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Performance evaluation of sequential batch biofilm reactor for the treatment of grey water

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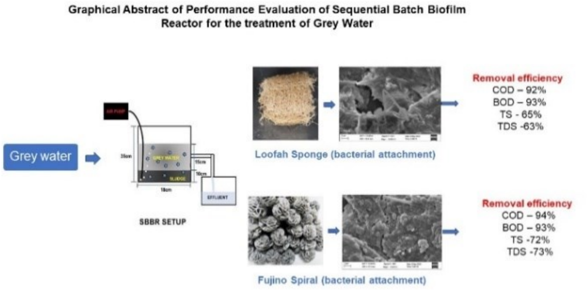
Graphical abstract



Abstract

The performance of a Sequential Batch Biofilm Reactor (SBBR) for the treatment of grey water was evaluated using two different bio-carries under different aeration duration. Two biofilm carriers such as fujino spiral and loofah sponge was used for biofilm formation in the reactor. The study demonstrated that the SBBR system with, both the biofilm carriers, effectively removed the contaminants from the grey water. The aeration time of 45 minutes demonstrated the highest removal efficiencies for organic matter, and suspended solids for the both biofilm carrier i.e., fujino spiral and loofah sponge. Comparing the two biofilm carriers, the Fujino spiral showed strong biofilm attachment and demonstrated excellent performance in pollutant removal. The removal efficiencies of COD, BOD, TS, TDS was found out to be 94%, 93%, 72%, 73% respectively. On the other hand, the loofah sponge exhibited slightly lower performance compared to the Fujino spiral. Being a natural material, the enhanced ability of the loofah sponge in favouring an effective bacterial attachment in its interior and exterior surface was evident. Hence it is proved to be an effective biofilm carrier, providing a suitable substrate for biofilm development and contributing to grey water treatment. The removal efficiencies of COD, BOD, TS, TDS was found out to be 92%, 93%, 65%, 63% respectively.

1. Introduction

Grey water generated from the household varies between 50 % to 80% of the total water used for the domestic purposes. (Ding *et al*. 2011). The nature of pollutants present in the grey water is highly dependent on the source of its generation. The grey water from the showers includes contaminants such as hair, residues of soaps, dyes, nutrients, body fats whereas the grey water from the kitchen includes oils, organic food particles etc. Among the several sources, the major portion of around 30 % of grey water is contributed form the laundry services and the contaminants from such sources includes cleaning chemicals which are highly inorganic in nature. The proper collection and its treatment of grey water is gaining importance because of the potential reuse of the treated grey water for flushing, gardening and thereby reducing the demand on the fresh water supply.

It is very much essential to adopt certain decentralised treatment system so as to treat the grey water onsite of its generation and maximise its reuse. There are scenarios where separate plumbing lines are installed in the households so as to separately collect the greywater and avoid its mixing with the blackwater (Saumya *et al.* 2018). The treatment of greywater is dependent on its quantity of its generation as well as its quality. A typical grey water contains COD ranging from 100 to 320 mg/L and BOD from 100 to 500 mg/L (Edwinetal 2013). The treatment of such wastewater using conventional activated sludge process would not be needed because of the low organic loading. Several physiochemical treatment methods including a combination of various filters such as soil along with alumina and hydrated silica (Itayama *et al*. 2004), sand filter with granular activated carbon (Sostar-Turk *et al.* 2005) were explored for the treatment of grey water. Some of the studies also reported the removal of various dissolved solids, nutrients using coagulation with aluminium salt (Chang *et al*. 2007), coagulation along with magnetic ion exchangers (Pidou *et al.* 2008) Coagulation with ferric salt, (Pidou *et al*. 2008). However, these methods may not be recommended for a decentralised treatment system because of the need for large space for its establishment and also separate treatment of the

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residual sludge is also necessary. In most of the cases these physiochemical treatment process renders only a partial treatment and which initiates for the need for the secondary treatment using a biological treatment system.

