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Advanced treatment of dairy industrial wastewater using vertical flow constructed wetlands

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ABSTRACT

Given the global increase in water consumption and the shortage of water resources, the global water crisis can be controlled through the utilization of current technology. Due to increasing water demand in industries, we have to replace the use of purified water with treated industrial wastewater to avoid further consumption of drinking water. Phytoremediation is a scientific, environmental cost-effective plant-based approach of remediation which can remove different contaminates such as heavy metals, rare elements, organic matters, petroleum products, and radioactive pollutants from water and soil. In this study, three constructed wetlands with vertical down flow were used. Bed number 1 remained unplanted as a blank (control), while reeds (*Phragmites australis*) and Rushes (*Juncaeae* spp.) were planted in beds number 2 and 3, respectively. Dairy wastewater was loaded on beds in saturated regime. Sampling was carried out daily and was transferred to the laboratory for analysis. The results showed the reduction of 67.62%, 93.62%, and 92.33% in chemical oxygen demand, and 78.50%, 86.04%, and 84.18% in total suspended solids for beds number 1, 2, and 3, respectively. Moreover, turbidity decreased from 246 to 74.7 NTU, 51.8, and 40.7 with the efficiency of 69.63%, 78.94%, and 83.46% for beds number 1, 2, and 3, respectively. The initial pH was 7.83 and decreased to 6.86 for bed number 1 and increased to alkaline value, as the final pH was 8.45 and 8.71 for bed 2 and bed 3; however, this range of pH is the optimum range for nitrogen removal process for both of the planted constructed wetlands. This method, which provides an efficient cost-effective treatment, also proved the important role of plants in constructed wetlands.

Keywords: Aquatic macrophyte; Macrophyte; Phytoremediation; Phragmites

1. Introduction

Wetlands have been used for centuries to drain sewage although the main reason is the convenience of sewage disposal rather than the sewage purification targets [1]. This occurs due to the lack of fund, or special skills and experiences required for the purpose of construction, the management and utilization of highly centralized facilities in developing countries, and also the untreated sewage disposed into multiple acceptor waters resources. The contradiction between developed and developing countries leads to a common requirement for alternative treatment methods in which an acceptable performance with minimal cost is merged. Due to the increasing environmental warnings and concerns, more parameters have been added to the pre-requisite conditions for new treatment methods so that the new methods must be sustainable with less environmental impact [1].

Phytoremediation, a scientific, environmental cost-effective plant-based approach of remediation, can remove different contaminates such as heavy metals, rare elements, organic matters, petroleum products and radioactive pollutants from water and soil. The presence of plant helps to

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prevent the wind and flood decay and the entry of contaminants into groundwater as well.

The global warming and drought have limited the access to fresh and healthy water [2]. By exploiting and utilizing current technology, we can prevent the widespread crisis of drinking water resources. Given the global increase in drinking water consumption and the shortage of water resources, the global water crisis can be controlled through the utilization of the current technology [3]. Due to the increasing water demand in industries, we have to replace the use of purified water with treated industrial wastewater to avoid further consumption of drinking water [4]. The wastewater, which was once considered as a source of contamination, is now in the list of new sources of water supplies [5].

Today the dairy industries are growing due to the need for providing communities with milk and its products. As a result, the need for water at various stages of these industries as well as the produced wastewater is increasing [6]. Dairy wastewater usually contains high values in biological oxygen demand $(BOD)_5$ (500–2,600 mg/L), chemical oxygen demand (COD) (2,000–7,000 mg/L), oil (90–500 mg/L, including fat, oil, and grease), nutrients (30–100 mg/L total nitrogen, 20–100 mg/L total phosphorus), suspended solids (200–1,000 mg/L), lactose, and detergents [7]. In addition, Whey is the most common wastewater of these industries, and the high contamination of dairy wastewater is a potential threat for the environment and ecosystem, especially if it is raw or just pre-treated [7].

