Simulation of Constructed Wetland in treating Wastewater using Fuzzy Logic Technique

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Abstract. Constructed wetlands act as a natural alternative to conventional methods of wastewater treatment. CW are found effective in wastewater containing inorganic matter, organic matter, toxic compounds, metals, nitrogen, phosphorous, heavy metals, organic chemicals, and pathogens. The treatment efficiency by the adaptation of CWs in treatment process is achieved by a complex interaction between plants, microorganisms, soil matrix and substances in the wastewater. Constructed wetland treatment systems are engineered systems designed in such a manner that it could take advantages of those processes occurring in natural wetlands in treating the wastewater concerned, but in a more controlled environment. Petrochemical wastewater was the type of wastewater taken for the study. Characteristics of petrochemical wastewater mainly oil, Biological Oxygen Demand (BOD) and Chemical oxygen demand (COD) were selected for treatment in constructed wetland as they are predominant in petrochemical wastewater. The conventional methods followed in the treatment are chemical and biological treatment. In this study, a fuzzy model for water quality assessment has been developed and water quality index value was obtained. The experiment conducted and further analysis using fuzzy logic indicated that interpretation of certain imprecise data can be improved within fuzzy inference system (FIS). Based on the analysis, we could observe that Typha sp. contained wetland cell showed greater efficiency in removal of parameters such as COD and BOD than Phragmites sp. wetland cell.

1. Introduction

The rapid industrialization and urbanisation which began in the early nineteenth century contributed to the development as well as the release of huge amount waste products ultimately leading to environmental pollution and water crisis [1]. Natural wetlands which are known as the “Kidneys of the nature” were playing a predominant role in the treatment of wastewater in the past. One of the consequences of industrialisation was deforestation which lead to the destruction of natural wetlands on a large scale. This scenario paved the way for development of constructed wetlands which in due course of time became effective and efficient in treating wastewater from different sources. [2-6]. Constructed wetlands (CWs) are manmade wastewater treatment systems that use natural processes such as filtration, volatilization, nitrification, denitrification etc in less than 1 m deep beds or channels with suitable substrates, usually soil, sand and gravels with a wide range of microorganisms to improve wastewater quality (EPA Manual 2004) [7]. The design of constructed wetlands can be based on the process requirements and the treatment efficiency required [8].

Constructed wetlands act as a natural alternative to conventional methods of wastewater treatment. The objective behind the adaptation of CWs in treatment process is achieved by a complex interaction between...
plants, microorganisms, soil matrix and substances in the wastewater. These complex mechanisms are yet to be investigated properly to get a clear understanding about the physiochemical and biogeochemical activities occurring inside the CW setup [9]. Constructed wetland treatment systems are engineered systems designed in such a manner that it could take advantages of those processes occurring in natural wetlands in treating the wastewater concerned, but in a more controlled environment. CW are found effective in wastewater containing inorganic matter, organic matter, toxic compounds, metals, nitrogen, phosphorous, heavy metals, organic chemicals, and pathogens [9]. This is accomplished by several natural processes occurring within the systems such as sedimentation, filtration, chemical precipitation, adsorption, microbial interactions and uptake or transformation by the plants in the wetland setups [10].

Another notable advantage of using CW is that it involves less capital investments and operating costs as in other conventional wastewater treatment plants and they do not require technical supervision and complicated machineries to workout [11]. In addition to low cost construction and maintenance, large tolerance of variable quality and quantity of waste loads, harmonious fitting into the landscape and providing habitat for wildlife also add the merits of constructed wetlands.

The expansion of petroleum development into new frontiers have paved the way for nation’s economic development and infrastructure, but the increased the spills and discharges from petroleum industries have caused acute accidents frequently as well as the deterioration of environment and associated resources. Petroleum refinery wastewater coming from petrochemical industries has attracted researchers due to its unique composition of hydrocarbons, chlorinated chemicals, organic as well as inorganic chemicals and high amounts of oil released into it during several operational processes. The extensive uses of petrochemical products as well as the products/by-products of the petrochemical industries are causing contamination to the surface soils and water environments [12]. Untreated petroleum industry wastewaters containing oil, grease, various hydrocarbons, phenolics, sulfides, and metals cannot be released into domestic/municipal sewages due to its potential toxicity which requires, physical, chemical and biological treatment prior to its discharge to the environment.