Some of the biological treatment method explored for the treatment of the grey water includes constructed wetlands (Gross *et al*. 2007) for a high strength mixed grey water, MBBR (including kitchen grey water) treatment unit under low SRT (down to 4d) and low HRT (2h) condition (Gnirss *et al*. 2006), Rotating biological contactors along with the sand filtration and chlorination as subsequent polishing treatment (Friedler *et al*.2005) and a Submerged MBR (membrane pore size,01µm) (Merz *et al.* 2007) with a permeate flux of 8 to 10 l/m^{2}h. Among the several methods adopted the application of the sequential batch moving bed biofilm reactor (SBBR) is gaining importance because of its ability to treat wastewater of different and varying organic loading rate (Tan N *et al*. 2013), increase rate of biodegradation because of the increased attached biosludge in the surface of the media, higher rate of conversion of ammonia to nitrate. SBBR has been studied upon for the treatment of municipal wastewater (Yunxiao *et al*. 2012), dairy wastewater (Ozturk *et al*. 2018), wastewater from paper mill (Lirong *et al*. 2019). In SBBR, some of the biocarrier media employed includes recycled corrugated wire hose cover (Tombola *et al*. 2019), Kaldness 1(K1) (Andrio *et al*. 2022). The bio-carriers mostly employed in the SBBR are usually the metals or plastics and most of the studies report the removal of COD, BOD and ammonia whereas not many studies have been reported on the removal of other nutrients. The advantage of SBBR over the sequential batch reactor in terms of treatment efficiency while treating such greywater and its application as a decentralised treatment system for the treatment of grey water need to be explored.

In the present study an attempt has been made to treat the grey water using sequential batch biofilm reactor and evaluating its performance while using two different bio-carriers. The two types of bio carriers used in the study are (i) Loofah sponge and (ii) Fujino Spiral.

Figure 1. Loofah Sponge

In general, for the treatment of domestic wastewater, the full cycle time in SBR is of 4 hours which includes 2 hours of aeration for biological oxidation, 1 hour for settlement (solid –liquid separation) and 1 hour for decanting the treated effluent. In the present study, treatment of grey water was attempted which was comparatively less in organic loading. Reduction in aeration duration can favour reduction in the energy consumption in such treatment system and it can be recommended as even more a sustainable treatment technology for treating wastewater with low organic loading. Hence in-order to understand the performance of SBR at a shorter duration of aeration (which is less than 2 hours) 30 minutes, 45 minutes, and 90 minutes were chosen.

The performance of the SBBR was evaluated in terms of its COD, BOD removal along with the removal of solids present in the greywater.

2. Materials and methods

2.1. Bio-carriers

The Loofah Sponge used in the present study is a natural material and it is reported to have good durability and ability to withstand high ammonia and varying pH (Zhang *et al.* 2019) in Figure 1. The Fujino spiral is a made up of vinyl chloride and it is comprised of plural S-shaped portions which are continuous with each other and defined outer boundaries enabling a high surface area (Yasuao *et al.* 2017) Figure. 2.

Figure 2. Fujino Spiral

2.2. Chemicals

All the chemicals are used in the study belong to LR-grade and double distilled water was used for the preparation of reagents and standards.

2.3. Activated sludge

The return activated sludge was collected from the Domestic sewage treatment plant, Chennai. The return sludge from the secondary clarifier was collected and used because of the presence of activated sludge.

2.4. Experimental setup

The Sequential batch biofilm reactor (SBBR) used in the present study comprised of and aeration tank with a capacity of 9.5 L. (Figure 3) The tank was made of flexi glass with the dimensions of 35cm × 18cm. Grey water was collected from the hostel laundry located in Vandalur, Chennai. The aeration tank was filled with 5L of grey water and 1.6 L of return activated sludge and 10 pieces of bio-carrier. The sludge proportion was fixed to 1.6 L based on the literature studies (Li *et al.* 2015). In the aeration tank the total volume occupied by the carrier was around 25 %. The air pump of 18W capacity was used for supplying air to the reactor. The treated grey water was collected in a collection tank of 5 L capacity made up of glass.

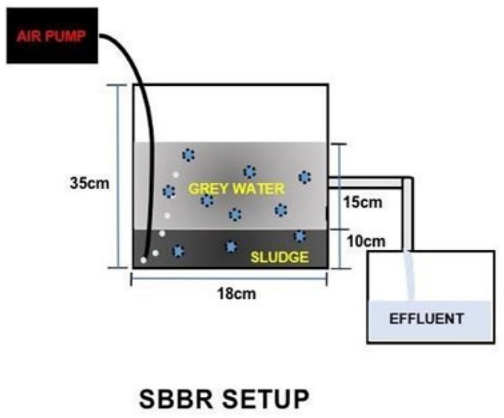

Figure 3. Experimental arrangement of SBBR

2.5. Analytical procedure

The untreated grey water sample and the treated water sample from the collection tank were filtered through a 0.45 µm pore size filter paper (Whatman, USA) and were analysed for soluble COD and BOD. The parameter tested also includes pH, Total suspended solids, Total solids, Sodium, potassium and calcium. All the test were conducted as per the Standard methods for the examination of water and wastewater. pH was monitored by the pH meter. The turbidity was measured using turbidity meter. The sludge volume index of the collected activated sludge was also conducted. The collected activated sludge was allowed to settle in 1L volume measuring cylinder for 30 minutes. The SVI was calculated using the eq (1).