In Iran, a dairy wastewater is mostly released to the environment after a pre-treatment stage, which leads to many environmental hazards since it has high values in BOD_5, COD, total suspended solids (TSS) and turbidity. However, it could be recycled and utilized in various applications such as heat exchanger systems and cooling towers or agricultural uses.

The domestic research on this subject has been basic or general studies [8] and reviews [9], for example the cases of urban sewage treatment [10–13] or the removal of particular types of pollutants [4,12,14–17]. However, there is no study having an approach to the treatment of dairy wastewater in Iran.

Similarly, only a few non-domestic studies have studied the methods of treating dairy wastewater [6,18–21]. For example, Bhutiani et al. [6] reported 75% and 54% removal of turbidity from 648 NTU in case of Eichornia (486 NTU) and Lemna (350 NTU) plants, respectively. In another study, Zingade [18] recorded that the pH value is observed nearly neutral, while COD reduces about 65%–70% and dissolved oxygen (DO) increases above 4.5mg/L. Furthermore, Queiroz et al. [20] showed that the best performance in the reduction of the organic matter was observed for *Polygonum* sp. (87.5% COD and 79.6% BOD) and *Eichhornia paniculata* (90% COD and 83.7% BOD) at dilution D1 (with an initial 3,133.63 mg/L of COD) on the 8th day of the experiment. The highest total solids removal was also observed for *Polygonum* sp. (32.2%) on the 4th day at dilution D2 (with an initial 2,506.53 mg/L of COD).

The importance of plant species in CWs is quite known and their positive impacts on the operation of the system have also been proven. It has now generally been accepted that CW plants offer a range of benefits and contribute to the creation of the necessary conditions which directly or indirectly affect the system efficiency [17].

2. Methods and materials

The macrophytes used in this study include *Phragmites australis* and *Juncaeae* spp, which are able to live and grow in mild, tropical, and subtropical climates, as well as in the saturated soils with brackish or saline water. The macrophytes were gathered in June from different local ponds in which water remains most time of the year. Next, the collected macrophytes were placed into civil pipe line water for 8 weeks in order to adapt themselves to the new environment and form a stable condition and get new roots of plant.

The constructed wetlands in this study include three galvanized steel cylindrical containers with dimensions of 100 cm height and 20 cm diameter with an approximate volume of 30 liters which were used as pilot mode. The CW1 was unplanted as blank, the CW2 was planted with *Phragmites australis*, and the CW3 was planted with *Juncaeae*. The CWs were filled from bottom to top as the description shown in Fig. 1:

1st layer: 10 cm of 40–80 mm stone (bottom),
2nd layer: 20 cm of 20–40 mm gravel,
3rd layer: 20 cm of 10–30 mm gravel,
4th layer: 20 cm of 1–3 mm sand,
5th layer: 20 cm of soil,
6th layer: The rest space remained free for loading wastewater (top).

After 8 weeks of the adaption of macrophytes, the CWs was planted in August and the macrophytes planting process started from the top of 10–30 gravel layer and almost continued to the top of the container which was filled with a thin layer of the soil. At the end of the study, we pulled out the substrate and observed that the roots of the plants had grown in the layers of soil and 1–3 mm sand as shown in Fig. 1 (the area which is called as root zone) and Fig. 2.

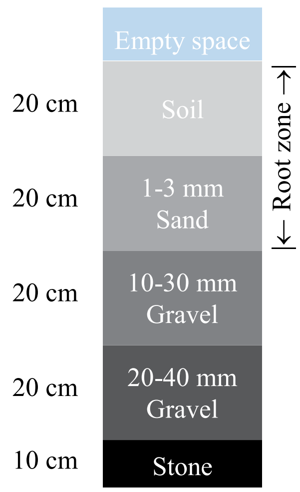

Fig. 1. Schematic layout of filtering layers.

Fig. 2. Plant grows until it reach to the 10–30 mm gravel layer.

Fig. 3. Vertical flow constructed wetlands during outdoor growth period.

