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Performance Evaluation of Laboratory Scale Vegetated Vermifilter for Domestic Wastewater

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Abstract:** Locally as well as globally, the Collection and treatment of wastewater are seen to have an impact on the environment and economy in one way or the other. Designing a system that minimizes this effect to the best possible scenario is of paramount importance, adding to greater sustainability in terms of economic, environmental, and social terms. The solutions such as on-site treatment of wastewater, local recycling, and reuse of resources contained in domestic wastewater (predominantly water itself) can be best summed up as Decentralized treatment of sewage which appears to be a coherent solution to address sustainability. Vermifiltration is a low-cost aerobic decentralized wastewater treatment option. Two lab-scale vertical flow filters are designed in this project, with both being assisted by* **Canna indica** *(MAVF), but only one introduced with* **Eisenia fetida. The experimental phase continued for 5 weeks with a hydraulic loading rate of 0.14 m^3 m^{-2} day^{-1} with an acclimatization period of 15 days. The results depicted that MAVF has a better organic degradation capacity than the one without earthworms alone. The quality of wastewater is determined by Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) to a great extent. Removal efficiencies of COD were 67 % for MAVF and 55 % for MAF, while for BOD, it was 80 % for MAVF and 69 % for MAF, respectively. The BOD and COD tests were assisted by other parameters like pH, and turbidity.*

***Keywords:** Domestic wastewater, Decentralized treatment, Aerobic treatment, Macrophyte Assisted Vermifilter (MAVF), Macrophyte Assisted Filter (MAF), Sustainability, Low-Cost Treatment, Canna Indica, Eisenia Fetida*

I. INTRODUCTION

According to UNICEF, in India, an estimated 564 million people practice open defecation, which is nearly the world's half population. According to the recent Census of India, 49.84 percent of people practice open defecation, whereas a toilet at home is available to 47% of households in India. Most Indian cities are only partially sewered. A huge 48 percent of urban Indian households depend on on-site facilities (largely septic tanks and pit latrines) for meeting their sanitation needs. The dependence on such on-site sanitation facilities is naturally increasing with rapid increment in population and urbanization. Thus, at the national level, it is evident to focus on a sustainable service delivery approach for sanitation. The cities in India often face a challenge to connect the outskirts or developing parts of the city with the existing sanitation system (i.e., wastewater treatment plant). A decentralized treatment approach is a logical solution in such circumstances. In this system, the wastewater is treated at or near the source, with a relatively small volume discharged from a single house to an entire community located in close proximity rather than connecting to a central sewer system. This system provides an advantage of recycling and reuse of wastewater for that particular area. The current approach of take, make, and dispose of can be countered with this system complementing the concept of 'circular economy. The greywater produced from a house may vary greatly from about 15 liters per person per day for poor households to as much as a hundred per person per day. Out of the 100%, 25% is contributed by black water whereas 75% is contributed by greywater which can increase to 90% in case of dry toilets. Greywater is responsible for 69% consumption of domestic wastewater. In order to recycle and reuse such a huge quantity of wastewater, treatment options need to be verified. One such solution is a decentralized treatment which allows a community to concentrate on the most pressing treatment needs while also allowing for smaller design flows and disposal regions. This concentrates the financial burden on individual properties rather than the entire neighbourhood. In the case of rural or remote residential or community applications, decentralized systems provide numerous advantages, and the appropriate approach differs from case to case. Officials and residents must be aware of the current problems and flaws in the community's wastewater treatment system(s), which may include antiquated or non-existent septic systems, leaking sewers, and over-capacity system, sewage overflows, underfunding, watershed issues, groundwater pollution, nutrient overloading in sensitive areas, and/or regulatory non-compliance. Vermifiltration is an emerging decentralized treatment option to be considered. In addition to the gravel and sand media used in traditional wastewater treatment filters, Worms make up a vermifilter. It's also known as a lumbrifilter or a vermi-digester. Nearly 80% of the water utilized by society is returned to the sewer system as sewage as municipal wastewater. Sewage contains toxic compounds, as well as extremely high levels of organic matter (BOD) and COD (chemical oxygen demand), as well as solids, both dissolved and suspended.

