19, Pp. 1051–1061, 2010.

[10] L.K. Agrawal, Y. Ohashi, E. Mochida, H. Okui, Y. Ueki, H. Harada and A. Ohashi, "Treatment of raw sewage in a temperate climate using UASB reactor and the Hanging Sponge Cubes processes", Water Science and Technology, Vol. 36, No. 433, 1997.

[11] J.B. Van and G. Lier Lettinga, "Appropriate technologies for effective management of industrial and domestic waste waters the decentralized approach", Water Science and Technology, Vol. 40, Pp. 171-178, 1990.

[12] K. Kaviyarasan, "Application of UASB Reactor in Industrial Wastewater Treatment", A Review International Journal of Scientific & Engineering Research, Vol. 5, 2014.

[13] M.M. Powar, V.S. Kore, S.V. Kore and G.S. Kulkarni, "Review on applications of uasb technology for wastewater treatment", International Journal of Advanced Science, Engineering and Technolog, Vol. 2, Pp. 125-133, 2013.

[14] G. Lettinga and L.W. Hulshoff Pol, "UASB process design for various types of wastewaters", Water Science and Technology, Vol. 24, Pp. 87-107, 1991.

[15] M. Farhadian, M. Borghei and V.V. Umrania, "Treatment of beet sugar wastewater by UAFB bioprocess", Bioresource Technology, Vol. 98, Pp. 3080-30, 2007.

[16] A. Punal, M. Trevisan, A. Rozzi and J.M. Lema, "Influence of C:N ratio on the start-up of up flow anaerobic filter reactors", Water research, Vol. 34, Pp. 2614–2619, 2000.

[17] K. Vijayaraghvan and D.V.H. Murthy, "Effect of toxic substances in anaerobic treatment of tannery wastewater", Vol. 16, Pp. 151-155, 1997.

[18] E. Sánchez, R. Borja, L. Travieso, A. Martin and M.F. Colmenarvejo, "Effect of organic loading rate on stability, operational parameters and performance of a secondary upflow anaerobic sludge bed reactor treating piggery waste", Bioresource Technology, Vol. 96, Pp. 335344, 2005.

[19] F Malpei, VAndreoni, D. Daffonchio and A. Rozzi, "Anaerobic digestion of print pastes: A preliminary screening of inhibition by dyes and biodegradability of thickeners", Bioresource Technology, Vol. 63, 1998.

[20] M. Faouzi, M. Merzouki and M. Benlemlih, "Contribution to optimize the biological treatment of synthetic tannery effluent by the sequencing batch reactor", Vol. 4, Pp. 532-541, 2013.

[21] G.R. Munavalli and P.S. Saler, "Treatment of dairy waste water by water hyacinth, Vol. 59, Pp. 713–722, 2009.

[22] R.V. Kavitha, S. Kumar, R. Suresh and V. Krishnamurthy, "Performance Evaluation and Biological Treatment of dairy waste water treatment plant by upflow anaerobic sludge blanket reactor", International Journal of Chemical & Petrochemical Technology, Vol. 3, Pp. 9 – 20, 2013.

[23] A. Donoso-Bravo and W.M.K.T.W. Bandara, H. Satoh and G. Ruiz-Filippi, "Explicit temperature-based model for anaerobic digestion: Appliation in domestic wastewater treatment in a UASB reactor", Vol. 133, Pp. 437-442, 2013.

[24] R. Sivakumar and V. Sekaran, "Performance Evaluation of Modified UASB Reactor for Treating Brewery Effluent", International Journal of Environmental Science:Development and Monitoring, Vol. 4, Pp. 1-7, 2013.

[25] L. Deepak and Joshi, "High Rate Anaerobic Treatment of Industrial Wastewater in Tropics", Thammasat Vol. 3, Pp. 1-7, 1998.

[26] U.S. Hampannavar and C.B. Shivayogimath, "Anaerobic treatment of sugar industry wastewater by Up flow anaerobic sludge blanket reactor at ambient temperature", International Journal of Environmental Sciences, Vol. 1, Pp. 631-639, 2010.

[27] E. Ravindranath, K. Chitra, B. Shamshath and G. Navaneetha, "A Effect of recirculation rate on anaerobic treatment of fleshing using UASB reactor with recovery of energy", Journal of Scientific and Industrial Research, Vol. 69, Pp. 790-793, 2010.

[28] P. Tamilchelvan and M. Dhinakaran, "Anaerobic Digestion Treatment of Tannery Waste Water", International Journal of Engineering Research and Applications, Vol. 2, Pp. 932-936, 2012.

[29] A.S. Tanksali, "Treatment Of Sugar Industry Wastewater By Up flow Anaerobic Sludge Blanket Reactor", International Journal of ChemTech Research, Vol. 5 , Pp. 1246-1253, 2013.

[30] G. Durai and M. Rajasimman, "Biological Treatment of Tannery Waste water", Journal of Environmental Scence and Technology, Vol. 4, Pp. 1-17, 2011.

[31] G. Farabegoli, A. Carucci, M. Majone, E. Rolle, "Biological treatment of tannery wastewater in the presence of chromium", Journal of Environmental Management. Vol. 1,Pp.345-349. 2004.

[32] S. Rajamani, T. Ramasami, J.S.A. Langerwerf and J.E. Schappman, "Environmental management in tanneries-feasible chromium recovery and reuse system", Proceedings of the 3rd International Conference on Appropriate Waste Management Technologies for Developing Countries (AWMTDC'95), Pp. 965-969, 1995.

[33] M. Wiemann, H. Schenk and W. Hegemann, "Anaerobic treatment of tannery wastewater with simultaneous sulphide elimination", Vol. 32, Pp.774-780, 1998.

[34] Metcalf and Eddy, "Wastewater Engineering treatment and reuse", fourth edition, 2003.