$$SVI\ (mL/g) = \frac{settled\ sludge\ volume\ (mL/L) \times 1000}{Total\ suspended\ solids\ (mg/L)} \qquad (1)$$

2.6. Experimental studies

In this study, the performance of SBBR was assessed for two different bio-carriers individually. During the start-up, the aeration tank was loaded with the required bio-carriers along with the activated sludge and was aerated for a minimum duration of 24hours. This was performed to favour an early attachment of the biomass in the carrier. After inoculation of 24hours, the aeration tank was drained and the fresh untreated grey water collected from the hostel was added for the treatment in the aeration tank. The filling of the aeration tank was done manually. During this study, the effect of aeration was studied under three different conditions such as 30 min, 45 min and 1h and 30 min. Each study was conducted for duration of 10 days and the characteristics of the untreated and treated grey water was examined to determine the treatment efficiency of the SBBR.

3. Results and discussion

The performance evaluation of SBBR at different aeration duration and for two different bio-carriers such as Fujino Spiral and Loofah Sponge was investigated. The sludge volume index was observed to be 53 ml/mg and it has been reported that SVI within this range has reported to have active bacteria supporting degradation and also exhibit good setting characteristics. The grey water collected from the hostel laundry was also investigated and COD was varying from around 350 mg/L and BOD was around 420 mg/L on an average. The total solids in the grey water were around 4000 mg/L and it since these values are beyond the discharge standards there is a need for the treatment of grey water.

3.1. Performance of SBBR using FUJINO SPIRAL as bio-carrier

In this study, the fujino spiral was added to the aeration tank and the performance of SBBR was evaluated for aeration time of 30 minutes, 45 minutes and 1hour and 30 minutes.

The pH of the treated water was observed to be in the neutral range. There was a reduction in turbidity noted from 18 NTU to approximately 5 NTU. Likewise, there was a drastic reduction in the total solids in the treated effluent. The total solid in grey water which was around 4000 mg/l was reduced to around 1000 mg/l. By comparison of aeration time in three different variation i.e., 30mins, 45mins, and 1hr 30 mins with fujino spiral as biofilm carrier, it is shown that 45 mins aeration time had more removal efficiency for TS as shown in Figure 4a.

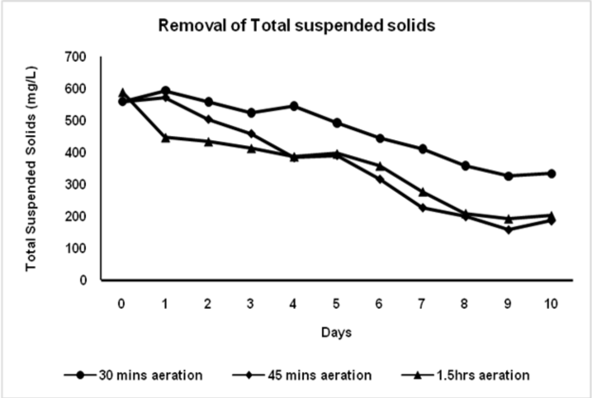

Figure 4a. Removal of total suspended solids using fujino spiral as biocarrier

In the grey water the presence of suspended solids is less when compared to the total dissolved solids and this can be attributed due to the presence of the use of chemicals during washing of utensils and clothes. The total dissolved solids reduced to 900mg/l. By comparison of aeration time in three different variations i.e., 30mins, 45mins ,1hr 30 mins with fujino spiral as biofilm carrier, it is shown that 45 mins aeration time had more removal efficiency for TSS as shown in Figure 4b.

The optimum aeration favours the formation of biofilms in the aeration tank through the generation of extracellular polymeric substance (EPS) by the biomass. From the perspective of the removal of TDS, certain microorganism and algae facilitate its removal. The specifically negatively charged functional groups in the EPS has the ability to adsorb some of the salts and the organic pollutants present in the wastewater (Laroche & Michaud 2016). Hence the combination of the physical adsorption and the subsequent biological assimilation of the solids in the biofilms have reported to reduce the dissolved solids from the wastewater.