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Sewage must be treated to minimize organic loads before being discharged into the environment (rivers and seas), or aerobic bacteria will use more dissolved oxygen (DO) from the river/ocean water in order to digest the organic materials, lowering DO levels. The survival of all aquatic species in rivers and oceans would be jeopardized as a result. Vermifiltration of wastewater utilizing waste-eating earthworms is a revolutionary technology that has only recently been developed. The general mechanism of 'ingestion' and biodegradation of organic wastes, heavy metals, and solids from wastewater by earthworms has been found to remove the five days' BOD (BOD_5) by over 90%, COD by 80–90%, total dissolved solids (TDS) by 90–92%, and total suspended solids (TSS) by 90–95% from wastewater by the general mechanism of 'ingestion' and biodegradation of organic wastes, heavy metals, and solids from wastewater and also by their 'absorption' through body walls. There is no sludge production in the process, which eliminates the need for additional landfill disposal costs. This process is also odorless, and the resulting vermifiltered water is safe to use for farm irrigation as well as in parks and gardens. Their burrowing operations generate aerobic conditions in waste materials, blocking anaerobic microbes from releasing foul-smelling hydrogen sulphide and mercaptans. Many impoverished countries cannot afford to build and operate expensive STPs. They require more low-cost sewage treatment alternatives. Due to ever-increasing demand, centralized sewage treatment systems may not be able to meet sustainable wastewater management requirements in the future in both the developed and developing worlds, at least for new developments. Individual households or groups of homes can treat their domestic wastewater at the source, reducing the burden (BOD and COD loads) on sewage treatment plants (STPs) further down the sewer system.

Fig. No. 01 – Composition of wastewater

II. EXPERIMENTAL DETAILS

Before going for experimentation, the basic need is to identify the characteristics of waste water, filter materials, plant and earthworm species used. The details of the same are discussed in this chapter.

A. *Material Characteristics*

1) *Domestic Wastewater*

a) *Organic Matter:* This is the predominant factor that affects the receiving water bodies, and it mainly contains carbohydrates, fats, and proteins. It may lead to a reduction in oxygen levels if released directly without any treatment.

b) *Nitrogen and Phosphorous:* Direct release of this constituents in water bodies leads to eutrophication and algal growth which contribute to pollution. Orthophosphate, polyphosphate and organic phosphate are the common form in which phosphorous is present whereas nitrogen in the form of proteinaceous matter urea. During the check of quality of receiving/affected water the nitrite and nitrate forms of nitrogen which represent sewage characteristics.

c) *Suspended Solids:* It can be divided into two main types organic (volatile) and inorganic (fixed) fractions. When organic fractions are disposed untreated it leads to sludge deposition and ultimately to anaerobic conditions. Suspended solids can be settled gravitationally.

d) *Dissolved Oxygen:* Although it is an unimportant sewage characteristic, it is a vital pollution monitoring factor. If untreated or partially treated wastewater is introduced into water bodies, it leads to depletion of dissolved oxygen.

e) *Bacterial Parameter:* Considering human heath, the fecal coliform serves as an important parameter. Daily around 100 to 400 billion coliforms are released by each person. Pathogenic organisms (mainly bacteria and viruses), when released into water

f) *Physical Characteristics:* Domestic wastewater has a grey colour, a musty odour, and a solids concentration of roughly 0.1 percent on a physical level. Faeces, food particles, toilet paper, grease, oil, soap, salts, metals, detergents, sand, and grit make up the solid stuff. The solids can be dissolved as well as suspended (approximately 30%). (About 70 percent). Chemical and biological methods can be used to precipitate dissolved materials. When suspended materials are discharged into the receiving environment, they might result in the formation of sludge deposits and anaerobic conditions.

g) Chemical Characteristics: Organic (70 percent) and inorganic (30 percent) components and different gases make up wastewater. Carbohydrates (25 percent), proteins (65 percent), and fats (10 percent) make up the majority of organic molecules, which reflect people's diets. In addition, heavy metals, nitrogen, phosphorus, pH, sulphur, chlorides, alkalinity, hazardous chemicals, and other inorganic components may be present. However, because wastewater has a higher percentage of dissolved solids than suspended solids, approximately 85 to 90% of the entire inorganic component is dissolved. In contrast, about 55 to 60% of the total organic component is dissolved. Hydrogen sulphide, methane, ammonia, oxygen, carbon dioxide, and nitrogen are all gases that are regularly dissolved in wastewater. The disintegration of organic matter produces the first three gases.

h) Biological Characteristics: Wastewater contains a variety of microorganisms, but those classed as Protista, plants, and animals are the ones to be concerned about. Bacteria, fungus, protozoa, and algae are all classified as Protista. Ferns, mosses, seed plants, and liverworts are examples of plants. The animal category includes both invertebrates and vertebrates. Protista, particularly bacteria, algae, and protozoa, are the most important category in wastewater treatment. In addition, wastewater contains a large number of pathogenic organisms, most of which come from individuals affected by a disease or who are carriers of disease. Typical faecal coliform concentrations in raw wastewater range from several hundred thousand to tens of millions per 100 ml of sample.

