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Assessment of Secondary Treatment Efficiency of Dairy Wastewater using Pilot Constructed Wetland with Hair Waste Modified Substrate

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Abstract

Background/Objectives: This work is conducted to study the secondary treatment efficiency of dairy wastewater using Constructed Wetland (CW) with keratin (hair) waste modified substrate. **Methods/Statistical Analysis:** A pilot Horizontal Sub-Surface Flow (HSSF) constructed wetland was built using HDPE plastic crates. Lemongrass (*Cymbsopoganflexuosus*) was planted in the constructed wetland system as the primary vegetation. Modification of substrate was done using keratin (hair) waste. Two dairy industries were considered based on the products manufactured. Batch feeding process with Hydraulic Retention Times of 24 h, 48 h and 72 h was adopted. **Findings:** The following parameters were analysed and studied; Bio-chemical Oxygen Demand, Chemical Oxygen Demand, Total Kjeldahl Nitrogen, Total Phosphorus and pH. The effect of varying Hydraulic Retention Times and modification of substrate by keratin waste were also studied. Results showed good removal efficiency of the pollutants by the pilot-scale constructed wetland system. Based on the analysis of the experimental trials, it was observe that the growth of *Cymbopoganflexuosus* had a positive impact on the removal efficiency of the pollutants considered. The modification of substrate by keratin waste also increased the removal efficiency of the pollutants. Proper stabilization of the CW system will have positive impact on the removal of TP by keratin waste modified substrate layer as the major removal of phosphorus is done by uptake from plant roots and even though if soil acts as an adsorbent and phosphorus having the tendency to be trapped on adsorbents, as hair is a good adsorbent. High BOD/COD ratio was also observed for the treated effluent. **Application/Improvements:** Modification of substrate by hair is not recommended for short hydraulic retention times as the compaction of modified substrate layer tends to restrict the movement of water resulting in lower flow rate.

Keywords: *Cymbopoganflexuosus* (Lemongrass), Constructed Wetland Dairy Wastewater, Hydraulic Retention Time, Keratin (hair) Waste

1. Introduction

Water is a resource without borders, irrespective of the borders being political or geographical. Water scarcity has become a global phenomenon, with more than 75% of the world's population living in a drier condition every day. The rapid rise in industrialization and urbanization is also aggravating the situation with an increase in water quality degradation. The growing number of human population means an increase in demand of food and water. This also means an increase in pollution levels, both industrial and agricultural, diseases and disasters caused due to lack of access to clean water and sanitation. With regulatory prohibitions, imposed by environmental protection agencies becoming more stringent, wastewater treatment has also become more expensive and compliance with the discharge quality standard is posing as a huge burden for the industries.

India is the world's largest producer of milk, accounting for more than 16% of the milk production in the world. It is also the largest consumer of milk and dairy products in the world, consuming much of its produce. The total

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amount of milk produced has tripled from 23 million tons back in 1973 to 95 million tons in 2008 and has reached a production level of 146.3 million tons in 2015[1]. Issues associated with dairy waste include the fact that majority of the waste produced by dairy processing industries is organic in nature and susceptible to faster decomposition causing problems in storage and handling. Further, dairy wastes include the discharge of nitrogen and phosphorus which can have an eutrophication effect on water bodies like lakes and ponds if the waste is discharged into them.

With the advent of new technologies and hardware, and with our understanding of natural processes, the calling for small and decentralized wastewater management systems has come. The idea of a complete sewerage system with a centralized treatment facility is next to impossible, for both economic and geographical reasons[2]. Constructed Wetlands (CW), is a lower cost, energy and technical-demanding wastewater treatment method, as evaluated through Cost-Benefit Analysis[3,4] when compared to a conventional wastewater treatment plant, have aroused more interests around the world. CWs have been applied for various wastewater treatments, such as sewage wastewater[5], industrial wastewater[6], rainstorm runoff in cities[7], wastewater out of farms[8], lake pollution[9].

Out of the various waste generated by anthropogenic activities, keratinous waste (e.g. skin, hooves, horns, hair, nails, teeth etc) is one among such kind of waste whose disposal is not an easy task . Numerous methods have been researched and applied to treat these wastes as biological decomposition is very time consuming, especially for hard keratin. Incineration is the most commonly adopted method, especially for hair which comes under municipal solid waste, in urban areas. Burning of these wastes releases gaseous pollutants which is again another issue altogether. Treating waste by another waste has always been a fascinating idea and at the same time, a challenging job. Adopting this technology can drastically improve the efficiency of any waste management system. Since, the role of natural biopolymers is safe, sound, and cost-effective and has certain advantages in green chemistry including prevention of environmental pollution, keratin application for the purification of metal contaminated natural and wastewater resources can be a promising technology[10-14].

