ICSBE2016-126

GREYWATER TREATMENT AND REUSE USING A BAFFLED CONSTRUCTED WETLAND

Ramprasad[1] and Ligy Philip[2*]

[1]*Research Scholar, Environmental and Water resource division, Department of Civil Engineering, IIT Madras*
[2] *Professor, Environmental and Water resource division, Department of Civil Engineering, IIT Madras*
**E-Mail: ligy@iitm.ac.in*

Abstract: Water is one of the world's most valuable resources. However it is under constant threat due to urbanization, explosive population growth and pollution. The most promising efforts to stem water crisis are to treat the wastewater in a sustainable way and reuse for non-potable applications. Grey water (GW) being highly voluminous and relatively less polluted, recycling for non-potable uses like urinal and toilet flushing, landscaping etc will decrease the stress on fresh water consumption and protect the environment from residual pollutant disposal. This paper discusses about the performance of a hybrid baffled constructed wet land for the treatment of grey water from a hostel located in Indian Institute of Technology Madras, Chennai, India campus. The hybrid constructed wetland is a combination of vertical and horizontal flow wetland achieved by providing baffles in the system. The objectives of this study were to evaluate the performance of newly developed baffled constructed wetlands in the removal of chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), nitrate – nitrogen (NO_3-N), suspended solids (SS), fecal contamination (FC), sodium do-decyl sulphate (SDS), propylene glycol (PG) and trimethyl amine (TMA) at different hydraulic retention times (HRT) and various organic loading rates (OLRs). The overall removal efficiencies obtained were in the range of 84-92%, 86-94%, 88-95%, 92-98%, 85-99%, 86-98%, 94-97% and 94-98% for BOD_5, COD, NO_3-N, SS, FC, SDS, PG and TMA, respectively for an HRT of 12.5 to 16.5 days. The system showed a distinct solids removal at higher HRT. The hybrid CW was able to eliminate the emerging contaminants such as SDS, PG and TMA from the treated water. The efficient performance of the baffled unit was due to the longer pathway provided by the baffles which in turn provided more contact of the wastewater with the plant, microbes and the matrix.

Keywords: Baffle constructed wetland; Greywater; Organic loading rate; Reuse; Surfactants and personal care products

1. Introduction

Most of the fresh water resources are extracted and are used in agriculture, various domestic and industrial purposes. It is estimated that within the next 50 years, more than 40% of the world's population will face severe water scarcity (WHO, 2006). To meet demand of urban, industrial and agricultural water requirements, recycling and reuse of water is very essential. It is better to use greywater in agriculture than to use fresh water, because crops benefit from the nutrients they contain. Thus, greywater can help to meet water demand and allow the preservation of high-quality water resources for drinking water supplies (WHO, 2006).

Greywater is defined as domestic wastewater that originates from bathtubs, showers, wash basins, clothes washing and laundry. Typically, greywater from bathroom sinks, tubs, showers kitchen sinks and dish washers, include 50-80% of household wastewater. By separating out black water, it is easy to treat less polluted greywater by simple methods. This recycled greywater can be utilized for household toilet flushing and other purpose, such as garden irrigation (Almeida et al, 1999). The greywater usually contains large quantities of biodegradable organic matter, nutrients, surfactants, heavy metals, oils and grease along with emerging contaminants (Bhaskar et al., 2009). Many methods of domestic level greywater treatment have been researched and employed by responsible nations around the globe (Yocum, 2006). There are many conventional and advanced wastewater treatment technologies available and time tested. Activated sludge process, biological aerated filter (BAF), sequencing batch reactor (SBR), rotating biological contactor (RBC) and membrane bio-reactor (MBR) are the most commonly used biological wastewater treatment systems. However, all these systems need uninterrupted power supply for their proper functioning. Moreover, the capital and maintenance cost of such systems are very high (Bhardwaj, 2011).