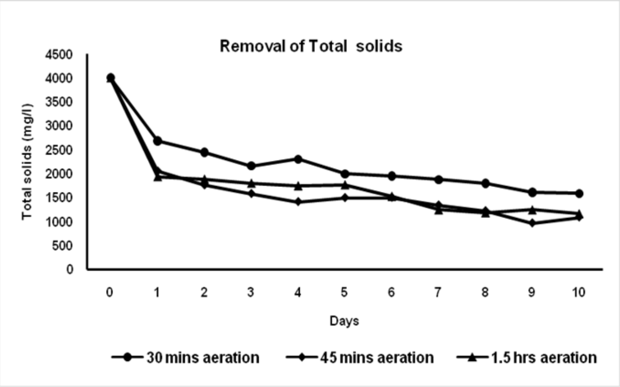

Figure 4b. Removal of total solids using fujino spiral as biocarrier

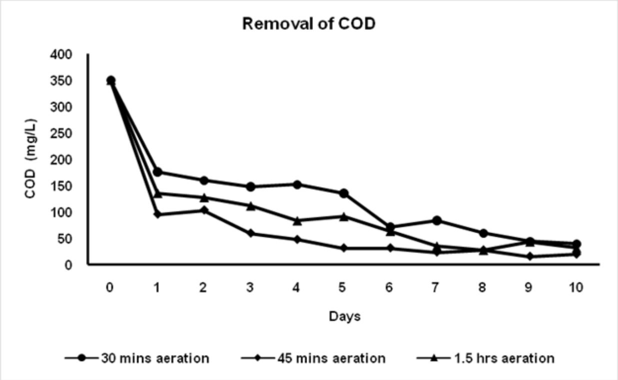

Figure 4 c. Removal of COD using fujino spiral as biocarrier

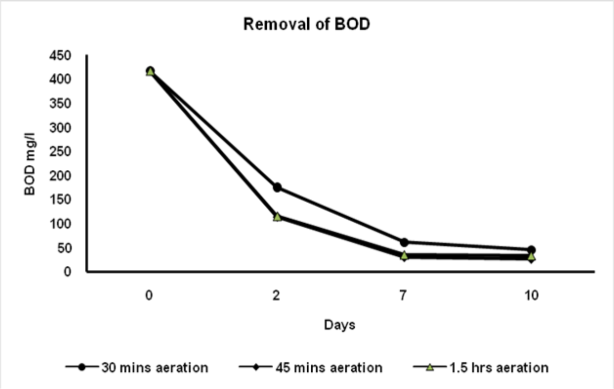

Figure 4d. Removal of BOD using fujino spiral as biocarrier

Significant reduction in COD and BOD was observed in the treated effluent. The reduction in the organic content could be due to the bacterial degradation. The bacterial attachment in the spiral has favoured the degradation of the organic content in the grey waste water. When compared to the different aeration, 45 minutes of aeration proved to have significant degradation. The higher aeration of 1hour and 30 minutes resulted in hydraulic shear in the spiral there by causing a detachment of the bacteria from the spiral in the tank. During 45 minutes aeration, the COD of the treated effluent reduced to 20 mg/l and it was very much less when compared to the other aeration time. By comparison of aeration time in three different variations i.e., 30mins, 45mins ,1hr 30 mins with fujino spiral as biofilm carrier, it is shown that 45 mins aeration time had more removal efficiency for COD as shown in Figure 4c.

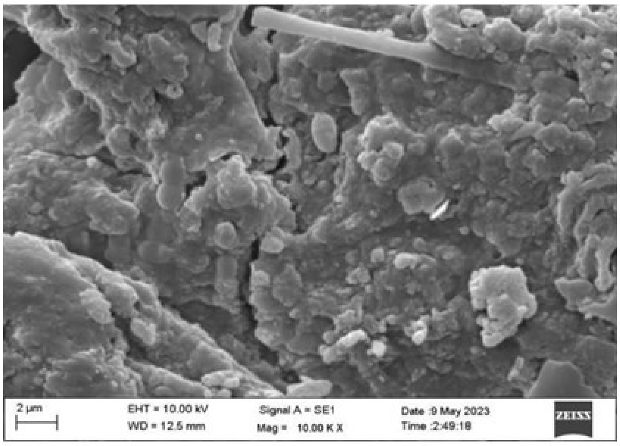

Figure 5a. Bacterial attachment in fujino spiral (45 minutes)