The CWs was filled with water for 4 weeks (6 d saturated with water and the 7th day discharging the bed). In order to prevent macrophytes from getting shocked with wastewater, the CWs was irrigated with diluted wastewater with ratio of 1 to 3 for one week, then with ratio of 2 to 3 for next week before the main wastewater treatment process started.

The dairy wastewater used in this study was an effluent of sedimentation pond of treatment plant which was collected after anaerobic and aerobic wastewater treatment units of a local dairy industry.

The CWs were placed outdoors during the growth period (Fig. 3) which was then brought indoors (in a 4 m × 4 m room) for the experiments with temperature of 18°C–24°C during this study. The plants received daylight through a window as shown in Fig. 4 during the days and with a combination of two (one white and one yellow colored) 36 W FPL energy saving compact fluorescent lamps with the intensity of 70 Lu/W during the nights (the procedure timeline is shown in briefly). The wastewater was loaded into each CWs with volume of 10 L and flow rate of 5 L/min as a vertical down flow until the bed became full and remained in a saturated regime for 8 d. The full procedure timeline is presented in Table 1.

Sampling used in this study was carried out from the bottom of CWs every 24 h as 500 mL sample and was immediately transferred to laboratory with ice for COD, TSS, Turbidity and pH analyses. For each bed, 3 cycles of 8 d were conducted, and the final data were the mean values.

Table 1
Procedure timeline

Process	Date/Duration		Status
Gathering of macrophytes	From the beginning of June		Outdoor
Remained in water for rooting	8 weeks		Outdoor
Planting macrophyes in CWs	From of the beginning of August		Outdoor
CWs remained saturated with water (4 Cycles)	6 d saturated	1 d drained	Indoor
	6 d saturated	1 d drained	
	6 d saturated	1 d drained	
	6 d saturated	1 d drained	
Diluted wastewater was added to CW (1 to 3)	1 week		Indoor
Diluted wastewater was added to CW (2 to 3)	1 week		Indoor
Sampling and tests (3 cycles)	1 month since the middle of October		Indoor

Fig. 4. Vertical flow constructed wetlands during the sampling, indoors with temperature range of 18°C–24°C.

The COD test was carried out using AQUALYTIC ET125 and AQUALYTIC AL800 devices with AQUALYTIC vials. The TSS was measured through the dry weight differential of a paper filter from which the sample passed through a Büchner funnel into the Büchner flask via a vacuum pump. The turbidity test was also carried out using AQUALYTIC AL450T-IR device and pH with ISTEK pH/ISE meter pH-25N device.

3. Results and discussions

The wastewater used in this study had 2100 ± 27.43 mg/L of COD, 1872.4 ± 74.62 mg/L of TSS, 246 ± 5.10 NTU of Turbidity and 7.83 ± 0.07 of pH, which were all considered as the mean values and standard deviation of each of the three runs.

COD is used to determine the oxygen equivalent of the organic materials in the wastewater which can be oxidized. As shown in Fig. 5, COD decreases from 2100 mg/L to below 200 mg/L, which indicates that the treated wastewater can be utilized for agricultural applications. The mean COD reduction for CW1 (blank), CW2 (*Phragmites australis*), and CW3 (*Juncaeae*) were reported 67.62%, 93.62%, and 92.33%, respectively. The COD removal done through the phytoremediation process highly depends on the microbiological degradation of the pollutants in the plant roots degradation of organic, whereas the inorganic matter depends on the amount of oxygen in the CWs during the process. As shown in Fig. 5, the COD removal was significant for the first day of treatment (32.71%, 70.29%, and 67.9% for blank, *Phragmites*, and *Juncaeae*, respectively) and the reduction of COD over the time. From the 2nd to the 8th day, the aerobic micro-organisms consumed the amount of DO of the bed, while the reduction of DO in bed led to the reduction the activities of micro-organisms. In this way, the reduction amount of COD gradually decreases over the time.