Constructed wetlands have been widely applied successfully in treating different types of wastewater such as municipal (Cooper et al., 1996), storm water (Scholes et al, 1998), industrial wastewater (Abira et al., 2005) agricultural wastewater and runoff (House et al., 1999) and refinery effluent (Knight, 1999). They are considered as a complex bioreactor with a number of physical, chemical and biological processes involving substratum, microbial communities and plants (Lee et al., 2009). CWs are generally classified as surface flow (SF) and subsurface flow (SSF) systems. Surface flows (SF) CWs are densely vegetated with open water depths (less than 0.4 m). In subsurface flow (SSF) CWs, the water flows beneath the substratum and through the plant roots. SSF–CWs are further subdivided into horizontal flow (HF) and vertical flow (VF) systems depending on the direction of water flow through the porous medium (sand or gravel) (Langergraber et al., 2009; Yalcuk and Ugurul, 2009). The SSF–CWs are reported to cause fewer problems arising from odors, insects or public exposure than SF–CWs (Yang et al., 2001) and hence are suitable for the onsite treatment and reuse of greywater. Studies showed that SSF–CWs are effective in removing pollutants such as suspended solids, organic matter and nutrients from wastewater. As a result of microbiological degradation, plant up-take and by combination of physico–chemical processes such as filtration, sedimentation and adsorption leads to such a removal. Anaerobic and aerobic processes were reported to take place within the pores of the filter media (Yalcuk and Ugurul, 2009). Based on the flow pattern the CWs are classified into horizontal flow constructed wetland (HFCW) and vertical flow constructed wetland (VFCW). The literature clearly indicates that HFCW are very effective in denitrification due to their low oxygen content, and VFCW are good in nitrification due to aerobic condition prevailing. Henceforth, the strengths of HF and VF system are combined in hybrid system (Masi and Martinuzzi, 2007; Vymazal, 2010).

Significant research effort has focused on the ability of these systems to remove common pollutants such as COD, BOD5, total solids, nitrogen, phosphorus, heavy metals and bacteria. On the other hand, there is a little information is available on the fate of specific organic micro pollutants such as linear alkyl benzene sulfonates (LAS) (Fountoulakis et al., 2009) in constructed wet lands. To the best of the author's knowledge, there is no information available on fate of specific pollutant like sodium do-decyl sulphate (SDS), propylene glycol (PG) and tri methyl amine (TMA) in constructed wetlands while treating real grey water. Hence, this study is focused on the design, construction and performance evaluation a hybrid baffle type constructed wetland,. There is very little information available on the performance of Phragmites australis in accumulating emerging contaminants, like surfactants and personal care products. Hence the present study examines the treatment of greywater in a hybrid baffled subsurface flow constructed wetland planted with common reed plant Phragmites australis. Also, the effects of hydraulic retention time and organic loading rate on the performance of HYSCW were evaluated. The findings from the study would be useful in developing simple, compact, cost effective and aesthetically pleasing constructed wetland system for greywater treatment and reuse purpose.

2. Materials and Methods

2.1 Reactor Set-up

The pilot scale hybrid (baffled type) subsurface flow constructed wetland (HYSCW) as shown in Fig. 1 was constructed with brick and concrete. The dimension of the HYSCW was 10.1x 2.55 x 1.3 m, with six compartments using 5 baffles of 7.62 cm thick. The flow was calculated using the Equation. (1) provided in UN-HABITAT manual and was estimated to be 2500 L/day for a surface area of 25.8 sq. m. The reactor was planted with *Phragmites australis* with an average height of 5 cm, and a plant density of 6 plants/ sq. m. The reactor was filled with <10 cm gravel at the bottom 30 cm of the tank. The top 60 cm was filled with equal proportion of sand and brick bats.