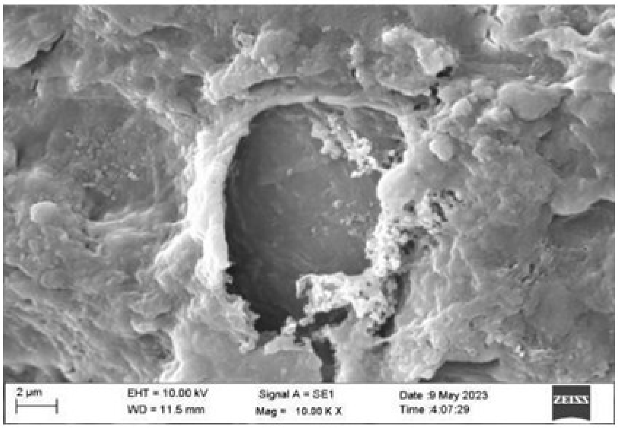

Figure 5b. Bacterial attachment in fujino spiral (30 minutes)

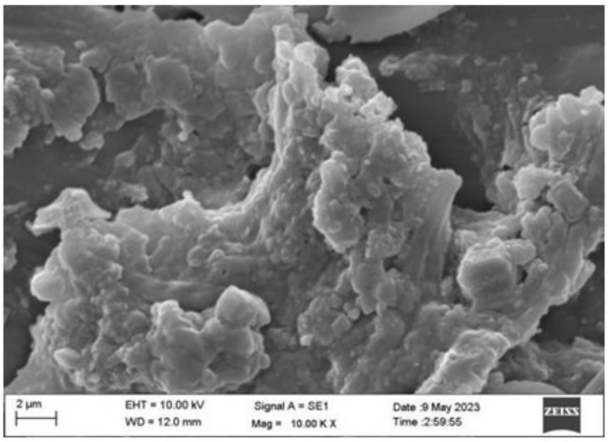

Figure 5c. Bacterial attachment in fujino spiral (1 hour and 30 minutes)

Likewise, BOD also was observed to 26.6 mg/l, which is also less for a duration of 45 minutes aeration. By comparison of aeration time in three different variation i.e., 30mins, 45mins ,1hr 30 mins with fujino spiral as biofilm carrier, it is shown that 45 mins aeration time had more removal efficiency for BOD as shown in Figure 4d

Biofilm formation on fujino spiral occurs through a process called biofilm adhesion. Initially, free-floating microorganisms in the water attach to the surface of the spiral. They then start to secrete extracellular polymeric substances (EPS), which form a matrix that helps bind the microorganisms together and to the spiral surface. The SEM analysis was conducted in crystal growth centre, Anna university, Chennai.

In fujino spiral, bacterial attachment was densely populated on its surface in the 45 minutes of aeration treatment as shown in the Figure 5a Whereas, in 30 minutes and 1 hour 30 minutes of aeration treatment the bacterial attachment was less densely as shown in the Figure 5b and Figure 5c respectively.

From images of SEM analysis, it is found to be that various types of bacterial species were formed on the surface of the spiral possibly represents the bacterial species such as escherichia coli and staphylococcus aureus and this is correlated with the literature reports. (Khatoon *et al.* 2013)

