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Process Design & Experimental Analysis of Lab scale Moving Bed Biofilm Reactor using Eco-friendly Carrier

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ABSTRACT: In the present study, an attempt has been made to reduce the secondary pollution footprint in our eco-system. On ground realities, we have worked on Moving Bed Biofilm Reactor with an eye on carrier. We have done a comparative study on two different carriers i) Eco-friendly carrier (Ridge gourd) & ii) conventional carrier (AnoxKaldnes™K1). The experiment was carried out by varying the carrier fill fraction of both carriers as 40%, 50% and 60%. The physical characteristics of both carriers were found out and the reactor has been designed based on lab scale and industrial scale conditions. The lab scale Moving Bed Biofilm Reactor having the dimension of 30X30X30 (all dimensions are in cm) and the Hydraulic Retention Time was kept as 15days. Carrier Performance was analyzed at a stroke of 7^{th}, 10^{th}& 15^{th} days with the help of Biofilm Generation. It was observed that for Eco-friendly carrier (Ridge gourd), the BOD removal was high at 50% of the carrier fill fraction while the conventional carrier (AnoxKaldnes™K1) the BOD removal was high at 60%.

Index term: Study of MBBR, Sampling, Wastewater Quality Assessment, Design of MBBR, Carrier Characteristics, optimum carrier fills percentage.

1. Introduction

Water is a vital substance for living system as it allows the transport of nutrients as well as waste products in the living systems. However, sustainable water supply is becoming more challenging by the day due to ever increasing demand of growing population as well as increasing contamination of water resources. At the same time, huge quantities of wastewater generated by industries of every hue and kind and also by exponential growth in the number of households are becoming a serious concern for society[1].

Industrial Wastewater Treatment: covers the mechanisms and processes used to treat waters that have been contaminated in some way by anthropogenic industrial or commercial activities prior to its release into the environment or its re-use.Most industries produce some wet waste although recent trends in the developed world have been to minimize such production or recycle such waste within the production process. However, many industries remain dependent on processes that produce wastewaters[2].

Pulp and Paper industry: is one of world's oldest and core industrial sector. The socio-economic importance of paper has its own value to the country's development as it is directly related to the industrial and economic growth of the country. Paper manufacturing is a highly capital investment, energy and water intensive industry. It is also a highly polluting process and requires substantial investments in pollution control equipment. The pulp and paper mill is a major industrial sector utilizing a huge amount of lignocellulosic materials and water during the

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manufacturing process, and releases chlorinated lignosulphonic acids, chlorinated resin acids, chlorinated phenols in the effluent. About 500 different chlorinated organic compounds have been identified including chloroform, chlorate, resin acids, chlorinated hydrocarbons, phenols, catechols, guaiacols, furans, dioxins, syringols, vanillins, etc. These compounds are formed as a result of reaction between residual lignin from wood fibres and chlorine/chlorine compounds used for bleaching. Colored compounds and Absorbable Organic Halogens (AOX) released from pulp and paper mills into the environment poses numerous problems. The wood pulping and production of the paper products generate a considerable amount of pollutants characterized by Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), and color when untreated or poorly treated effluents are discharged to receiving waters. The effluent is toxic to aquatic organisms and exhibits strong mutagenic effects and physiological impairment[2].

2. Literature Review

In the previous chapter a snapshot was given on the industrial wastewater treatment and a detailed insight on wastewater generated at paper industry was discussed. In this chapter, a detailed review of literature is done in the field of Moving Bed Biofilm Reactor.