$$A_h = \frac{Q_d (\ln C_i - \ln Ce)}{K_{BOD}} \qquad Eq.(1)$$

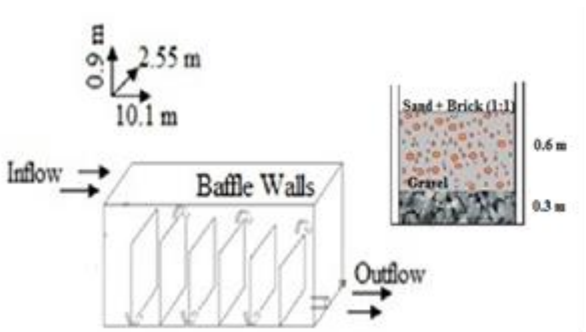

Fig. 1 Hybrid Baffled type constructed wetland reactor setup

2.2 Physico-Chemical Analysis

The performance of the HYSCW was evaluated by collecting and analyzing the inlet and outlet water samples. The parameters monitored include pH, BOD, COD, TSS, nitrate-nitrogen (NO_3 – N), fecal coliform and emerging contaminants like SDS, PG and TMA. The analyses were carried out as per the Standard methods for examination of water and wastewater (APHA, 2005). The bacterial contamination in-terms of fecal coliforms were measured using chromocult nutrient pads supplied by Sartorius, Germany.

2.3 Surfactants Analysis

The samples of 10 mL volume were taken in extraction vessel and were first acidified with 100 µL acetic acid. The dying pigment viz. acridine orange of 100 µL were added into the extraction vessel. The extraction solution (toluene) of 10 mL was added into the vessel and shaken for 10 min. The aqueous phase was discarded and the sodium dodecyl sulphate (SDS) extracted in the toluene was analyzed using UV 1800 spectrophotometer (Shimadzu, Japan) at 467 nm (Adak et al., 2005). Propylene glycol and trimethyl amine were analysed using PerkinElmer Clarus 500, USA Gas chromatography fitted with flame ionization detector. The column used for the analysis was PE 624, 30 m x 0.53 mm x 0.5 mm thickness. The injector temperature was kept at 60 °C, oven temperature was kept at 250 °C and the column temperature was 280 °C. The high pure nitrogen gas at a flow rate of 1 mL/ min was used as the carrier gas. The samples before injecting into the instrument it were extracted with equal portion of n-hexane.

3. Results and Discussion

3.1 Greywater Characteristics

Inlet and outlet samples were taken and analysed for the parameters as discussed above and the results are presented in Table 1. The raw greywater quality was comparable to early reported values (Eriksson et al., 2002; Mohamed et al., 2014) except for fecal contaminants. The concentrations of surfactants and personal care products were also slightly different from the reported values (Zapater et al., 2011). The source of grey water was from washing machines and bath rooms, as it was collected from a student's hostel. Moreover, there was no kitchen wastewater mixing with the grey water. The reason for high values is due to presence of emerging contaminates (ECs) (SDS, PG and TMA) in the grey water.

Table 1 Greywater Characteristics

Parameters	Raw Greywater	USEPA standard limits for reuse
pH	7.24 – 8.34	6.5 – 8.5
COD (mg/L)	216 – 320	NA
BOD (mg/L)	72 – 138.2	<10
TSS (mg/L)	224 – 320	<10
NO_3 – N (mg/L)	12.3 – 17.8	NA
FC (CFU/100 mL)	50 – 120	Nil
SDS (mg/L)	14.9 – 35.9	1
PG (mg/L)	11.9 – 46.6	NA
TMA (mg/L)	8.7 – 15.5	NA

