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Assessment of Secondary Treatment Efficiency of Dairy Wastewater using Pilot Constructed Wetland with Lemongrass (*Cymbopogan flexuosus)*

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Abstract—*This comparative study intends to investigate the secondary treatment efficiency by two sub-surface constructed wetlands, one planted with Cymbopogan flexuosus and one kept unplanted, of dairy wastewater from dairy industry selected based on the products manufactured. The primary aim of the study is to identify an effective decentralized way of treating industrial effluent using constructed wetland after its primary treatment and to check the response of Cymbopogan flexuosus to study the effect of varying hydraulic retention times and the natural variability of wastewater for tolerance, survival and growth. It also aims to meet deficiencies in lack of uniformity in the treatment process by providing a cost-effective and decentralized method of treating dairy industry wastewater after its primary treatment. Two dairy industries were considered based on the products manufactured with the objective of attaining standard effluent discharge limits after treatment. Pot culture study was conducted to determine the dilution ratio of wastewater to be fed. Horizontal Sub-surface flow regime and Batch feeding process with Hydraulic Retention Times of 24 h, 48 h and 72 h were adopted and the following parameters were analyzed and studied; Bio-chemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP) and pH. The effect of varying Hydraulic Retention Times on the removal efficiency of the parameters were studied. Comparative analysis between the results of the two constructed wetland viz. the unplanted one and the one planted with Cymbopogan flexuosus showed good removal efficiency of the pollutants by the pilot-scale constructed wetland system with Cymbopogan flexuosus. 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.*

1. INTRODUCTION

At the beginning of the 21st century, the world faces a water crisis, both of quantity and quality, caused by continuous population growth, industrialization, food production practices, increased living standards and poor water use strategies. Wastewater management or the lack of has a direct impact on the biological diversity of aquatic ecosystems, disrupting the fundamental integrity of our life support systems, on which a wide range of sectors from urban development to food production and industry depend[1]. Many sources of Wastewater, irrespective of the source, will discharge harmful and sometimes toxic and hazardous pollutants. These sources include but are not limited to agricultural and livestock farms, communities, villages, homes, urban areas and industries. Many of these discharges are either unregulated or are ignored. The impact of these discharge are not only limited to and resisted by the natural environment, whose innate capacity to treat and tolerate environmental pollutants in wastewater going well beyond the threshold limit, but is also impacting affecting various economic sectors ranging from health to industry, agriculture, fisheries and tourism. In all cases, it is the poorest that are the most severely affected.

India accounts for almost 17% of the world's total milk production and is the world's largest producer of milk. It also ranks at the top for being the largest consumer of milk and dairy products in the world, consuming much of its produce. The total amount of milk produced has tripled from 23 million tonnes back in 1973 to 95 million tonnes in 2008 and has reached a production level of 146.3 million tonnes in 2015[2]. Wastewater, in a dairy industry, is generated, mostly in pasteurization, homogenization of fluid milk and the production of dairy products such as butter, cheese, milk powder etc. High BOD and COD contents, high levels of dissolved or suspended solids including fats, oils and grease, nutrients such as ammonia or minerals and phosphates are characteristics of dairy wastewater and therefore require proper attention before disposal. Wastewater from dairy industry creates severe water pollution, which seriously endanger the natural environment with Eutrophication being the prevailing major water quality problem due to presence of nutrients viz. Nitrogen and Phosphorus.

The idea of a complete sewerage system with a centralized treatment facility differed with the ground reality situations from what was conceptualized for reasons, both economically and geographically[3]. Small and decentralized wastewater management systems are the need of the hour, with the advent of new technologies and hardware, and our increasing knowledge of natural processes, for a better sustainable way of wastewater management. Decentralized

Wastewater Management may be defined as the collection, treatment, and reuse/dispersal of wastewater from individual homes, clusters of homes, isolated communities, industries, or institutional facilities at or near the point of waste generation[4]. One of the popular decentralized system of wastewater treatment is by the method of constructed wetlands and have been recognized as attractive alternatives to conventional wastewater treatment methods. 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]. This is due to their high pollutant removal efficiency, easy operation and maintenance, low energy requirements, high rates of water recycling, and potential for providing significant wildlife habitat[10] [11].