This study focuses in the analysis of industrial waste water from Petroleum Industry to study its characteristics and to develop a technique to reduce the pollution concentration so that it can be reused or either discharged to surface water body. The CW designed was Horizontal Sub-Surface flow CW’s with reference to U.S’s EPA manual for constructed wetland.

2. Materials and Methods

Before initiating the trails the Pot culture study was done for three months to check the phyto-remediation potential Wetland plants namely Cattail (Typha) and Reed (Phragmites). Petrochemical waste water at different dilution ratios were poured in to pot with plants to check how the plant will use the waste as nutrient and grow and to ascertain its resistance capacity towards petrochemical compounds.

2.1. Design of Constructed Wetland Setup

Importance was given in the degradation of the contaminant present in the sediment in a microbial mediated manner in addition to the sorption by macrophytes. For the experimental purpose, we used plastic crates of size 12”×24”×16” size. The crate was fixed with an inlet valve to regulate waste flow. The baffle walls were fixed at regular intervals. Near the inlet valve, gravel was filled then the rest of the crate is filled with substrate. The outlet valve was fixed at the other end of the crate at the bottom. The experimental unit consisted of Horizontal Flow (HF) CWs which comprises of gravel or rock beds above which layers of sand and soil is incorporated and is planted with wetland vegetation. The wastewater entering the inlet zone follows a horizontal path and reaches the outlet zone traversing through the bed of soil, sand and porous media. The constructed Wetland (CW) lab unit was designed and fabricated as per the guidelines of Environmental Protection agency (EPA).

2.2. Treatment Using Constructed Wetland

After the pot culture study a dilution ratio was obtained and the petrochemical wastewater was fed to the CW prototype. The experiments were carried out for three dilutions for 90 days long, taking samples after 15, 30, 45, 60, 75 and 90 days. The treated water was analyzed for the above mentioned parameters and also the nutrient uptake of the plant was analyzed as per the EPA guidelines.
2.3. Analysis of Data

The efficiency of treatment was calculated as percentage difference between inlet and outlet. The results obtained in the work were subjected to fuzzy logic using MATLAB software.

2.4. Study Area

This work was carried out in SRM University near sewage treatment plant-1, located in SRM nagar of Potheri Village (12º9’ N to 12º 49’ N and 80º2’ E to 80º 3’ E), Kancheepuram district of Tamil Nadu, India. This maximum temperature and minimum temperature of the area is of 40 ºC and 20ºC respectively with an average rainfall of 1403 mm. The University is located along NH 45, about 40 km way from Chennai city.

Petrochemical effluent was collected from Chennai Petrochemicals Corporations Pvt ltd. (CPCL) located at Manali, Ambattur Industrial Area at Chennai, Tamil Nadu, India which was then thoroughly analyzed for the chemical properties and for the experimental setup. The wastewater samples collected from a depth of 10 cm were transported to the laboratory in polyethylene plastic bottles and were stored in the dark at 4°C until the experiment [13].

3. Results and Discussions

The petrochemical wastewater with suitable dilution subjected to trials in the lab scale Constructed Wetland(CW) units . As the oil content was high, there were chances of the roots of the wetland plants getting clogged. Different steps that were taken to rectify the issues were maintaining suitable flow rate to the system , providing filter media (20 mm crushed stone) at both the inlet and outlet so that most of the oil & grease, emulsified oil etc. were removed. By adopting batch process, the feasibility of the treatment became better. Locally available plant species were used because of their adaptability to the present environment. Pot culture study was carried out for two weeks so that an appropriate dilution ratio could be obtained which could be easily adjusted by the plants for its growth and survival. Different dilutions (20%, 40%, 60%, 80%) of industrial effluent were made and used for irrigating the units having phragmites and typha as vegetation on which the physical symptoms was studied. Certain physical parameters as change in colour of leaves, width, length, rolling of leaves, drying, death of new shoots and entire plant was observed when the vegetation was irrigated with samples having more than 60% dilution with a daily dose of 1000 ml per day.