2) Canna Indica: Canna indica is a perennial plant with enormous leaves up to 50cm long and 25cm wide that grow in bunches 150-300cm tall. The stems emerge from a rhizome that is big, thick, and tuber-like. The plant has the appearance of a tiny banana plant, with its broad leaves wrapping a central stalk. It is frequently grown on a limited scale in Australia as a commercial supply of arrowroot for these purposes, particularly in South America and Southeast Asia. The plant is extensively grown as an ornamental throughout the tropics and subtropics and is prized for its beautiful flowers and leaves. The plant produces food (particularly the root), medications, and a variety of other products. Canna can be grown anywhere from sea level to 2,700 meters above sea level, but it thrives in temperate, tropical, or subtropical mountain climates between 1,000 and 2,000 meters above sea level. An average temperature of 14 to 27 degrees Celsius and annual rainfall ranging from 500 to 1,200 millimetres. Canna grows best in light sandy-loamy soils, but it will thrive in heavy soils if they are not damp. It is unconcerned about the soil's reaction (pH value). It is also required to soak the seeds in water for two to three days to germinate. When wastewater is passed it will be cleansed as it passes through the plant due to the activity of the canna roots. The plant absorbs nitrates and phosphates found in sewage water. Because they are abundantly present in "natural wetlands," the three plant species, Canna indica, Typha latifolia, and Phragmites australis, are found to be the most suited in the Indian environment. These species have also been successfully used in the majority of India's operational sewage treatment plants. The plant's shoot (particularly through photosynthesis in the leaves) and root system (rhizosphere) both contribute to the improvement of performance. This can be approximated to be around ten percent. When compared to Canna indica (yellow flower), the Canna indica (red flower) species appears to eliminate more COD, TP, TKN, and TOC by about 10%, 11%, 60% and 29%, respectively.

Fig. No. 02 – Canna Indica

3) *Eisenia Fetida:* Eisenia fetida, also known as manure worm, redworm, brandling worm, panfish worm, trout worm, tiger worm, red wiggler worm, and other common names, is a type of earthworm that prefers to feed on decaying organic matter. Rotting plants, compost, and manure are ideal habitats for these worms. Vermicomposting of both home and industrial organic waste is done with Eisenia fetida worms. Tiger worms are also being examined to see whether they can be used in a flush less toilet. They're epigean, meaning they don't live in the soil. They are similar to Lumbricus rubellus in this regard. In their coelomic fluid, Eisenia fetida has a unique natural defence system: cells called coelomocytes emit a protein called lysenin, a pore-forming toxin (PFT) that can permeabilize and lyse invading cells. It works best against foreign cells that have a lot of sphingomyelin in their membranes. Earthworms have a lot of potential for removing hydrocarbons from the soil, including PAHs like BaP that is resistant to degradation. The earthworms survived in an environment with high levels of PAHs, yet they have low levels of PAHs in their tissues. When food was available, they lost little weight and produced cocoons in soil contaminated with levels of PAHs not generally found in soil. Earthworms can be employed to extract polycyclic aromatic hydrocarbons (PAHs) from the soil; however, this could jeopardize their life and lead to contamination accumulation. Earthworms can be found in various soils and can account for 60–80% of total soil biomass. Many lipophilic organic pollutants are accumulated by earthworms through passive absorption through the body wall and intestinal uptake during soil transit through the gut. As the pollutant concentration in the soil environment rises, so does the accumulation. Autochthonous microorganisms break down hydrocarbons; however, adding earthworms to soil improves aeration and stimulates microbial activity, resulting in increased biodegradation. Earthworms also exude muco-proteinaceous slime and nitrogen metabolism products that are easily digested by microorganisms, boosting their activity and growth.

Fig. No. – 03 Eisenia Fetida

4) *Laterite:* Laterite is a heavily worn mineral rich in iron, aluminium, or both secondary oxides. It is almost devoid of bases and primary silicates, but substantial amounts of quartz and kaolinite may be present. It is either firm or has the potential to harden when wetted and dried. Kaolinite, gibbsite, and dry Iron compounds are the most common minerals found in lateritic soils. Lateritic soils are distinguished by their distinct hue, high clay content, and inadequate cation exchange capacity. Lateritic soils also have a lot of iron and aluminium oxides in them. An acid solution is used, followed by precipitation, to remove phosphorus and heavy metals at various sewage treatment facilities. For phosphorus elimination, calcium-, iron-, and aluminium-rich solid media are advised.

Fig. No. 04 – Laterite

5) *Charcoal:* Peat, coal, wood, coconut shell, and petroleum are all used to make ordinary charcoal. "Activated charcoal" is a type of charcoal that is comparable to regular charcoal. Activated charcoal is prepared by heating traditional charcoal in the presence of a gas. As a result of this process, the charcoal develops a large number of internal gaps, or "pores." These holes aid in the "trapping" of chemicals by activated charcoal. Activated charcoal is safer than chemical odour neutralizers in neutralizing scents like pet odour, mould, and human faeces.

Fig. No. 05 – Activated Charcoal

B. *Design of Lab-scale model and procedure*

1) *Design*

By thumb rule,

Approximately, 1 Hectare area is required to treat 200 Kg BOD_5

i.e., 10000 m^2 can treat 200 kg BOD_5

For 1 Kg BOD_5, = 10000/200

= 50 m^2

15-liter wastewater is to be treated.