This study intends to investigate the secondary treatment efficiency by a horizontal sub-surface flow constructed wetland (HSSF-CW), planted with *Cymbopoganflexuosus*, of dairy wastewater. The primary aim of the study is to identify an effective decentralized way of treating industrial effluent using CW after its primary treatment and to identify suitable wetland species on the basis of response to the natural variability of wastewater for tolerance, survival and growth and study the effect of hydraulic retention times (HRT). This study will also investigate the effect of modification of substrate with keratin waste (hair) on the treatment efficiency of the CW to meet deficiencies in treatment of dairy industry wastewater which lacks uniformity in the treatment process by providing a 'green' method of treating dairy industry wastewater after its primary treatment.

2. Materials and Method

2.1 Description of the Constructed Wetland System

The work was carried out at Manipal Institute of Technology located in Mani pal, Udupi District (13.34 °N, 74.78 °E) in Karnataka, India. This area experienced maximum and minimum average temperatures of 33.8 °C and 24 °C, respectively and an average rainfall of 4173 mm in 2015.

A pilot-scale CW is built wherein it is planted with *Cymbopoganflexuosus* (lemongrass) vegetation and a modification in substrate with steam treated keratin (hair) waste. The wetland cell is a HDPE plastic crate having internal dimensions of length, width, and depth of 610 mm, 405 mm and 305 mm respectively. The wetland units are provided with 1-2 % bottom slope. The media consists of a gravel bed underlain by an impermeable layer[15]. Gravels of size class of 20 mm and 12.5-17.5 mm were used. Gravels of 20 mm were packed to a height of 40 mm followed by gravels of size 12.5-17.5 mm of 30 mm height. This next layer is modified with steam treated keratin waste (hair) to a height of 40 mm followed by another 30 mm layer of gravels followed by sand to a height of 100 mm which was then covered by local sandy-clay-loam soil up to a height of 40 mm. The outlet zone is designed to allow variations in levels of water discharge. A 15 mm connector pipe was provided, with micro-meshing by synthetic fibres, at the posterior portion of the outlet connected to a 20 mm ball valve. The plastic crates are covered with black LDPE plastic sheets to prevent fungal and algal growth. Uniformity of the hair waste was maintained to a maximum of 2 cm.

2.2 Operation of the System

The systems began running at the beginning of Nov, 2015, which followed batch feeding process with influent loading rate of 8 litres for every batch. Batches, divided based on varying HRT i.e. 24 h, 48 h and 72 h, retention period were adopted. A 24 h period break was provided to the system after every batch. This research was over early May, 2016.

2.3 Sampling and Testing

Hair waste was collected from local salons and barber shops in and around the study area. Dairy wastewater samples were collected by grab sampling, after its primary treatment, from two industries located at Udupi (Industry I) and Bhramahvar (Industry II) districts of Karnataka. Pot culture study was carried out for 3 weeks, with dilution ratio of 30%, 50% and 70% wastewater, for the analysis of suitable concentration of industrial effluent that vegetation can withstand toxicity and grow well in the pilot scale model. The influent and effluent were analysed for Bio-chemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), using standard methods[16] and pH was measured using digital method.

3. Results and Discussions

3.1 Pot-Culture Study

Good observable growths were noticed in all the plants irrigated with dairy wastewater from collected from Industry I. Therefore, minimum dilution ratio of 30% was chosen. In the plants irrigated with dairy waste effluent collected from Industry II, stunted growth was observed, in the system fed with 30% dilution, as well as drying and curling of leaves. Therefore, dilution ratio of 50% was chosen. For safety reasons, the final dilution ratio to be adopted have an incretion of 10% i.e. 40% and 60% dilution of effluent from Industry I and Industry II, respectively.

3.2 Total Water Treatment Efficiency

During the period of experiment, concentrations of BOD, COD, TP and TKN were lower in the effluent water than in the influent, which differed significantly among the two systems.