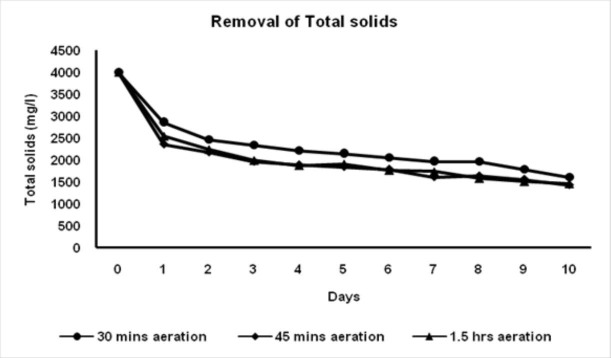

Figure 6a. Removal of total solids using loofah sponge as bio-carrier

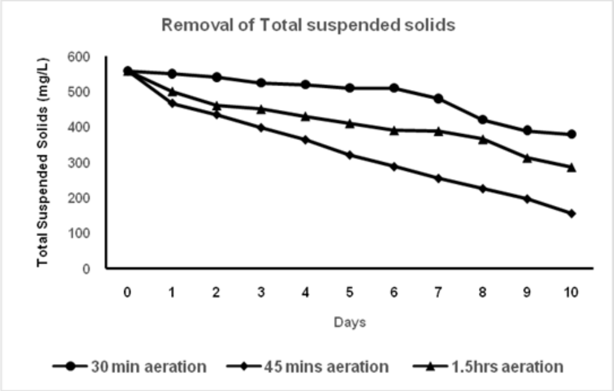

Figure 6b. Removal of total suspended solids using loofah sponge as bio-carrier

3.2. Performance of SBBR using LOOFAH SPONGE as bio carrier:

In this study, the loofah sponge was added to the aeration tank and the performance of SBBR was evaluated for aeration time of 30 minutes, 45 minutes and 1hour and 30 minutes. The pH of the treated water was observed to be around 7. There is a reduction turbidity noted from 18 NTU to approximately 8 NTU. Like there was a reduction in the total solids in the treated effluent. The total solids in grey water which was around 4000 mg/l was reduced to around 1430 - 1500mg/l. By comparison of aeration time in three different variation i.e., 30mins, 45mins ,1hr 30 mins with loofah sponge as biofilm carrier, it is shown that 45 mins aeration time had more removal efficiency for TS as shown in Figure 6a. This could be due to the collection of suspended solids within the porous structure of loofah sponge. The fibers in the loofah sponge entraps more of the suspended solids within the structure and reducing the suspended solids in the treated water

The total dissolved solids reduced to 1200mg/l. By comparison of aeration time in three different variations i.e., 30mins, 45mins ,1hr 30 mins with loofah sponge as biofilm carrier, it is shown that 45 mins aeration time had more removal efficiency for TSS as shown in Figure.6b.

Significant reduction in COD and BOD was observed in the treated effluent. The reduction in the organic content could be due to the bacterial degradation. The bacterial attachment in the loofah has favored the degradation of the organic content in the grey waste water. Loofah being a natural product obtained from the plants also favored more adsorption of the organic content present in the wastewater and it also contributed to a greater reduction in COD.

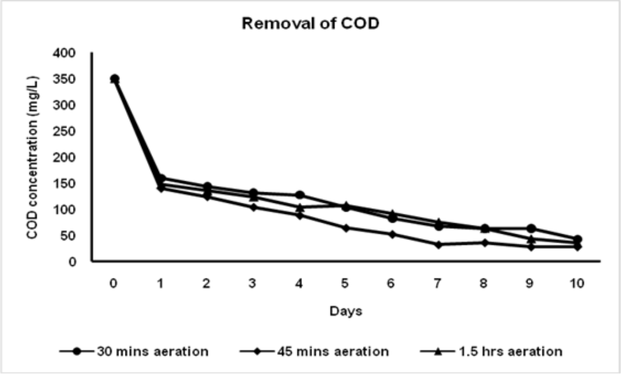

Figure 6c. Removal of COD using loofah sponge as bio-carrier

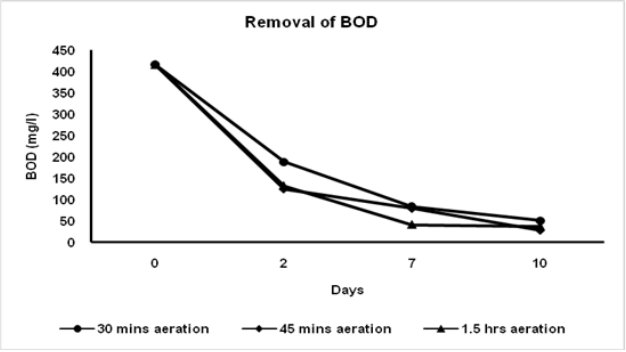

Figure 6d. Removal of BOD using loofah sponge as bio-carrier

Increase in aeration duration enhances bacterial attachment in the loofah sponge. 30 minutes duration of aeration favoured bacteria's attachment within the internal pores of the loofah sponge when compared to its outer surface. These establish microenvironments where satisfactory oxygen transfer efficiency may not be achieved and this could have resulted in the comparatively less dense microbial microbiological growth on a loofah sponge.

During 45 minutes aeration, the COD of the treated effluent reduced to 28 mg/l and it was very much less when compared to the other aeration time. The 45 minutes of aeration favoured more bacterial attachment in both the exterior and the interior surface of the loofah sponge. This subsequently increased the contact available with the wastewater and the bacteria and thereby resulting in the rapid proliferation of bacteria over the entire surface of the loofah sponge.

By comparison of aeration time in three different variation i.e., 30mins, 45mins ,1hr 30 mins with loofah sponge as biofilm carrier, it is shown that 45 mins aeration time had more removal efficiency for COD as shown in Figure 6c

Likewise, BOD also was observed to 28.8 mg/l, which is also less for a duration of 45 minutes aeration by comparison of aeration time in three different variations i.e., 30mins, 45mins ,1hr 30 mins with loofah sponge as biofilm carrier, it is shown that 45 mins aeration time had more removal efficiency for BOD as shown in Figure 6d.