BOD_5 was calculated for a week taken from the same source, which was 320 mg/l

= 15 X 148

= 2220 mg

= 2220/1000

= 2.22 mg

1000 gm can be treated with 50 m^2 area

1 gm can be treated with area =50/1000

= 0.05 m^2

For 6.4 mg of BOD_5, area required will be;

= 0.05 X 2.22

= 0.11 m^2

Actual area provided,

0.33 X 0.33 = 0.11 m^2

From the literature review studied, the depth of the filter should not exceed 75 cm. from the study the filter depth is decided to be 75 cm.

Dimensions of filter = 1 X 1 X 2 feet

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2) *Procedure:* A tank was divided into six parts of 10 cm each. It was filled with laterite soil of size ranging from approximately 6 mm to 12 mm in ascending order from top to bottom. The topmost layer of 10 cm was considered as free board followed by laterite soil of size < 6 mm. Below that three layers of 10 cm each having laterite fractions of 6 – 8 mm, 8 – 10 mm and 10 -12 mm respectively are introduced. Activated charcoal was used one of the layers of very fine size. Both the filters were planted with Canna indica plant (each had 4 saplings). One filter was introduced with earthworms (Eisenia Fetida) and other was without it. From a literature study, it was found that the earthworm load of 20 gm/l is optimum. In total, 300 gm of earthworms were introduced into one filter. For the influent storage, a plastic bucket having a volume of 22 litre was used. (Separate for both filters). It had tap induced with flexible plastic pipe for both filters which will allow influent water to pass through the bucket to the filter. The lab-scale model was set-up in an environment which allowed enough light and ventilation for the plants. An acclimatization period of 15 days was given for the plant and earthworms for adjustment and settlement.

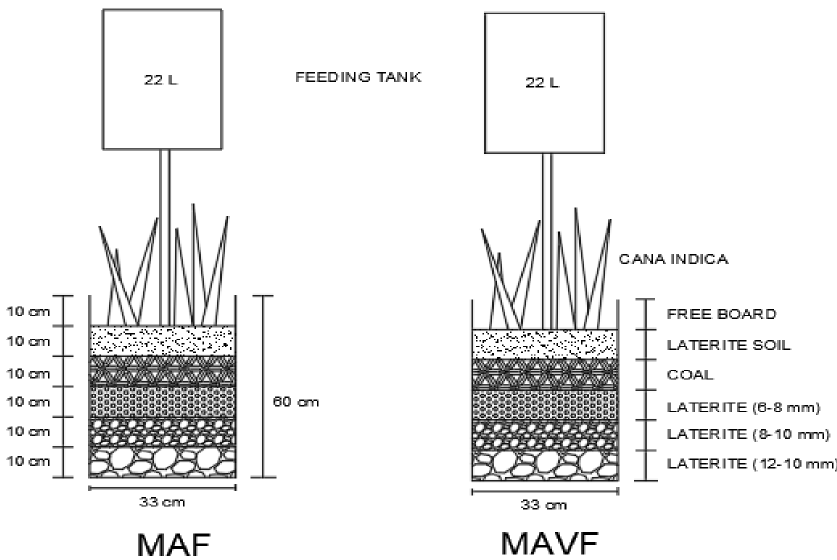

Fig. No. 06 – Sketch of model

Fig. No. 7 Lab- scale model

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III.RESULTS AND DISCUSSIONS

For the designed filter system an acclimatization period of 15 days was selected. During the 15 days, same load as actual testing was applied to the filter but diluted to a ratio of 14:1 (wastewater: fresh water).

During the literature survey, an experiment with same media proved that a hydraulic retention time (HRT) of 72 hour was optimum. Therefore, for actual testing, the results were taken for a period of 72 hour only.

A. pH test

Table no. 01 – pH results

pH	1st filling	2nd filling	3rd filling	4th filling	5th filling	6th filling	7th filling	8th filling	9th filling	10th filling	11th filling
Influent	7.89	8.1	7.9	8.0	8.1	7.5	7.89	7.9	7.6	7.5	7.6
72-hour MAVF	7.69	7.8	7.78	7.65	7.4	6.9	7.1	7.21	6.9	6.98	7.12
72-hour MAF	7.8	7.81	7.56	7.45	7.31	7.0	7.1	7.25	7.1	7.2	7.25

pH	12th filling	13th filling	14th filling	15th filling
Influent	7.45	7.9	7.85	7.65
72-hour MAVF	7.1	7.0	7.2	7.1
72-hour MAVF	7.2	7.11	7.25	7.12