3.2 Effect of Hydraulic retention time on pollutant removal

The hybrid baffle type constructed wetland was operated at two different hydraulic retention times 12.5 days and 16.5 days. It was observed from Fig 1(a) that the removal efficiency (treated water concentration) of organic pollutants (COD) was increased from 93% (16 mg/L) to 97% (8 mg/L) when the HRT was increased to 16.5 d. High removal efficiency was obtained for nitrates and solids also. It is clear from the results that as retention time increased the removal efficiency also increased. It is evident from Fig 2(b) that the solids in the effluent increased to 18 mg/L (91%) as the HRT reduced to 12.5 days and was 8 mg/L (98%) when HRT was 16.5 days. The fecal coliform was also found to be decreasing with the increasing HRT, from 5 CFU/ 100 mL to 2 CFU/ 100 mL. The removal efficiency of the emerging contaminants such as SDS, PG and TMA were also found to increasing with increasing HRT. The SDS removal efficiency was found to be 86% at 12.5 days HRT and has significantly increased to 96% at 16.5 days HRT (Fig 3(b)). The removal efficiencies of propylene glycol and trimethyl amine were also found to be affected by the change in HRT (Fig. 4(a) and (b)). The removal of organic pollutants such as surfactants in the wetlands is accomplished by combination of physical and microbial processes (Zapater et al., 2011). High HRT implies lower loading rate and more contact time which in turn results in high microbial degradation and sorption thereby resulting in higher removal efficiency of pollutants

3.3 Effect of Organic loading rate on pollutant removal

It was observed that as the OLR increased from 7.1 g COD/ cu. m/ day to 10.7 g COD/ cu. m/ day, the removal efficiency decreased as shown in Fig. 1 - 4 It was found that as OLR increased (7.1 to 10.7 g COD/ cu. m/ day) the organics and nitrate removal efficiency decreased, which indicates that the OLR exceeded the degradation capacity of the wetlands (Dalahmeh et al., 2014). At an OLR of 7.1 g COD/ cu. m/ day, effluent COD was 8 ± 8 mg/L whereas at an of OLR of 10.7 g COD/ cu. m/ day the effluent COD increased to 32 ± 16 mg/L (Fig 1(a)). The SDS removal efficiency was found to be 92% during an OLR of 7.1 g COD/cu. m/ day and has reduced to 82% when OLR was increased to 10.7 g COD/ cu. m/ day. Similar trend was observed for PG and TMA also. Due to addition of external carbon source, the degradation rates of organic pollutants were hindered. Sucrose is a readily biodegradable compound than SDS, PG and TMA. Therefore, microbial consortia would have utilized more sucrose as a carbon source than the target pollutant. As a result, lesser biodegradation was observed for target pollutants with increase in OLR. Similar trend was reported by other researchers also (Nyberg et al., 1992). It was found that as OLR increased (7.1 to 10.7 g COD/ cu. m/ day) the organics and nitrate removal efficiency decreased.

4. Conclusion

In the present study demonstrated that the newly developed Hybrid baffle type subsurface flow constructed wetland showed a very good performance while treating grey water. The system was very efficient in removing emerging contaminants such as detergents and personnel care products which are very common in grey water. The better performance of the newly developed baffle type wetland may be due to the up-flow and down-flow conditions sequentially existing in the wetland which allowed the wastewater to travel through a longer pathway resulting in more contact with the rhizomes and micro-aerobic zones. The system performance was affected by change in hydraulic retention time and organic loading rates. The treated wastewater was meeting the quality requirement for reuse of water for secondary uses such as gardening, house cleaning and toilet flushing.

Acknowledgement

The authors wish to thank for the financial support provided by Department of science and technology, Government of India, New Delhi.

References

[1]. Abira MA, Bruggen JJA, Denny P. (2005). Potential of a tropical subsurface constructed wetland to remove phenol from pre-treated pulp and paper mill wastewater. *Water Science and Technology*, 51: 173-175

[2]. Adak, A., Bandyopadhyay, M., & Pal, A. (2005). Removal of crystal violet dye from wastewater by surfactant-modified

[3]. Almeida, M. C., Butler, D., & Friedler, E. (1999). At-source domestic wastewater quality. *Urban Water*, *1*, 49–55

[4]. APHA, AWWA. "WEF, 2005." *Standard methods for the examination of water and wastewater* 21 (2005): 258-259.

Baskar, G., Deeptha, V. T., and Abdul Rahaman, A. (2009). "Root Zone Technology for Campus Wastewater Treatment." *Journal of Environmental Research and Development*, 3(3), 695–705.

Bhardwaj, K. (2011). Municipal Wastewater Management in India.