As we had a better COD reduction in the planted CWs as compared with the unplanted CW (as a blank or control CW), we can conclude that the plants have essential roles in transferring oxygen to bed through the roots, up taking the pollutants, creating a suitable biofilm for batteries and providing feed for them in a better way.

However, the COD removal did not differ significantly between these two macrophyte species although *Phragmites australis* had slightly higher removal efficiency than *Juncaeae* species.

TSS represents all particles suspended in the water but not filtered out through a normal filter. A high TSS results in increased sediment build up, lowering DO levels and increasing pathogenic activities [22,23]. Changes in TSS highly depend on the type of filter through which the wastewater passes. The density of macrophyte's root zone is an important term which makes a simple sand-gravital filter into a more compacted filter with a sticky phase for suspending solids.

Moreover, the raw wastewater had a TSS load of 1,872.4 ± 74.62 mg/L. The highest mean removal efficiency was recorded for the *Phragmites australis* in CW2 by 86.04% as compared with 84.18% for *Juncaeae* species in CW3 and 78.50% for the control bed in CW1 (Fig. 6). Influent TSS was reduced by treatment in the planted CWs as compared with unplanted CW (blank) during the entire monitoring period. However, the TSS removal did not had a significant difference between the two plant species, wheras the difference between the planted and unplanted CWs was clearly obvious.

A reduction in Turbidity was satisfying since it reduced from 246 ± 5.10 NTU as initial value to 74.7 ± 1.07 NTU, 51.8 ± 2.27 NTU, and 40.7 ± 1.24 NTU and that we had a mean reduction of 69.63%, 78.94%, and 83.46% for CW1 (control bed), CW2 (*Phragmites australis*), and CW2 (*Juncaeae*), respectively. However, CW3 (*Juncaeae*) had a better turbidity reduction in comparison with CW2 (*Phragmites australis*), while both of them acted close to each other. However, the differeneces between the planted and unplanted CWs was quite obvious as shown in Fig. 7.

In addition to turbidity, the color of waste water changed from dark brown to very light yellow.

The results showed that the presence of macrophyte leads to acidity reduction in CWs. In the CW1 (control), pH

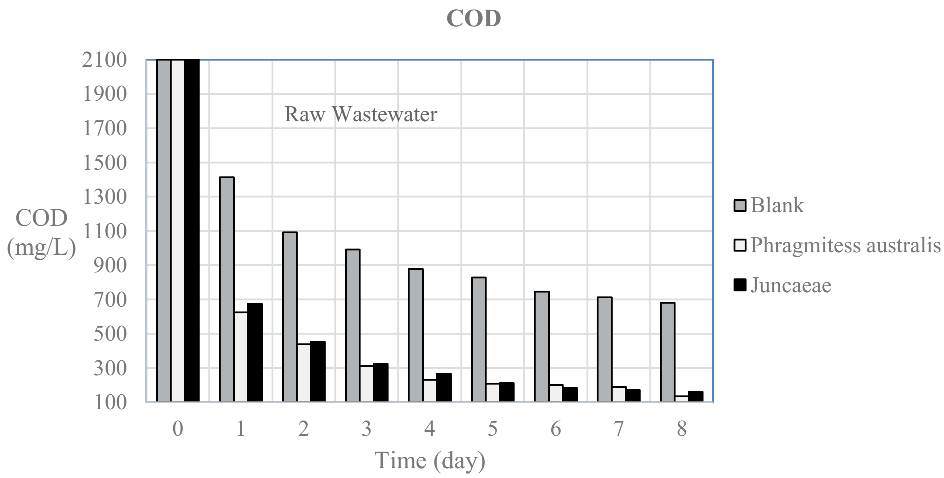

Fig. 5. COD per day changes in CWs (day 0 refers to raw wastewater).