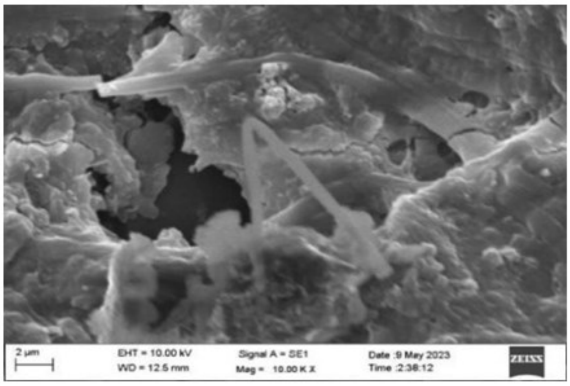

Figure 7a. Bacterial attachment in loofah sponge (45 minutes)

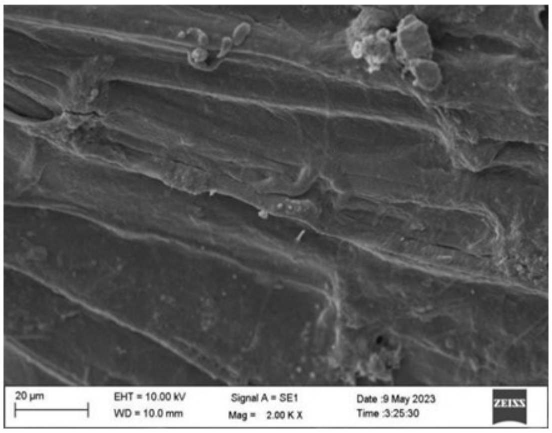

Figure 7b. Bacterial attachment in loofah sponge (30 minutes)

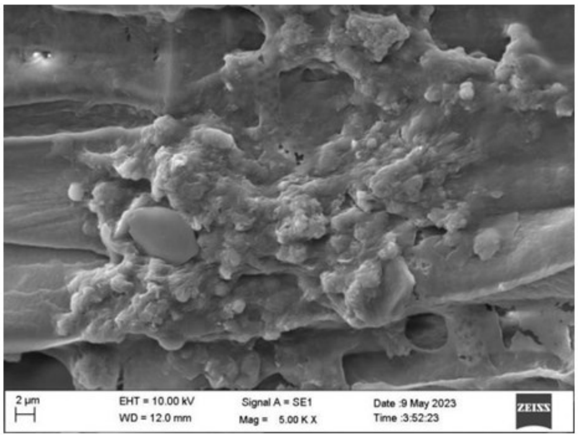

Figure 7c. Bacterial attachment in loofah sponge (1 hour 30 minutes)

In loofah sponge, the bacterial attachment in 45 minutes and 1 hour 30 minutes of aeration treatment was densely populated as shown in Figure 7a and Figure 7c whereas, in 30 minutes of aeration treatment the bacterial attachment was elongated and spread like sheets as shown in the Figure 7b.

As per images from the SEM analysis, comparatively 45 minutes of aeration treatment had a more bacterial attachment than 30 minutes of aeration treatment and it represents the bacterial species such as pseudomonas aeruginosa and escherichia coli. This is correlated with the literature reports (Zainab *et al.* 2019)

Staphylococcus aureus and pseudomonas aeruginosa are aerobic bacteria and escherichia coli is anaerobic bacteria which have property to adhere to the surface of any media and they also reported in degradation of a pollutants such as COD, BOD (Khatoon *et al.* 2013) nitrogen and phosphorus. The E. coli are also predominantly available in the wastewater collected from the washing and other clean activities.

SEM analysis provides valuable insights into the formation of biofilms, composition, attachment mechanisms and showcasing the formation of microcolonies, extracellular polymeric substances (EPS), and the presence of various microbial species.

4. Conclusion

The study indicates that the SBBR system, when operated with both biofilm carriers, effectively removed contaminants from grey water. The reactor exhibited high pollutant removal efficiency, particularly in terms of total solids, total dissolved solids, COD and BOD concentrations. Fujino spiral and loofah sponge as bio-carriers exhibited maximum COD reduction for a duration 45 minutes. But when compared with loofah sponge, the degradation of pollutants was much higher in fujino spiral. This aeration period allowed for more extensive oxygen transfer, promoting the growth and activity of aerobic microorganisms responsible for the degradation of contaminants. The enhanced ability of the loofah sponge to serve as a bio-carrier was evident. Overall, the performance evaluation of the SBBR using Fujino spiral and loofah sponge demonstrates its potential as an efficient and sustainable solution for grey water treatment, contributing to water conservation and environmental protection.

References

Ding D., Feng C., Jin Y., Hao C., Zhao Y. and Suemura T. (2011). Domestic sewage treatment in a sequencing batch biofilm reactor (SBBR) with an intelligent controlling system. *Desalination*, **276**(1–3), 260–265.

