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Design and development of a hybrid macrophyte assisted vermifilter for the treatment of dairy wastewater: A statistical and kinetic modelling approach

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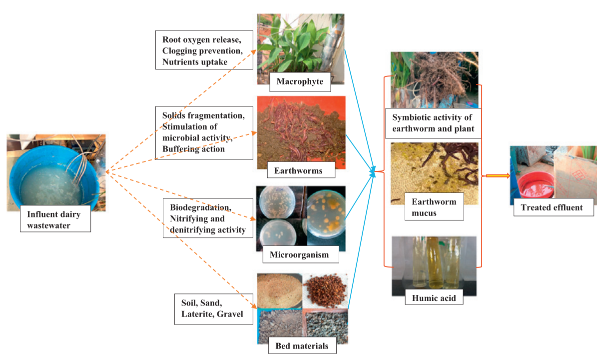
HIGHLIGHTS

- Earthworm *Eisenia fetida* and macrophyte *Canna indica* have been used to develop macrophyte assisted vermifilter (MAVF).
- Vertical flow (VF) unit promote nitrification and horizontal flow (HF) unit promote denitrification.
- Earthworm and plant maintained requisite dissolved oxygen (DO) in filter bed.
- Stover-Kincannon model showed high regression coefficient value.

GRAPHICAL ABSTRACT



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ABSTRACT

Global urbanization, exponential increase in population and sophisticated life style of the present generation are the major causes leading to a rapid increase in water demand in recent years. In order to nullify this rising water demand, it's high time to reuse domestic as well as industrial effluent after providing suitable chemical/biological treatment. Macrophyte filter incorporated with earthworm is identified as one of the most economic system for the treatment purpose in developing countries. However, very few literatures and technical information are available to scale up the design and its easy operation. This paper aims to develop a hybrid system and assess its performance for the purification of dairy wastewater. In the present study, two stage macrophyte assisted vermifilters (MAVFs) have been designed. The 1st stage encompassed a vertical flow (VF) unit, and the 2nd stage contained a horizontal flow (HF) unit. Both the units were inoculated with earthworm *Eisenia fetida* and were planted with *Canna indica*. Box-Behnken model was applied to design the system and study the effect of various parameters. It was observed that hybrid MAVF system removed a maximum of 83.2% COD and 57.3% TN at HLR 0.6 m/d and an active layer depth of 30 cm. Ammonification and nitrification typically occurred in the active layer (earthworm inoculated zone) of VF unit due to high activity of earthworms and its associated gut microbes, whereas HF unit facilitate denitrification process. Earthworm growth characteristics in the system were monitored, which is an imperative factor for the design of MAVF reactor. Kinetic modelling of 1st order, grau 2nd order and Stover-Kincannon model were performed and the Stover-Kincannon model showed high regression coefficient (COD, R^2 0.9961 and TN, R^2 0.9353) supporting its applicability as compared to the other models.

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1. Introduction

The rapid urbanization in most of the developing countries is massively contaminating the existing water resources in the recent years. The industrial growth and various changes in manufacturing processes increase the generation and complexity of wastewater. Effluents from various industries may also contain toxic pollutants, which have to be reduced to protect the environment and public health (Dan et al., 2011; Vymazal, 2007). Numerous problems are encountered by industrial wastewater discharges such as hydraulic overload, temperature extreme, excessive amounts of FOG (fat, oil and grease), acidic or alkaline constituent, suspended solid, and inorganic or organic content, etc. (Demirel et al., 2005; Arias et al., 2005). A vastly organic rich effluents are produced from food industry, paper plants, wool processing industry, pharmaceutical industry, petrochemicals and refinery, dairy industry, brewery and fermentation factory, dye industry, etc. (Sinha et al., 2008; Samal et al., 2017a; Borghei et al., 2008; Carballeira et al., 2017; Mansouri et al., 2014). Wastewater from dairy industry has detrimental impact on environment due to its high concentration of biodegradable pollutants. It is calculated that 6–10 L of waste effluents are generated per litre of milk produced. Carbohydrate, protein and fat content of wastewater degrade rapidly and get converted into odorous sludge, which has a lot of ill effects on natural water bodies like increase in turbidity, toxicity, heat retention, pH imbalance, eutrophication, dissolve oxygen reduction, etc. (Rodgers et al., 2006; Samal et al., 2017b). Several physical, chemical and biological treatment processes like filtration, sedimentation, desalination, membrane technology, sonication, ozonation, advanced oxidation process, electrocoagulation, activated sludge, rotating biological contactors, aerated lagoon, stabilization pond, and constructed wetland are available. However, challenges still exists due to environmental, economic, social and legal concerns (Arias et al., 2005; Borghei et al., 2008; Mansouri et al., 2014; Rodgers et al., 2006).