Cooper, P.F., Vymazal, J., Brix, H., Green, M.B and Haberl, R. (1996). *Removal mechanism and type of constructed wetland. Constructed wetland for wastewater treatment in Europe*, Backhuys publishers, Leiden, The Netherlands, pp. 17-66.

[5]. Dalahmeh, S. S., Pell, M., Hylander, L. D., Lalander, C., Vinnerås, B., & Jönsson, H. (2014). Effects of changing hydraulic and organic loading rates on pollutant reduction in bark, charcoal and sand filters treating greywater.*Journal of environmental management*, *132*, 338-345.

[6]. Eriksson, E., Auffarth, K., Henze, M., & Ledin, A. (2002). Characteristics of grey wastewater. *Urban water*, *4*(1), 85-104.

[7]. Fountoulakis, M. S., Terzakis, S., Kalogerakis, N., and Manios, T. (2009). "Removal of polycyclic aromatic hydrocarbons and linear alkylbenzene sulfonates from domestic wastewater in pilot constructed wetlands and a gravel filter." *Ecological Engineering*, 35(12), 1702–1709.

[8]. House, C. H., Bergmann, B. A., Stomp, A. M., & Frederick, D. J. (1999). Combining constructed wetlands and aquatic and soil filters for reclamation and reuse of water. *Ecological Engineering*, *12*, 27–38.

[9]. Knight, R. L. (1999). Critical Review The Use of Treatment Wetlands for Petroleum Industry Effluents. *Environmental Science & Technology*, *33*(7), 973–980.

[10]. Langergraber, G., Leroch, K., Pressl, A., Sleytr, K., Rohrhofer, R., & Haberl, R. (2009). High-rate nitrogen removal in a two-stage subsurface vertical flow

constructed wetland. *Desalination*, *246*(1), 55-68.

[11]. Lee, C. G., Fletcher, T. D., & Sun, G. (2009). Nitrogen removal in constructed wetland systems. *Engineering in Life Sciences*, *9*(1), 11-22.

[12]. Masi, F., & Martinuzzi, N. (2007). Constructed wetlands for the Mediterranean countries: hybrid systems for water reuse and sustainable sanitation. *Desalination*, *215*(1), 44-55.

[13]. Mohamed, R. M. S. R., Wurochekke, A. A., Chan, C. M., & bin Mohd Kassim, A. H. (2014). The use of natural filter media added with peat soil for household greywater treatment. *GSTF Journal of Engineering Technology (JET)*, *2*(4), 33.

[14]. Nyberg, U., Aspegren, H., Andersson, B., Jansen, J. L. C., & Villadsen, I. S. (1992). Full-scale application of nitrogen removal with methanol as carbon source. *Water Science and Technology*, *26*(5-6), 1077-1086.

[15]. WHO. (2006). WORLD H EALTH S TATISTICS 2006. *WHO Press, World Health Organization, Geneva, Switzerland*, 1–80.

[16]. Vymazal, J. (2010). Constructed wetlands for wastewater treatment. *Water*, *2*(3), 530-549.

[17]. Yalcuk, A., & Ugurlu, A. (2009). Comparison of horizontal and vertical constructed wetland systems for landfill leachate treatment. *Bioresource Technology*, *100*(9), 2521-2526.

[18]. Yang, L., Chang, H. T., & Huang, M. N. L. (2001). Nutrient removal in gravel-and soil-based wetland microcosms with and without vegetation. *Ecological engineering*, *18*(1), 91-105.

[19]. Yocum, D. (2014). Design Manual : Greywater Biofiltration Constructed Wetland System. *Bren School of Environmental Science and Management, University of California, Santa Barbara*, 1–13.