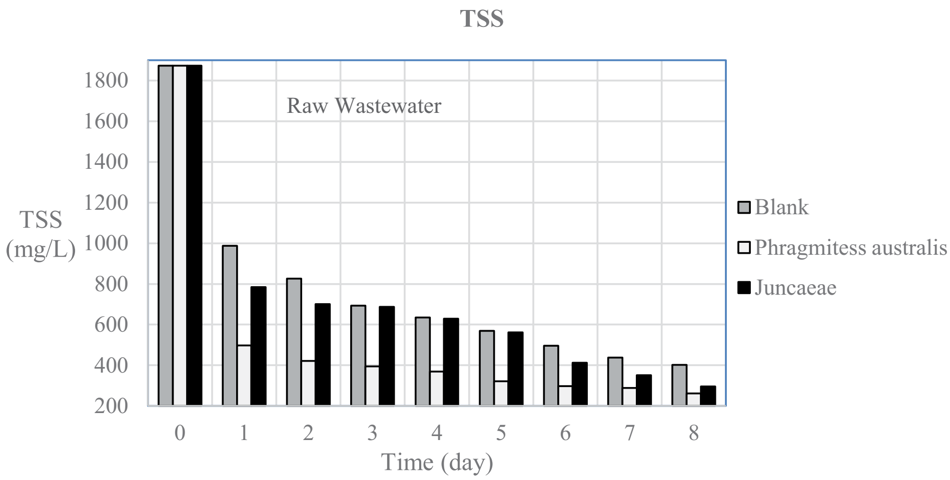

Fig. 6. TSS per day changes in CWs (day 0 refers to raw wastewater).

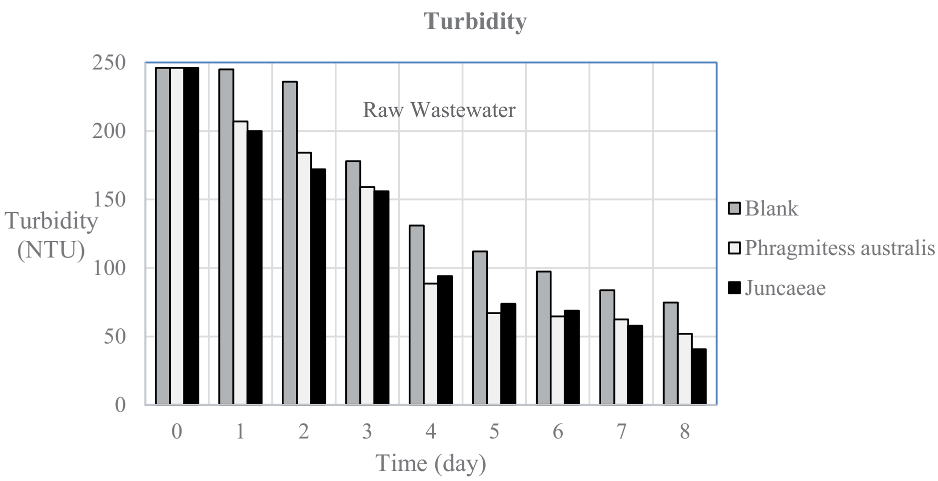

Fig. 7. Turbidity per day changes in CWs (day 0 refers to raw wastewater).