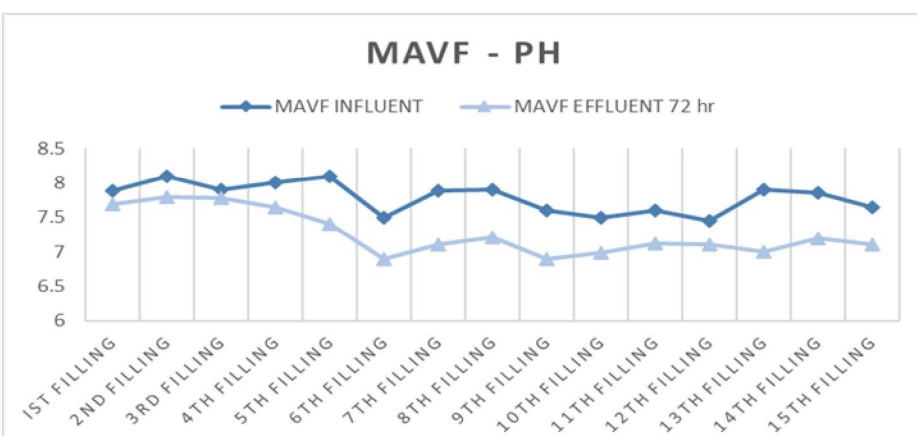

Fig. No. 08 – pH results (MAVF)

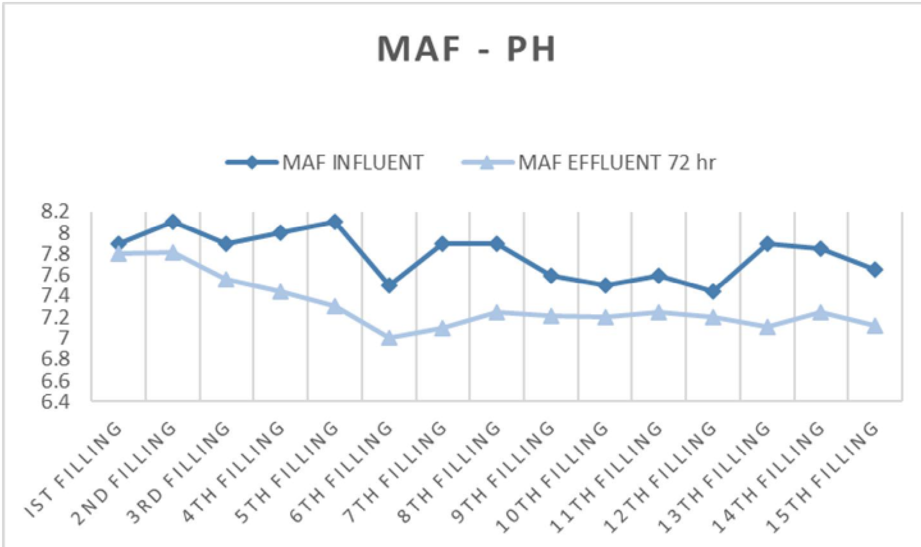

Fig. No. 09 – pH results (MAF)

The influent pH values for both MAVF and MAF are in the range of 7.4 to 8.1, which is alkaline in nature. For both the filters, during the acclimatization period, i.e., till the 5th filling (15 days), the results don't show much variation and are still alkaline. After the adjustment period, the pH results are seen to drop to a range of 7.0 to 7.2, which is almost in the range of neutral. The Macrophyte Assisted Vermifilter (MAVF) and the Macrophyte Assisted Filter (MAF) don't show any difference in pH removal, which means results are nearly identical. This shows that the earthworms (Eisenia Fetida) have no prominent role in pH neutralization.

B. *Turbidity*

Table no. – 2 Turbidity results

Turbidity (NTU)	1st filling	2nd filling	3rd filling	4th filling	5th filling	6th filling	7th filling	8th filling	9th filling	10th filling	11th filling
Influent	158	165	178	154	185	160	165	164	170	172	168
72-hour MAVF	45	47	41	38	21	22.7	20.9	22.5	19.6	18.4	19
72-hour MAF	47	51	39	32	21	21.5	21	22.5	20	19	21

Turbidity (NTU)	12th filling	13th filling	14th filling	15th filling
Influent	159	160	163	167
72-hour MAVF	21.8	18.5	19	21
72-hour MAF	20.5	19	20.5	18.5

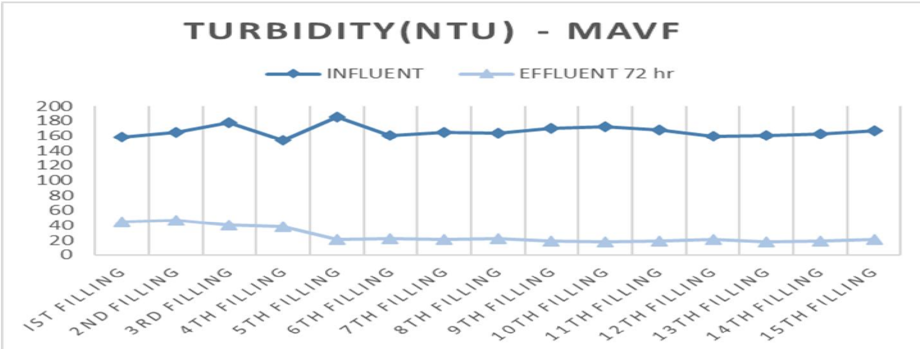

Fig. No. 10 Turbidity removal results (MAVF)