Vermifilter (VmF) has the potential to treat high organic matters present in wastewater. It involves the inoculation of earthworms in traditional geo-filter to further enhance the efficiency of wastewater treatment. Earthworms stimulate and accelerate the microbial activity by increasing the population of soil microorganisms within filter bed. The symbiotic activity of earthworms and microorganisms fragment the pollutants that exist in wastewater. The fragmented particles have higher surface area, which quicken the biodegradation process. Planting macrophyte on VmF bed significantly improves the efficiency of biofilter, as the microbial community propagates on the root system and speed up the decomposition process (Singh et al., 2017; Bajsa et al., 2003). The majority of previous studies are either on utilization of vermifiltration or only on macrophyte filtration system. However, not much comprehensive reports are available on vermifilter integrated with macrophyte filter or macrophyte assisted vermifilter (MAVF) to treat wastewater in an effective manner (Fig. 1).

One-Variable-At-a-Time (OVAT) is a conventional methodology for calculating the effect of various parameters and their interaction. If the experimental parameters are increased, number of experiments also increase for a particular process, which is both, time consuming and hectic process. Response surface methodology (RSM) is a convenient tool in which individual effect of various parameters and their interaction can be observed simultaneously by performing less number of experiments. Therefore, the major objective of this study includes designing and development of an eco-friendly, low cost and sustainable bio-filter for treatment of various types organic and nutrient rich wastewater. It can be achieved through following steps: (i) investigation of the organic and nitrogen removal efficiency in hybrid MAVF, (ii) application of RSM to optimize experimental parameters and subsequently develop statistical models for COD and TN removal in hybrid MAVF, (iii) determination of pollutants degradation kinetics and mechanisms in filter bed; and (iv) analysis of earthworm and plant growth characteristics.

2. Materials and methodology

2.1. Design of reactors

Two stage laboratory scale reactors were designed made up of persplex and arranged as shown in Fig. 2 and Fig. 3. Raw wastewater pumped to the 1st vertical flow (VF) unit at different hydraulic loading rate (0.3–0.9 $m^3\ m^{-2}\ d^{-1}$) from a feeding tank and the effluent again transferred to the 2nd stage horizontal flow (HF) unit. Table 1 displays the major assemblies of the system. Garden soil and vermicompost mixed in the ratio of 1:3 by volume and filled in the upper layer of VF. This layer is called worm active layer as earthworm (*Eisenia fetida*) are inoculated in this zone at a density of 10,000 worms/m^3 and height of this layer varied from 15 to 45 cm. *Eisenia fetida* was selected because of its tolerance towards highly moistened environment and their higher reproductive ability than the other species applied in vermiremediation. It is even reported that *Eisenia fetida* can survive waterlogged conditions for certain period of time (Arora et al., 2016; Hait and Tare, 2011). Being surface-dweller in nature, *Eisenia fetida* is preferred over endogeic and anecic earthworm species. The 2nd, 3rd and 4th layers from the top were taken as washed sand (10 cm thick), 4–6 mm laterite stone (15 cm thick) and 8–10 mm coarse gravel (15 cm thick), respectively. The HF unit bed was completely filled

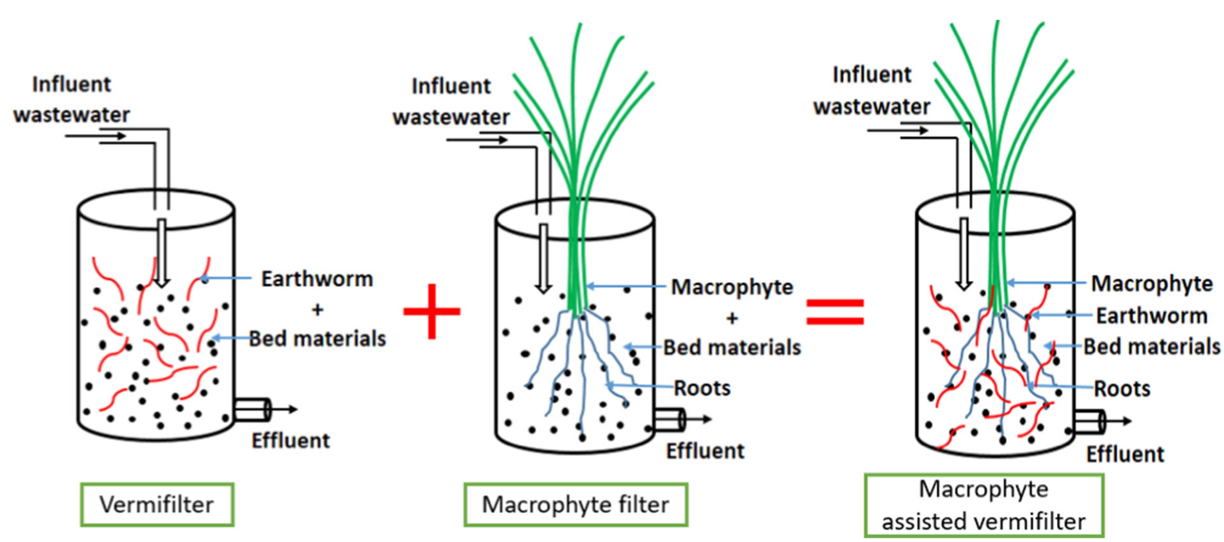

Fig. 1. Diagrammatic representation of a Macrophyte Assisted Vermifilter (MAVF).