[20]. Zapater, M., Gross, A., & Soares, M. I. M. (2011). Capacity of an on-site recirculating vertical flow constructed wetland to withstand disturbances and highly variable influent quality. *Ecological Engineering*, *37*(10), 1572-1577

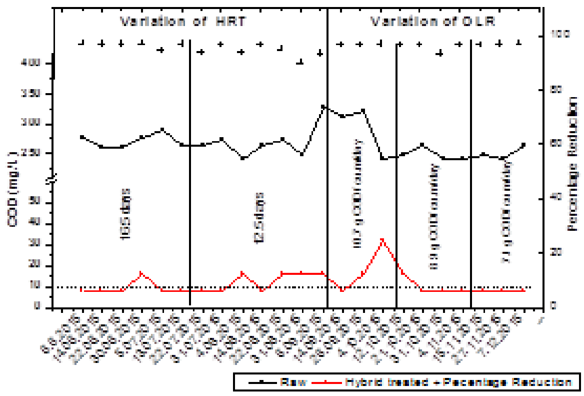

Fig. 1(a) COD

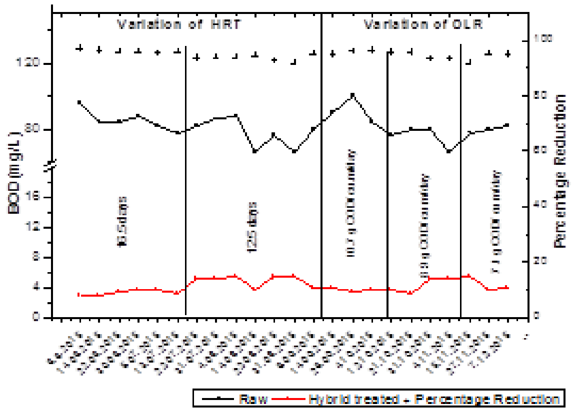

Fig. 1(b) BOD

Fig. 1 Removal efficiency and inlet and outlet concentrations of (a) COD and (b) BOD in HYSCW at various HRT (12.5 and 16.5 days) and at various OLR (10.7, 8.9 and 7.1 g COD/ cu. m/ day)

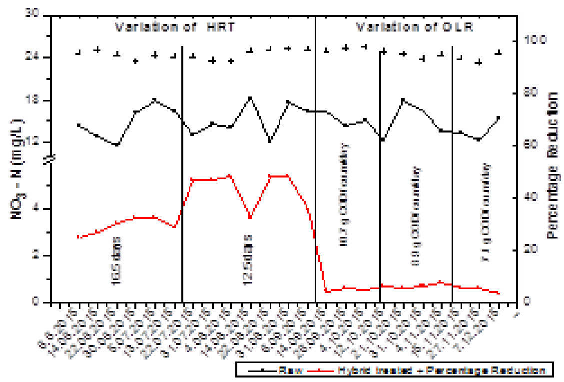

Fig. 2(a) $NO_3 - N$

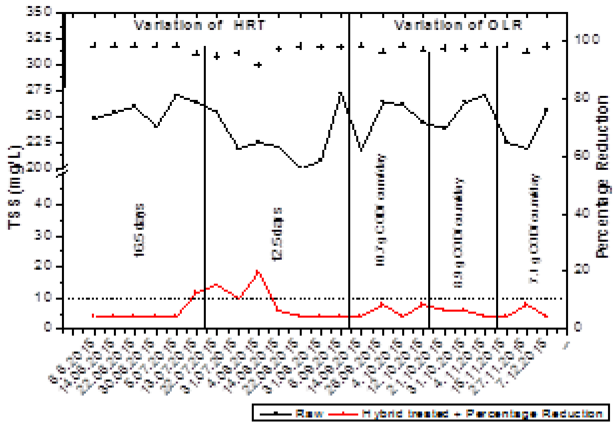

Fig. 2(b) TSS

Fig. 2 Removal efficiency and inlet and outlet concentrations of (a) NO3 - N and (b) TSS in HYSCW at various HRT (12.5 and 16.5 days) and at various OLR (10.7, 8.9 and 7.1 g COD/ cu. m/ day)