Delattre C., Pierre G., Laroche C. and Michaud P. (2016). Production, extraction and characterization of microalgal and cyanobacterial exopolysaccharides. *Biotechnology advances*, **34**(7), 1159–1179.

Edwin G.A., Gopalsamy P. and Muthu N. (2014). Characterization of domestic gray water from point source to determine the potential for urban residential reuse: a short review. *Applied Water Science*, **4**, 39–49.

Friedler E., Kovalio R. and Galil N.I. (2005). On-site greywater treatment and reuse in multi-storey buildings. *Water science and technology*, **51**(10), 187–194.

Gross A., Shmueli O., Ronen Z. and Raveh E. (2007). Recycled vertical flow constructed wetland (RVFCW)—a novel method of recycling greywater for irrigation in small communities and households. *Chemosphere*, **66**(5), 916–923.

Itayama T., Kiji M., Suetsugu A., Tanaka N., Saito T., Iwami N., Mizuochi M. and Inamori Y. (2006). On site experiments of the slanted soil treatment systems for domestic gray water. *Water Science and Technology*, **53**(9), 193–201.

Lei LiRong L.L., Cai FangRui C.F., Wang CaiMeng W.C., Li YouMing L.Y. and Li GuangSheng L.G. (2019). Improving treatment performance of a sequencing batch biofilm reactor (SBBR) for wastewater from a paper mill making coated products.

Lesjean B. and Gnirss R. (2006). Grey water treatment with a membrane bioreactor operated at low SRT and low HRT. *Desalination*, **199**(1–3), 432–434.

Li F., Wichmann K. and Otterpohl R. (2009). Review of the technological approaches for grey water treatment and reuses. *Science of the total environment*, **407**(11), 3439–3449.

Merz C., Scheumann R., El Hamouri B. and Kraume M. (2007). Membrane bioreactor technology for the treatment of greywater from a sports and leisure club. *Desalination*, **215**(1–3), 37–43.

Naz I., Batool S.A.U., Ali N., Khatoon N., Atiq N., Hameed A. and Ahmed S. (2013). Monitoring of growth and physiological activities of biofilm during succession on polystyrene from activated sludge under aerobic and anaerobic conditions. *Environmental monitoring and assessment*, **185**, 6881–6892.

Oh K.S., Leong J.Y.C., Poh P.E., Chong M.N. and Von Lau E. (2018). A review of greywater recycling related issues: Challenges and future prospects in Malaysia. *Journal of Cleaner Production*, **171**, 17–29.

Ozturk A., Aygun A. and Nas B. (2019). Application of sequencing batch biofilm reactor (SBBR) in dairy wastewater treatment. *Korean Journal of Chemical Engineering*, **36**, 248–254.

Ramadanti K., Elystia S. and Andrio D. (2022). Pertumbuhan Biomassa Dan Penyisihan Cod Menggunakan Sequencing Batch Biofilm Reactor (Sbbr) Pada Limbah Grey Water. *Jurnal Teknologi Pertanian Andalas*, **26**(1), 8–16.

Šostar-Turk S., Petrinić I. and Simonič M. (2005). Laundry wastewater treatment using coagulation and membrane filtration. *Resources, Conservation and Recycling*, **44**(2), 185–196.

Tan C., Ma F. and Qiu S. (2013). Impact of carbon to nitrogen ratio on nitrogen removal at a low oxygen concentration in a sequencing batch biofilm reactor. *Water science and technology*, **67**(3), 612–618.

Tombola R., Buttiglieri G., Auset M. and Gonzalez-Olmos R. (2019). Recycled corrugated wire hose cover as biological carriers for greywater treatment in a sequential batch biofilm reactor. *Journal of environmental management*, **240**, 475–484.

Winward G.P., Avery L.M., Frazer-Williams R., Pidou M., Jeffrey P., Stephenson T. and Jefferson B. (2008). A study of the microbial quality of grey water and an evaluation of treatment technologies for reuse. *Ecological engineering*, **32**(2), 187–197.

Zainab A., Meraj S. and Liaquat R. (2020). Study on natural organic materials as biofilm carriers for the optimization of anaerobic digestion. *Waste and biomass valorization*, **11**, 2521–2531.

Zhang J., Yang J., Tian Q., Liang X., Zhu Y., Sand W., Li F., Ma C., Liu Y. and Yang B. (2019). Durability and performance of loofah sponge as carrier for wastewater treatment with high ammonium. *Water Environment Research*, **91**(7), 581–587.