The treatment efficiency of the constructed wetland differs for the wastewater generated by the two industries. Industry I reported lower concentrations of the pollutants being analysed than Industry II. As a result, the treatment efficiency of treating wastewater from Industry I is higher. The effect of varying HRT can be noticed for the parameters TKN, BOD, COD and TP, as it increases in efficiency with time. This can be contributed to its longer contact period with the keratin modified substrate.

The initial concentration of Industry I (Figure. 1) is lower than Industry II (Figure. 2) which resulted in the CW treating wastewater more successfully from Industry I as compared to Industry II. There is a very high removal efficiency of BOD and COD even though the influent was diluted before it was sent into the pilot scale CW both for Industry I (Figure. 1) and Industry II (Figure. 2) which gradually saturates at around 95% removal efficiencies (Table 3 and Table 4) at 72 h HRT. The removal rate of TKN is also high when compared to the removal rate of Total Phosphorus both for Industry I (Figure. 1) and Industry (Figure. 2). All parameters have maximum reduction at HRT of 72 h, except for TP of Industry II which has maximum reduction at HRT of 48 h.

There were intrusions by other local species of vascular plants in the CW system, which were immediately cleared off when they reached visible size of growth in order to let the lemongrass vegetation to work on the removal of nutrients on its own. Presence of algal biofilm was also

Table 1. Characteristics of dairy wastewater before and after treatment - Industry I

Parameter	Reported Conc. (mg/L, except for pH)	Hydraulic Retention Time (mg/L, except for pH)		
		24H	48H	72H
pH	6.4 ± .30	6.97 ± 0.46	7.14 ± 0.28	6.94 ± 0.61
TKN	74 ± 1.3	35.21 ± 2.42	33.31 ± 1.27	29.94 ± 1.31
BOD	1001 ± 24	105.33 ± 8.86	73.81 ± 8.83	56.73 ± 7.45
COD	1466.5 ± 5.5	121.63 ± 7.09	104.38 ± 1.38	94.47 ± 4.71
Phosphorus	36 ± 1.7	23.95 ± 1.77	24.55 ± 2.16	22.13 ± 1.01

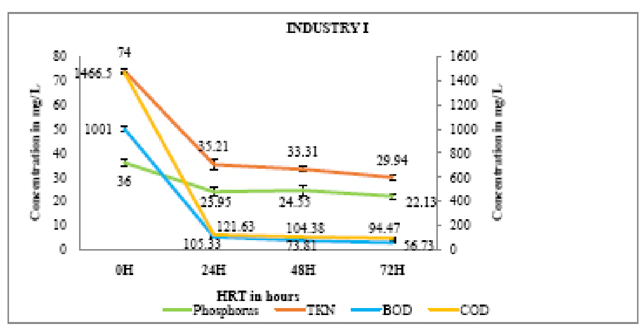

Figure 1. Reduction trend of pollutants w.r.t HRT – Industry I.

Table 2. Characteristics of dairy wastewater before and after treatment for Industry II

Parameter	Reported Conc. (mg/L, except for pH)	Hydraulic Retention Time (mg/L, except for pH)		
		24H	48H	72H
pH	6.1 ± 0.2	6.17 ± 0.54	6.9 ± 0.10	6.97 ± 0.11
TKN	97.63 ± 0.43	39.81 ± 1.18	44.28 ± 4.82	37.09 ± 0.76
BOD	2249.21 ± 9.38	153.53 ± 4.41	136.33 ± 15.86	114.21 ± 18.31
COD	3013.5 ± 38.5	260.08 ± 4.88	239.08 ± 21.09	209.55 ± 25.24
Phosphorus	37.55 ± 1.75	29.32 ± 1.30	28.38 ± 1.30	28.78 ± 0.61

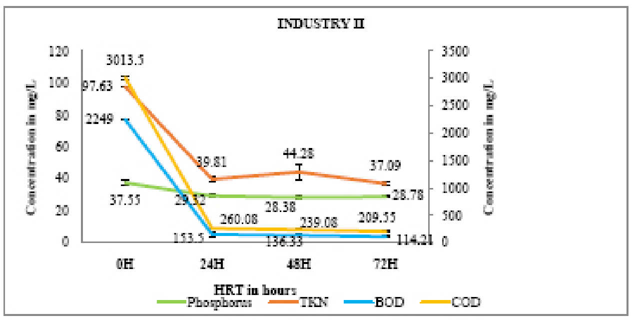

Figure 2. Reduction trend of pollutants w.r.t HRT – Industry II.