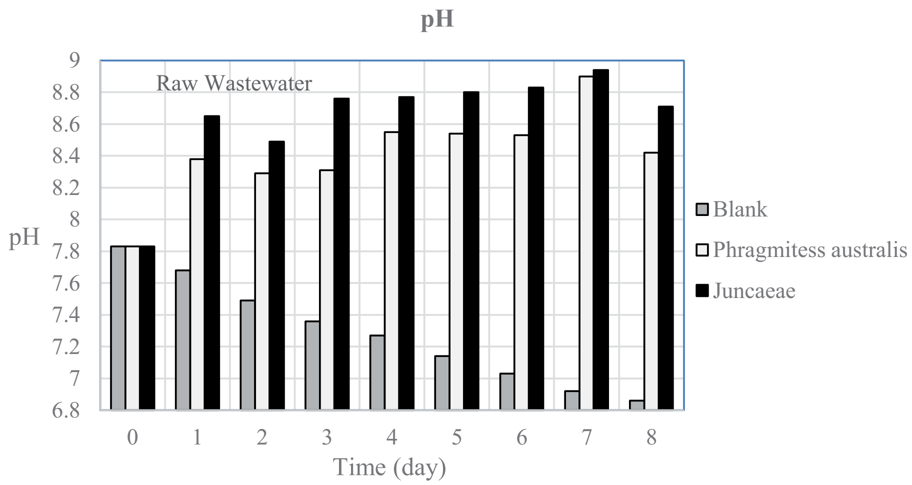

Fig. 8. PH changes per day in CWs (day 0 refers to raw wastewater).

value consistently deceased, and the water became acidic to approximate pH of 6.86 ± 0.05, whereas in the planted CW2 and CW3, the pH value of water increased to 8.42 ± 0.02 and 8.71 ± 0.02, respectively as shown in Fig. 8. The removal of acidity from the wastewater may be due to the degradation of acid in the root zone environment.

In fact, the pH affects the biological activities occurring during the treatment of wetlands and potentially influences the efficiency of the nutrient removal. On the other hand, the nitrifying bacteria are very sensitive to pH and the Nitrosomonas has an optimal pH between approximately 7.0 and 8.0, and the optimum pH range for Nitrobacterium is approximately 7.5 to 8.0. Thus, an increase in pH (to greater than 9) may reduce the occurrence of nitrification process. However, fortunately the pH used in this study did not exceed to this range although pH has an effect on plant growth and the low pH value can completely stop the plant growth.

The pH remained in range of 7–9 in the planted CWs (CW2 and CW3) during the treatment period, which is the optimum range for this purpose. Changes in pH were also small during the period of experiment; therefore, it shows that a planted CW can control the pH in an acceptable range and can be useful for further studies.

4. Conclusion

It is observed that constructed wetlands with macrophytes in vertical subsurface flow can be a good alternative for dairy wastewater treatment in comparison with the conventional wastewater treatment methods. In this regard, macrophytes play an essential role due to the oxygen diffusion to the CW from their roots, which provide oxygen for aerobic bacteria and helps to uptake the nutrients. Furthermore, maximum pollutant removal was found in *Phragmites australis* CW; therefore, i can be concluded that *Praghmites australis* had better performance in pollutants removal of dairy industry effluent in comparison to *Juncaeae* spp.

The results showed that COD decreased from 2,100 mg/L to below 200 mg/L (93.62% and 92.33%) for the planted CWs. This is a better result than the reported findings by Zingade [19] (i.e., 65%–70% and 87.5%–90%). The study indicated a high reduction of TSS from over 1,800 to below 300 mg/L (86.04% and 84.18%). The Turbidity value was also shown to have 78.94% and 83.46% reductions (from 246 to below 50 NTU), which is a very satisfying result comparing with the reported 75% and 54% by Bhutiani et al. [6]. The pH also remained between 7–9, which is a very desireble range for expecting N and OM removals.

COD is the most important parameter in the quality of wastewater, especially when it is released to the environment. Using vertical flow constructed wetland (VFCWs) for the purposes of our study is both efficient and practical in comparison with other type of CWs due to their less space, fewer equipment and requirements, and more oxygen transferred to the CW. The only problem about VFCWs is that oxygen demand of the CW increases in time; hence the operation should be optimized. In this case, we should drain the CW and let it rest for a few days to ventilate air and oxygen in the root zone and get prepared for the next wastewater load.

Although this paper has investigated several contaminants removal in CWs; however, more studies need to be done to explore the treatment effectiveness of removing different contaminants using this method. Finally, different Macrophytes, pollutants or wastewaters can also be used in other constructed wetland designs for future studies.

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Disclosure

It is to specifically state that "No competing interests are at stake and there is no conflict of interest", and none of the authors of this paper has a financial or personal relationship with other people or organizations which could inappropriately influence or bias the content of the paper.

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