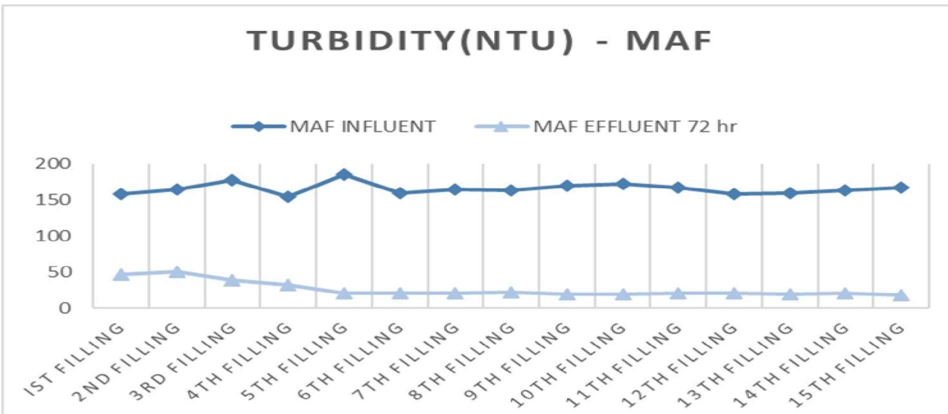

Fig. No. 11 Turbidity removal results (MAF)

Both MAVF and MAF have influent turbidity values in the range of 150 to 170 NTU. For both the filters during the acclimatization period which is till the 5th filling (15 days) shows a removal efficiency of 75-80 %. After that the efficiency slowly increased to about 85-88%. There is no significant difference in turbidity removal between the Macrophyte Assisted Vermifilter (MAVF) and the Macrophyte Assisted Filter (MAF), implying that the outcomes are almost equal. A study shows that within the pH range of 6 to 7.5, the turbidity removal is most. This might be the reason of increase in efficiency after the 15-day period. Although, the MAF started to clog due to absence of earthworms. It could be caused by the deposition of surplus particles from wastewater in the top layer, resulting in the formation of sludge and microbial colonies.

C. Biochemical Oxygen Demand (B.O.D.)

Table no. – 3 B.O.D. Results

BOD (mg/l)	1st filling	2nd filling	3rd filling	4th filling	5th filling	6th filling	7th filling	8th filling	9th filling	10th filling	11th filling
Influent	128	135	132	120	125	127	130	129	121	126	135
72-hour MAVF	56	58	52	48	35	31	32	28	28	25	21
72-hour MAF	74	68	71	72	65	59	54	56	51	53	53

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BOD (mg/l)	12th filling	13th filling	14th filling	15th filling
Influent	138	137	131	129
72-hour MAVF	22	23	21	23
72-hour MAF	49	50	49	45

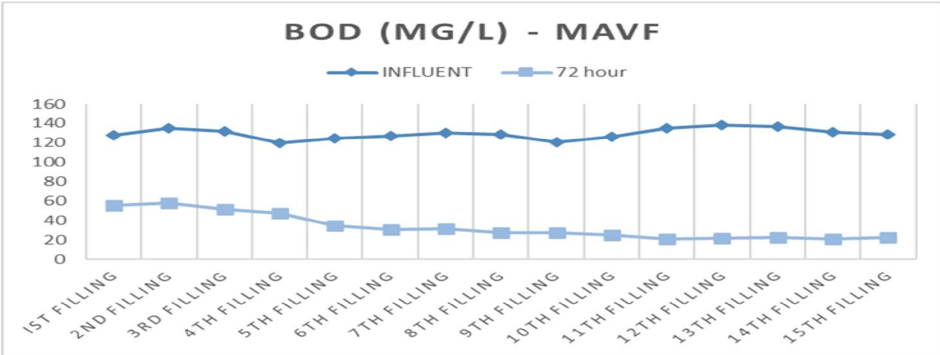

Fig. No. – 12 BOD removal results (MAVF)