This comparative study intends to investigate the secondary treatment efficiency by two sub-surface constructed wetlands, one planted with *Cymbopogan flexuosus* and one kept unplanted, of dairy wastewater collected from two different dairy industry selected based on the products manufactured. The primary aim of the study is to identify an effective decentralized way of treating industrial effluent using constructed wetland after its primary treatment and to check the response of *Cymbopogan flexuosus* to study the effect of varying hydraulic retention times and the natural variability of wastewater for tolerance, survival and growth. It also aims to meet deficiencies in lack of uniformity in the treatment process by providing a cost-effective and decentralized method of treating dairy industry wastewater after its primary treatment[12] [13].

2. MATERIALS AND METHOD

2.1. Description of the Constructed Wetland System

The work was carried out at Manipal Institute of Technology located in Manipal, 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.

Two pilot-scale constructed wetlands are built wherein one is kept unplanted (System I) and one is planted with Cymbopogan flexuosus (lemongrass) vegetation (System II). HDPE plastic crates were used as the wetland cell. Internal dimensions of length, width, and depth are 610 mm, 405 mm and 305 mm, respectively. Bottom slopes of 1-2 % were provided for the wetland units. Gravel bed underlain by an impermeable layer was used as the media. Gravels of size class of 20 mm and 12.5-17.5 mm were used. 20 mm gravels were packed to a height of 40 mm. The following layer is up to a height of 90 mm consisting of 12.5-17.5 mm gravels. The next layer of substrate is sand compacted to a height of 100 mm which was then covered by local sandy-clay-loam soil till the top (approximately 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 fibers at posterior end, at the outlet connected to a 20 mm ball valve. Black LDPE plastic sheets are used for fungal and algal growth prevention on the wetland cell units.

2.2. Operation of the System

Batch feeding mode was adopted with variations in HRT of 24 h, 48 h and 72 h. The pilot scale CW began running in the beginning of Nov, 2015, with influent loading rate of 8 liters for every batch. A 24 h period break was provided to the systems after every batch. This research was over early May, 2016.

2.3. Sampling and Testing

The two dairy industries selected are located at Udupi (Industry I) and Bhramahvar (Industry II) districts of Karnataka. The samples were obtained by grab sampling after its primary treatment. Dilution ratios of 30%, 50% and 70% wastewater were adopted for pot culture study to analyze the suitable concentration of industrial effluent that vegetation can withstand toxicity and grow well in the pilot scale model. The influent and effluent were analyzed for Bio-chemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), Total Solids (TS) using standard methods[14] and pH and Turbidity were measured using digital method. A total of three trials were conducted for each group of batch.

3. RESULTS AND DISCUSSIONS

3.1. Pot-Culture Study

30% dilution ratio was chosen for plants irrigated with dairy wastewater from collected from Industry I as good observable growths were noticed in all the plants. In the plants irrigated with dairy waste effluent collected from Industry II, stunted growth, drying and curling of leaves were observed, in the system fed with 30% dilution. Therefore, dilution ratio of 50% was chosen. An incretion of 10% i.e. 40% and 60% dilution of effluent from Industry I and Industry II, respectively were adopted for safety measures.

3.2. Total Water Treatment Efficiency

As Table 1, Table 2, Table 3 and Table 4 shows lower concentrations of BOD, COD, TP, TKN, TS and turbidity were lower in the effluent water when compared to the influent, which had significant difference in the two types of wetland CW, during the experimental period. Vegetation of lemongrass showed more positive results.