Table 3. Percentage reduction of pollutants w.r.t. HRT - Industry I

Parameter	Reported Conc. (mg/L, except for pH)	Hydraulic Retention Time		
		24H (%)	48H (%)	72H (%)
pH	6.4 ± .30	−7.53 ± 8.84	−11.013 ± 1.62	−7.26 ± 8.48
TKN	74 ± 1.3	55.01 ± 4.73	54.90 ± 1.62	74.64 ± 1.43
BOD	1001 ± 24	95.32 ± 0.40	96.72 ± 0.40	97.41 ± 0.28
COD	1466.5 ± 5.5	91.74 ± 0.46	92.90 ± 0.11	93.61 ± 0.30
Phosphorus	36 ± 1.7	23.91 ± 6.37	23.65 ± 6.04	31.15 ± 2.60

Table 4. Percentage reduction of pollutants w.r.t. HRT - Industry I

Parameter	Reported Conc. (mg/L, except for pH)	Hydraulic Retention Time		
		24H (%)	48H (%)	72H (%)
pH	6.1 ± 0.2	−1.068 ± 8.92	−12.01 ± 0.56	−8.20 ± 9.25
TKN	97.63 ± 0.43	58.86 ± 1.53	54.35 ± 4.91	61.82 ± 0.72
BOD	2249.21 ± 9.38	93.17 ± 0.19	93.93 ± 0.69	94.92 ± .82
COD	3013.5 ± 38.5	91.30 ± 0.17	92.13 ± 0.72	93.08 ± 0.87
Phosphorus	37.55 ± 1.75	24.26 ± 3.86	26.91 ± 3.76	26.50 ± 1.41

observed on the surface of the soil in small patches which dried up after the 24 h period break. The CW system also experienced a steady rise in the population of insects and regular visits by small animals.

Nitrogen and phosphorus are two of the main pollutants which cause eutrophication of water bodies. Nitrogen removal in constructed wetlands is achieved by volatilization, ammonification, nitrification/de-nitrification, plant uptake and matrix adsorption[17]. Wetlands use physical, chemical, and biological means to reduce phosphorus[18]. Organic pollutants are removed by a combined action of anaerobic and aerobic bacteria which yield energy by breaking down the carbon content in the wastewater which has more than 50% carbon content. The functions vary with temperature and it is possible that as temperatures increase greater amounts of gas can be released[19].

4. Conclusion

From results obtained from the analysis of the primarily treated dairy waste, it is observed that the BOD and COD are high both for Industry I and Industry II. It has also been observed that due to the varying product line from the two facilities and varying quantity in generation of wastewater, the environmental pollutants analysed from the second industry's wastewater have higher reported concentrations. Even though the discharge limit for Total Kjeldahl Nitrogen is met, the reported concentrations for both the industries are high.

Pot culture study shows that optimum concentrations can lead to healthy growth of plants and high concentrations led to negative physical changes, such as chlorosis, necrosis, uneven growth etc. Primary treatment of industrial effluent may be necessary in order to prevent clogging of root nodules and sand by particles, oil and grease etc. Based on the analysis of the experimental trials, we can observe that the growth of *Cymbopoganflexuosus* had a positive impact on the removal efficiency of the pollutants considered. The modification of substrate by keratin waste also increased the removal efficiency of the pollutants. The keratin modified substrate followed the removal mechanism of adsorption. Proper stabilization of the CW system will have positive impact on the removal of TP by keratin waste modified substrate layer as the major removal of phosphorus is done by uptake from plant roots and even though if soil acts as an adsorbent and phosphorus having the tendency to be trapped on adsorbents, as hair is a good adsorbent. The problem of using hair was the effluent flow rate was lower than the designed flow rate. This can be contributed to the compaction of the modified layer with time.

The removal mechanism of various pollutants in a CW system is a result of combination of actions by hydrology, microbes, vegetation (vascular and non-vascular), substrates and insects and animals. Even though the effluent properties of the wastewater treated by the pilot-scale CW do not meet the discharge standards, good reduction efficiency was obtained and incorporating another similar system will further treat it and make it meet the relevant standards. Hence, based on the analysis after treatment of dairy industrial wastewater in HSSF-CW, with modified substrate by keratin waste, it can be said that wetland vegetated with *Cymbopoganflexuosus* is working well in degradation of waste with BOD/COD ratio as high as 0.8 and is suitable for tropical and sub-tropical Indian climates.

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