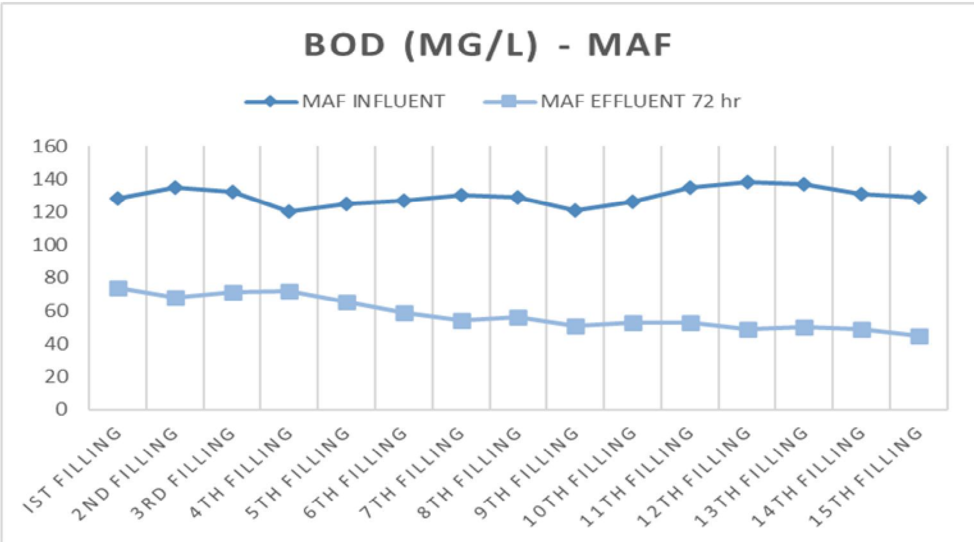

Fig. No. – 13 BOD removal results (MAF)

The BOD_5 of influent wastewater is in the range of 120-140 mg/l. For MAVF, the initial removal efficiency is about 65% and after that the efficiency increases to about 70-85 %. The average efficiency for 45 days is 75 %. For MAF, 40-50 % efficiency is obtained during initial stage and then for testing period it was found to be 50-65%. The overall efficiency is 55% for entire period. This depicts that MAVF is more efficient as compared to MAF for removal of BOD_5. Thus, earthworms play a role in BOD_5 removal and it is 20% more removal efficiency is observed for MAVF. Initially, removal efficiency was modest, but it gradually improved when microbial and metabolic activity in the rhizosphere was stimulated. The breakdown process was enhanced by the release of root exudates from the plant and enzymes from the earthworm. Because earthworms rely on biodegradable materials, BOD removal was higher in MAVF reactors than MAF. The greater MAVF efficiency for organic matter could be attributed to the macrophyte's root system, which provides surface area for microbial colony formation and improves the physical filtration process.

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D. Chemical Oxygen Demand (C.O.D.)

Table No. 4 COD results

COD (mg/l)	1st filling	2nd filling	3rd filling	4th filling	5th filling	6th filling	7th filling	8th filling	9th filling	10th filling	11th filling
Influent	305	285	295	298	275	289	301	298	292	289	287
72-hour MAVF	135	142	145	138	118	95	97	89	98	91	92
72-hour MAF	158	162	165	159	148	135	132	127	125	129	132

COD (mg/l)	12th filling	13th filling	14th filling	15th filling
Influent	279	282	294	298
72-hour MAVF	94	89	102	99
72-hour MAF	131	133	139	132

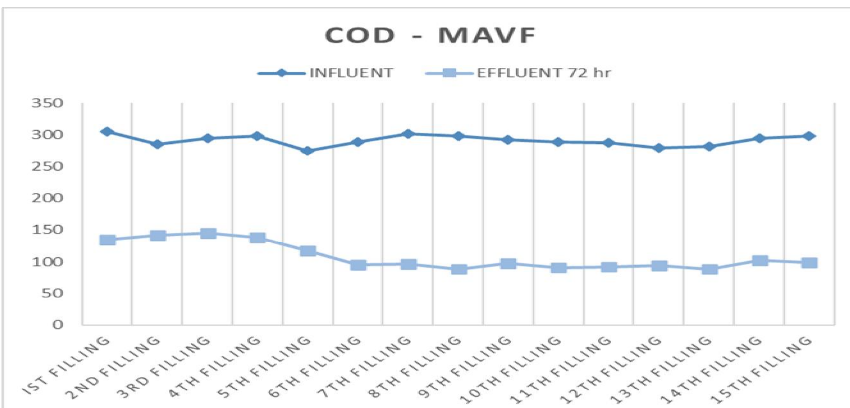

Fig. No. – 14 COD removal results (MAVF)

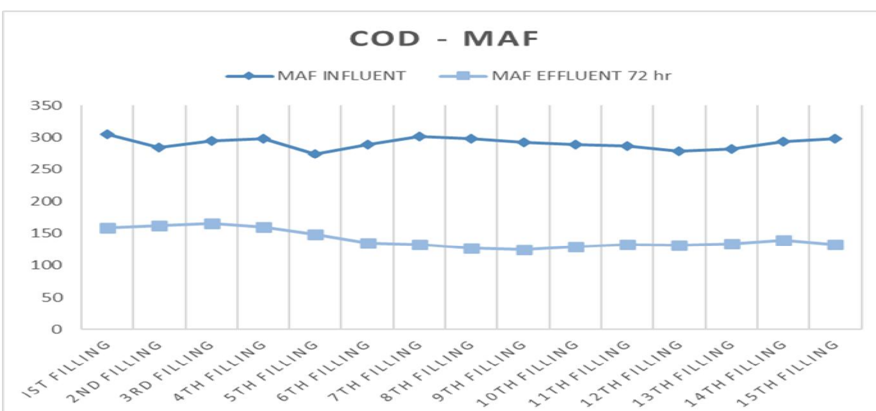

Fig. No. – 15 COD removal results (MAF)

The influent values of COD were in the range of 298 – 305mg/l. For MAVF the acclimatization period had a removal efficiency of 50-55%, whereas it was 45-50% for MAF. The average removal efficiencies of MAVF and MAF for the entire period was 62% and 51% respectively.