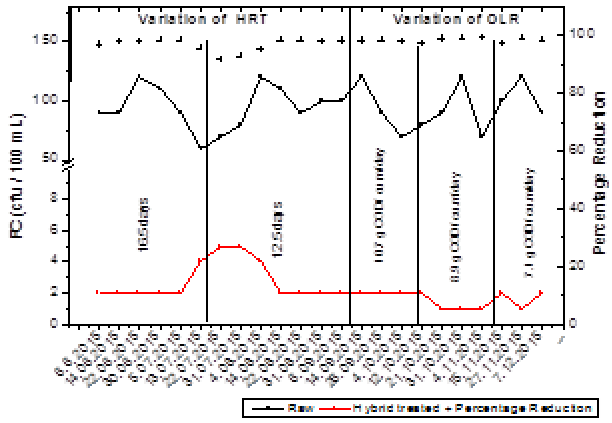

Fig. 3(a) FC

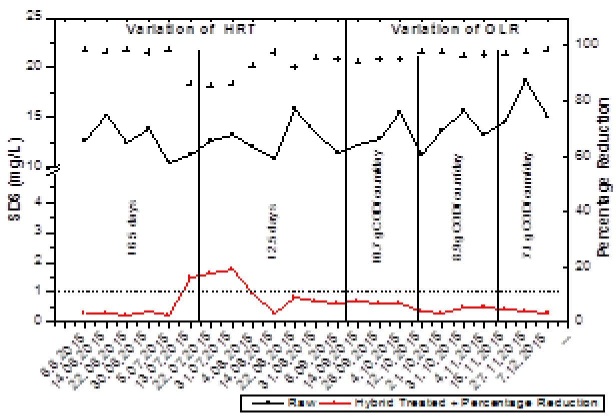

Fig. 3(b) SDS

Fig. 3 Removal efficiency and inlet and outlet concentrations of (a) Fecal Contamination and (b) SDS in HYSCW at various HRT (12.5 and 16.5 days) and at various OLR (10.7, 8.9 and 7.1 g COD/ cu. m/ day)

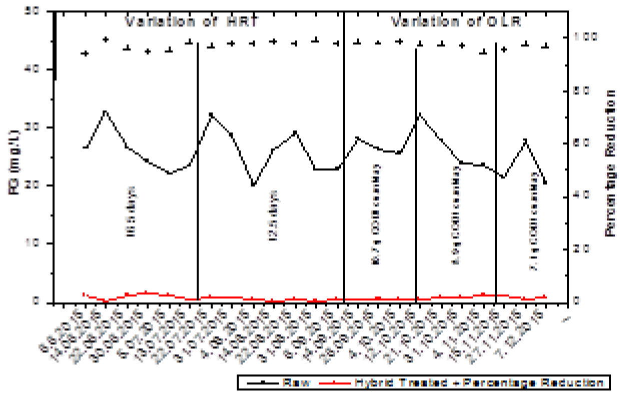

Fig. 4(a) PG

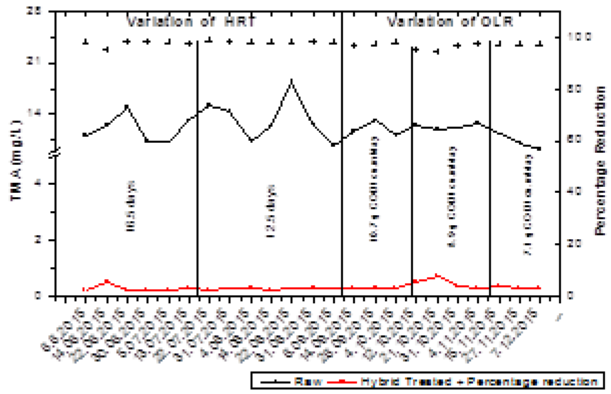

Fig. 4(b) TMA

Fig. 4 Removal efficiency and inlet and outlet concentrations of (a) Propylene Glycol and (b) Trimethyl amine in HYSCW at various HRT (12.5 and 16.5 days) and at various OLR (10.7, 8.9 and 7.1 g COD/ cu. m/ day)