Table 1: Characteristics of dairy wastewater before and after treatment – Industry I

Parameter	Reported Conc. (mg/L, except for pH)	System I		
		24H	48H	72H
pH	6.4±.30	6.6±0.77	7.27±0.14	6.92±0.43
TS	2165±19	711.58±18.12	685.09±26.14	727.15±54.80
TKN	74±1.3	64.37±1.44	62.64±1.91	63.36±1.81
BOD	1001±24	245.61±14.96	213.41±18.19	180.14±3.43
COD	1466.5±5.5	178.99±37.11	194.05±12.65	171.92±2.54
TP	36±1.7	34.20±5.12	36.28±7.51	39.82±3.14

Table 2: Characteristics of dairy wastewater before and after treatment – Industry I

Parameter	Reported Conc. (mg/L, except for pH)	System II		
		24H	48H	72H
pH	6.4±.30	6.97±0.44	6.9±0.82	6.55±0.55
TS	2165±19	614.49±37.73	558.52±71.73	571.99±14.17
TKN	74±1.30	35.57±9.53	32.81±4.73	28.71±0.78
BOD	1001±24	112.80±16.75	91.30±10.11	59.43±8.05
COD	1466.5±5.5	124.84±10.36	114.31±8.36	99.4±5.53
TP	36±1.7	33.43±4.68	29.93±5.86	29.27±6.81

Table 3: Characteristics of dairy wastewater before and after treatment – Industry II

Parameter	Reported Conc. (mg/L, except for pH)	System I		
		24H	48H	72H
pH	6.1± 0.2	6.59±0.66	6.56±0.52	6.53±0.61
TS	2720±30	722.69±31.03	714.35±14.55	729.07±14.01
TKN	97.63±0.43	85.47±1.31	86.04±3.14	86.41±2.34
BOD	2249.21±9.38	283.50±6.20	271.13±8.87	255.04±6.35
COD	3013.5±38.5	438.28±7.46	425.46±14.7	398.13±9.65
TP	37.55±1.75	44.83±1.27	43.75±1.89	41.85±2.80

Table 4: Characteristics of dairy wastewater before and after treatment – Industry II

Parameter	Reported Conc. (mg/L, except for pH)	System II		
		24H	48H	72H
pH	6.1± 0.2	6.17±0.65	6.58±0.47	6.92±0.11
TS	2720±30	584.23±11.27	610.18±37.80	631.69±21.21
TKN	97.63±0.43	44.36±4.77	40.35±1.29	44.6±3.37
BOD	2249.21±9.38	134.85±9.32	119.84±8.54	104.34±8.53
COD	3013.5±38.5	239.93±7.17	216.19±17.57	198.87±14.74
TP	37.55±1.75	36.14±5.49	41.19±6.70	31.31±0.10

The treatment efficiency of the constructed wetlands differs for the wastewater generated by the two industries with System II having a higher efficiency. The effect of varying HRT can be noticed for the parameters TKN, BOD, COD and TP, as it increases in efficiency with time. The initial concentration of Industry I is lower than Industry II which resulted in both the CW systems 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 System II both for Industry I and Industry II which gradually saturates at around 95% removal efficiencies 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 and Industry II. All parameters have maximum reduction at HRT of 72 h for System II, with exceptions for TP.

Table 5: Percentage reduction of pollutants w.r.t. HRT - Industry I

Parameter	Reported Conc. (mg/L, except for pH)	System I		
		24H (%)	48H (%)	72H (%)
pH	6.4±.30	-1.559±9.40	-11.61±0.15	-7.19±8.56
TKN	74±1.3	12.64±1.25	14.87±2.89	13.86±3.01
BOD	1001±24	89.09±0.63	90.51±0.80	91.99±0.16
COD	1466.5±5.5	87.85±2.51	86.8±0.84	88.37±0.16

TP	36±1.7	-8.72±17.54	-12.86±22.93	-23.81±8.77

Table 6. Percentage reduction of pollutants w.r.t. HRT - Industry I

Parameter	Reported Conc. (mg/L, except for pH)	System II		
		24H (%)	48H (%)	72H (%)
pH	6.1± 0.2	-7.481±8.57	-7.06±9.06	-1.37±9.47
TKN	97.63±0.43	58.67±3.64	55.63±6.07	60.96±1.34
BOD	2249.21±9.38	94.99±0.73	95.99±0.40	97.36±0.35
COD	3013.5±38.5	91.52±0.72	92.23±0.54	93.27±0.36
TP	37.55±1.75	-5.96±13.77	7.04±16.98	9.12±20.33