IV. CONCLUSIONS

From above results and discussions, following conclusions are drawn:

A. MAVF had a much better treatment efficiency than MAF, indicating that the integrated approach is more effective and long-term. Clogging was not seen in MAVF for the entire operation period due to the earthworm and plant's symbiotic and synergistic activities.
B. Although little water logging was observed in MAF during the very end of the treatment period. This might be due to the absence of earthworms.
C. Earthworm tunnelling in the filter bed aerates the substrate, allowing water, nutrients, oxygen, and microorganisms to pass through which increased performance efficiency of MAVF.
D. Because the macrophyte aided vermifiltration (MAVF) system reduced BOD and COD in domestic wastewater by 70-80%, it can be employed as an effective and alternative technique for various decentralized wastewater treatment systems.

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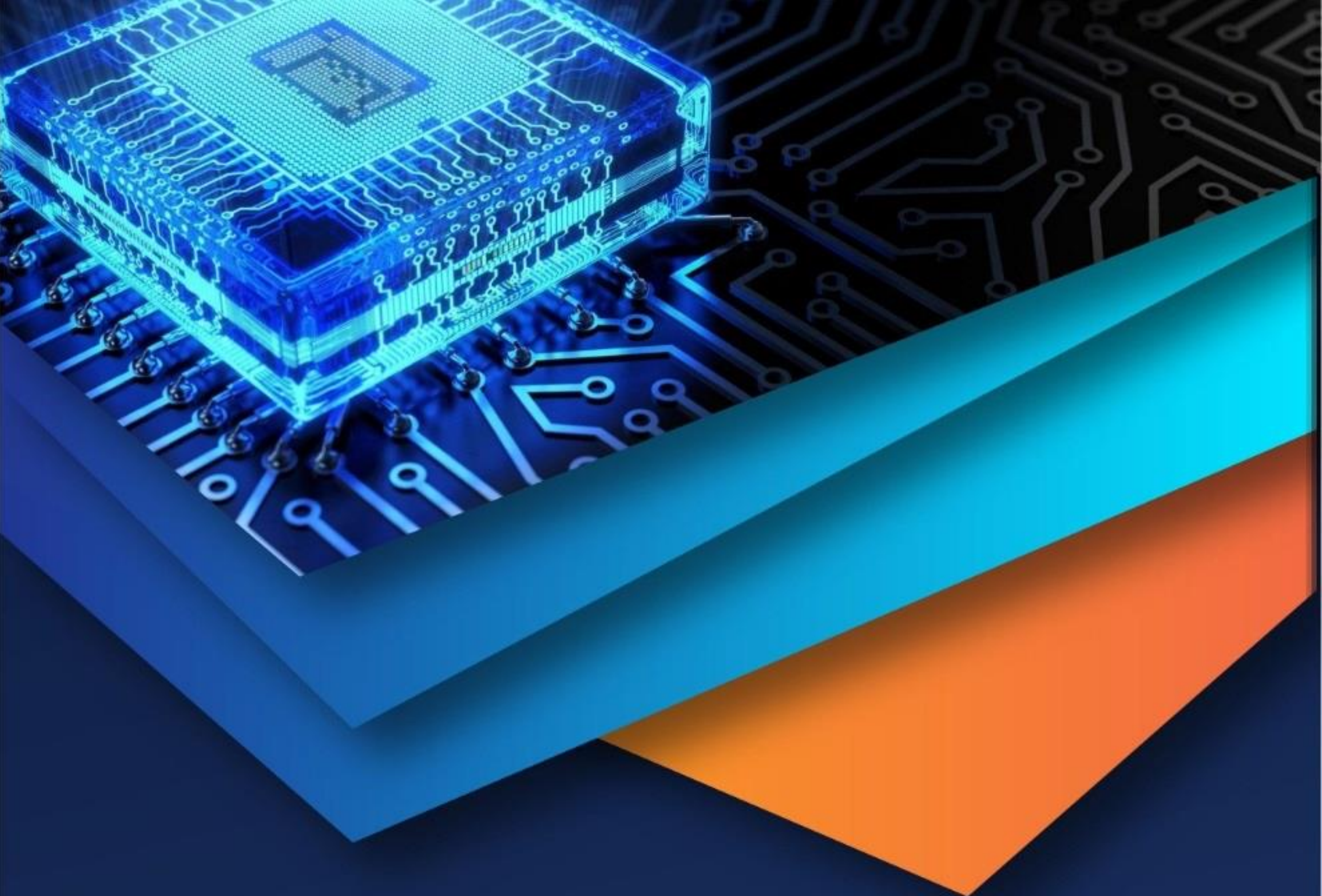

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