The water quality for the treated wastewater with wetland methodology was assessed with the FWQ index. Calculated FWQ indices according to FIS are given in Table .2. Fuzzy logic (FL) is a problem-solving control system methodology that allows solving difficult simulated problems with many inputs and output variables. FL is applied in wastewater engineering for designing control strategies to keep the process in good working condition, for comparison of input and output data for each unit, and to evaluate the wastewater index.

In this study, a fuzzy model for water quality assessment has been developed and water quality index value was obtained. The Water Quality Index (WQI) developed has no unit, with numbers ranging from 1 to 100; a higher number is indicative of better water quality [14a]. This is used to classify water in accordance with the quality assessment made. Robustness of the system depends on the number and quality of the rules.

| Table 1. Fuzzy index for treated wastewater [Trial I] and [Trial II] |
|-----------------|--------------|--------------|--------------|
| TRAIL I         | 24 hrs       | 48 hrs       | 72 hrs       |
| **Phragmites**  | 80.6845%     | 50%          | 50%          |
| **Typha**       | 82.1726%     | 81.9350%     | 50%          |
| **TRIAL II**    | 24 hrs       | 48 hrs       | 72 hrs       |
| **Phragmites**  | 82.0456%     | 80.5816%     | 81.813%      |
| **Typha**       | 82.5766%     | 82.3652%     | 50%          |
The three crucial steps in fuzzy inference process are membership functions, fuzzy set operations and inference rules. In this study the Constructed Wetland water quality was evaluated by fuzzy model. Water quality data from the Wetland was analysed by conventional method and was used to evaluate Membership functions. A membership function is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. The input space as universe of discourse and the output space as \( \mu \). \( \mu_A(x) \) is the membership function of \( x \) in \( A \). The general fuzzy set operations are: OR, AND and NOT. The model thus generated was evaluated later with data based on Mamdani fuzzy inference system.

Even though, in this approach, each of the ten input quality determinants was divided into two categories, and the Gaussian curve membership function. The membership functions were assigned. Two fuzzy sets were considered to be suitable for this study. The amount of overlap, the width and the shape of fuzzy sets should be considered for each input variable. Ranges for fuzzy sets were based on the environmental (Protection) Rules, 1986, Schedule VI (Rule schedule IV 2011) [14b, 14c]. Ranges of fuzzy sets used are shown in Table 3. Ten quality determinants were selected to evaluate water quality by means of an aggregated index called fuzzy water quality (FWQ) index. Defuzzification of output was achieved by centroid method as it was found to be the most prevalent and physically appealing to all available methods.

For the selected set of four water quality determinants, the most prominent 9 rules have been used.

**Table 2.** General standards for discharge of Environmental Pollutants (The environmental (Protection) Rules, 1986, Schedule VI)

| Sl No | Parameters | Inland Surface Water (Low – L) | Marine Coastal Areas (High – H) |
|-------|------------|--------------------------------|--------------------------------|
| 1     | pH         | 5.5 – 9.0                       | 5.5 – 9.0                      |
| 2     | Turbidity  | Not Specified                   | Not Specified                  |
| 3     | BOD        | 30                              | 100                            |
| 4     | COD        | 250                             | 250                            |

**Table 3.** Reduction percentage of Wetland cells with *Phragmites spp.* and *Typha spp.* cultivation (a) Trial I (b) Trial II

| Parameters | Reduction percentage (Phragmites spp.) | Reduction percentage (Typha spp.) |
|------------|---------------------------------------|-----------------------------------|
| Turbidity  | 66.028 24hrs 56.214 48 hrs 58.972 24hrs 48 hrs | 58.972 24hrs 47.991 48 hrs |
| BOD        | 85.337 92.162 90.419 93.942 91.558 91.884 91.558 91.884 91.558 91.884 |
| COD        | 89.975 95.373 93.831 97.687 93.831 97.687 93.831 97.687 93.831 97.687 |