Table 7: Percentage reduction of pollutants w.r.t. HRT - Industry II

Parameter	Reported Conc. (mg/L, except for pH)	System I		
		24H (%)	48H (%)	72H (%)
pH	6.1± 0.2	-7.79±8.98	-5.87±7.91	-7.45±8.77
TKN	97.63±0.43	11.74±0.97	11.29±3.26	11.05±2.03
BOD	2249.21±9.38	87.39±0.3	87.93±0.39	88.66±0.26
COD	3013.5±38.5	85.35±0.26	86±0.44	86.86±0.22
TP	37.55±1.75	-15.79±3.98	-12.66±5.59	-6.88±7.15

Table 8: Percentage reduction of pollutants w.r.t. HRT - Industry II

Parameter	Reported Conc. (mg/L, except for pH)	System II		
		24H (%)	48H (%)	72H (%)
pH	6.1± 0.2	-0.91±8.26	-6.38±8.72	-13.96±0.07
TKN	97.63±0.43	54.19±4.74	58.4±1.26	54.07±3.68
BOD	2249.21±9.38	94.01±0.42	94.66±0.37	95.36±0.38
COD	3013.5±38.5	91.98±0.24	92.88±0.60	93.44±0.44
TP	37.55±1.75	6.58±14.83	-6.13±17.81	20.04±0.16

The CW system experienced a steady rise in the population of insects and small animals. In order for the lemongrass vegetation to work alone on the removal of, intrusions by other local species of vascular plants in the CW system were immediately cleared off when they reached visible size of growth. Presence of algal bio-film was also observed on the surface of the soil in small patches which dried up after the 24 h period break. Nitrogen and phosphorus are two of the main pollutants which cause eutrophication of water bodies. Nitrogen removal in constructed wetlands is achieved by volatilization, plant uptake, matrix adsorption, ammonification and Nitrification/de-nitrification[15]. Wetlands use physical, chemical, and biological means to reduce phosphorus[16]. 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[17].

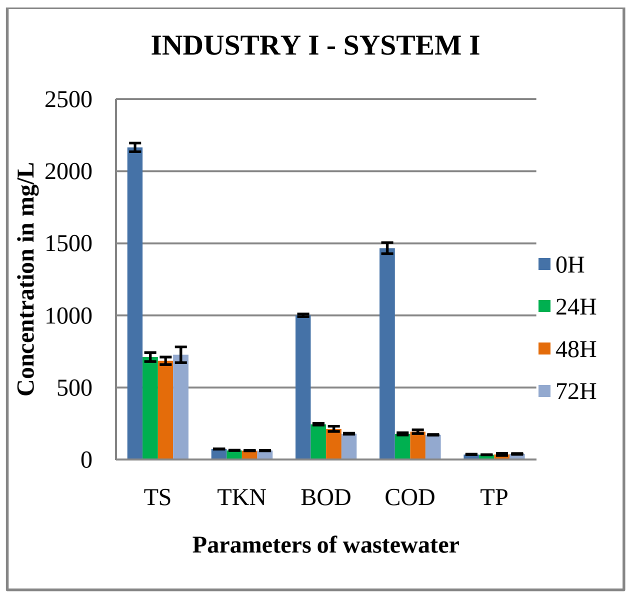

Figure 1: Reduction trend for wastewater treated by System I from Industry I for different HRT

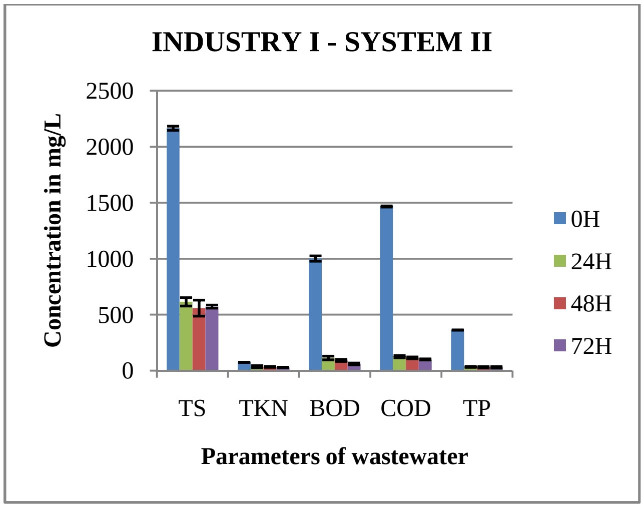

Figure 2. Reduction trend for wastewater treated by System II from Industry I for different HRT

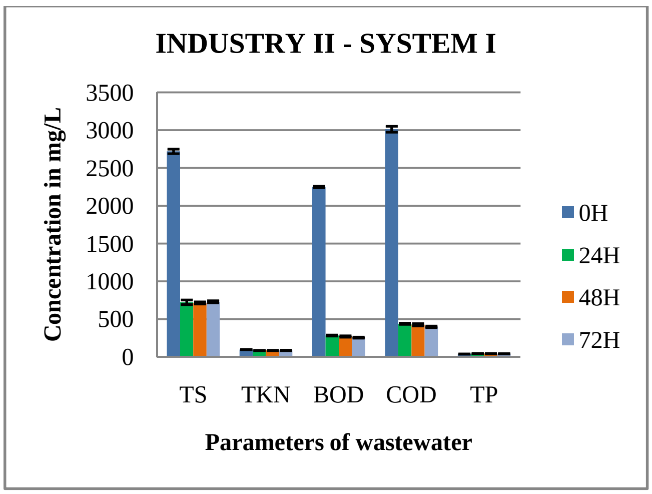

Figure 3. Reduction trend for wastewater treated by System I from Industry II for different HRT

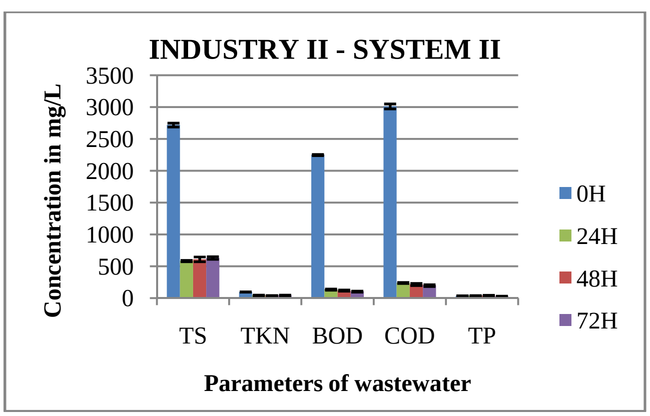

Figure 4. Reduction trend for wastewater treated by System II from Industry II for different HRT

4. CONCLUSION

It was Industry II reported higher concentrations of the parameters analyzed. The BOD and COD concentrations are high both for Industry I and Industry II. The TKN concentrations met the discharge standards but are still high. This can be contributed from the fact that the varying product line from the two facilities and varying quantity in generation of wastewater.

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. To prevent clogging of root nodules and sand by particles, oil and grease etc., primary treatment of industrial effluent is necessary.

Based on the analysis of the experimental trials, we can observe that the growth of *Cymbopogan flexuosus* had a positive impact on the removal efficiency of the pollutants considered. Since the major removal of phosphorus is done by uptake from plant roots, even though it is also removed by soil, stabilization of the CW system will have positive impact on the removal of TP.

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 it can be said that wetland vegetated with *Cymbopogan flexuosus* is working well in degradation of waste with COD/BOD ratio as low as 1.25 and is suitable for tropical and sub-tropical Indian climates.

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