Based on the data as mentioned in table 3 showing the FWQI (Fuzzy water quality index) for *Phragmites sp* wetland cell at 24, 48 & 72 hrs, we could infer that the quality of water was degraded with time. The reason could be an increase in turbidity. The reduction percentage of turbidity varied from 66.28% at 24hrs, 56.21% at 48 hrs and 10.75% at 72 hrs respectively for *Phragmites* and 58.972%, 47.99% and 2.8% at 24, 48 and 72 hrs respectively for *Typha*. *Phragmites* was found to have a greater reduction percentage when compared with *Typha* planted wetland cell.
The interactions between the substrate and the biofilm may be responsible for the variation in pH in all units from neutral to slightly acidic values [3, 15]. While in the reduction efficiency of BOD and COD the dependence of temperature is much more significant [16]. Due to the presence of elaborate root system cattails show more removal efficiency for organic matter [17]. The vegetation played an important role in nitrogen removal through plant uptake, ammonia volatilization and matrix adsorption in addition to microbial activity [18–23]. The plant uptake alone can raise the removal efficiency by about 40%. Another important opposite phenomenon observed was the removal efficiency of organic content which may be due to neutral or slightly alkaline pH in the system which favours the phosphorus adsorption from carbonate materials [24–27, 3]. The mean values in comparison were statistically different (Table 2.), which indicated that all the above findings are true and that vegetation has significant role in both nitrogen and phosphorus removals, and that cattails seem to be more effective. The better ability of cattail to treat BOD and COD is probably related to the fact that this plant has higher stand and leave mass. It was also observed that the FWQI shows more than 80%, which is credible and this water can be used for various purposes such as gardening, steam generation etc instead of simply diffusing in the sea.

The overall reductions shown during the first trial was more 95% for BOD and COD for trials I and I for Phragmites cell system. For Typha the reduction percentages was 97% for BOD and COD respectively and the same was stressed upon by several scientist [28]. The observed results showed that the cells planted with Typha (cattails) showed higher percentage reduction for the various parameters. The observed results are expressed in the form of FWQ.

FWQ is applicable more as an estimator for the water quality generated after the treatment rather than in determining the strength of a pollutant parameter or a physical parameter. Fuzzy water quality index evolved in this work provides a simple representation of the extensive and complex variables (physical, biological and chemical) that govern the overall quality of surface water that is intended for potable use. Based on experiment done water quality parameters such as Turbidity, pH, BOD, COD, were considered as the significant indicator parameters of FWQI to assess the quality of Treated wastewater using lab scale constructed wetland.

4. Conclusions

Primarily treated petrochemical wastewater was found to have COD content as high as 415mg/l. Apart from that it was found that it had very high concentration of floating oil and grease much higher than the discharge limits. After the pot culture study a dilution ratio of 60% was found appropriate and was fed to the wetland units. Based on the analysis, it was observed that Typha sp contained wetland cell showed greater efficiency in removal of parameters such as COD and BOD than Phragmites sp. Change in the design criteria is very important for treatment of different kind of industrial effluent and its filter media also plays a crucial part. In the future the change in filter media, its effect on treatment efficiency based on the local climatic factors and flow of industrial effluent is a major area to be explored. Relative analysis of change in vegetation can help in improving the treatment efficiency of wetland wetland cell. The physical characteristics such as length, new shoots, nitrogen intake was observed more in Typha spp.

Hence, based on the analysis after treatment of Petrochemical waste in Horizontal Sub-surface Flow Constructed Wetland by batch process it can be said that wetland vegetated with both Phragmites sp and Typha sp is highly efficient in treating highly concentrated wastewaters in Indian climatic conditions. This model of Constructed Wetland should be taken into account in the treatment of industrial effluent as Constructed Wetlands are used from past time to remove the organic pollutant, but the selective wetland species would make it very useful in removal of inorganic pollutant too.

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