WWTPs usually operate conventional activated sludge treatment, which is inefficient for full removal of pharmaceuticals (Ternes et al., 2004; Joss et al., 2006). Consequently, on-site treatment of hospital wastewater has been discussed in industrialized and developing countries as a solution to decrease the amount of pharmaceuticals entering WWTPs (Verlicchi et al., 2010; Pauwels and Verstraete, 2006). This motivation to treat hospital wastewater increases with the size of the hospital and it gets more relevant the smaller the wastewater catchment is. Interestingly and mostly due to pathogen-spreading concerns, a few countries like China and Japan are already treating hospital wastewater on-site via conventional wastewater treatment or MBRs (Membrane Bioreactors) (Pauwels and Verstraete, 2006; Liu et al., 2010). Also in Europe, some hospitals treat wastewater to eliminate pharmaceuticals: Marienhospital Gelsenkirchen and Waldbr€ol (Germany), Isala clinics in Zwolle (The Netherlands), Cantonal Hospital of Baden (Switzerland) (Pills, 2012), a hospital in Ioannina (Greece) (Kosma et al., 2010) and Herlev hospital (Denmark) (Nielsen et al., 2013). Several post-treatment technologies such as activated carbon, advanced oxidation processes (AOPs), photolysis, osmosis or Nano filtration have been used to remove pharmaceuticals from wastewater (Pauwels and Verstraete, 2006; Joss et al., 2008). Therefore, in some cases where the treatments were conducted with reactors with activated sludge supported by membranes (MBR), the systems were complemented with AOPs or photolysis to be efficient (Nielsen et al., 2013; K€ohler et al., 2012; Kovalova et al., 2013, 2012). Alternatively, fungal fluidized-bed bioreactors have been tested for the removal of pharmaceuticals in hospital wastewater (Cruz-Morat_o et al., 2014), and showed better efficiency than conventional activated sludge systems. Biofilm systems such as MBBRs (Moving Bed Biofilm Reactors) have not been investigated for direct removal of pharmaceuticals in hospital wastewater. MBBRs rely on biofilms that are grown on small (1e4 cm diameter) plastic carriers which are suspended and mixed in a reactor. In this manner, MBBRs offer the advantages of biofilm reactors while being, design-wise, as robust as activated sludge treatment (Ødegaard et al., 1999). MBBRs have already been recognized as compact and robust reactors for wastewater treatment in respect of enhancing nitrification.

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In recent times different biofilm technologies were shown to be able to remove micropollutants, e.g. (Bester and Schafer, 2009; Escol_a Casas and Bester, 2015; Heberer et al., 2004; Hijosa-Valsero et al., 2011; Janzen et al., 2009; Li et al., 2014; Reungoat et al., 2011; Zearley and Summers, 2012). Among these biofilm technologies, MBBRs have also appeared to be a promising solution to remove micropollutants (Hapeshi et al., 2013; Falås et al., 2012, 2013). For example, Falås et al. (2012) compared the capacity of activated sludge and MBBR to remove acidic pharmaceuticals from effluent wastewater and found that MBBRs achieved higher removal rates for most of the pharmaceuticals per unit of biomass than activatedsludge plants. Falås et al. (2013) also described the role of biofilmcarriers in a hybrid biofilm-activated sludge process and found thatbiofilm carriers could remove more diclofenac and trimethoprimthan the activated sludge fraction. Additionally, Hapeshi et al.(2013) studied the removal efficiency of MBBR to remove two Xraycontrast media and found that these usually recalcitrant compoundscould be degraded by means of MBBR. Finally, MBBRs maybe used for industrial wastewater from pharmaceutical industrydue to its robustness and high ability to degrade chemicals(Gunderson, 2012)[8].

AYGUN ET AL has worked on the paper, Influence of High Organic Loading Rates on COD Removal and Sludge Production in Moving Bed Biofilm Reactor (AYGUN ET AL.) A laboratory scale Plexiglas reactor with a total liquid volume of 2 l and a final settler (volume equal to 1.2 l) was used in the study (Figure 2). The reactor was filled with the kaldnes bio media K1 to 50% of the volume of empty reactor and without recycle. Diffusers were used for oxygen supply and mixing. The DO was measured in the reactor every day at 2 hours interval. The average DO levels in the MBBR ranged from 0.30 to 3.00 mg O2/l depending on the influent organic loading rate. Although the amount of air increased to 1.8 and 2.3 l/min, DO levels decreased to an average of 0.83 mg/l and 0.30 mg/l when 48 and 96 g total COD/ m2.d surface organic loading rates were applied, respectively. Low dissolved oxygen concentrations could affect COD removal efficiency at 48 and 96 g total COD/ m2.d surface organic loading rates [1].

3. Methodology

General: The literature review on MBBR for the organic pollutant removal by using conventional carrier has reported in chapter 2. In this chapter, the experimental methodology adopted for the Moving Bed Biofilm Reactor has been discussed in detail.

Moving Bed Biofilm Reactor – Design Considerations

- Ability to by-pass any one reactor for operation & maintenance flexibility
- Expandability – consider oversizing tanks by 25-50% to allow future expansion with just media addition
- Need headworks screening (min ¼”)
- Oversize or double up media retention sieves
- Need approx. 8” to 12” of available head to fit MBBR system into ex. facility
- Provide D.O. monitoring/PID control. Need to maintain a min. mixing energy to keep media moving
- Blower design to allow for air/energy flexibility
- Consider polymer system to assist with solids settling

Design steps for a Moving Bed Biological Reactor – Lab Scale [4]

1. The overall Lab Scale MBBR design follows the step by step design procedure developed by the Harlan H. Bengston, “MBBR Wastewater Treatment Processes”.

➢ BOD Loading Rate, BOD_{LR}= Q x BOD in g BOD / day.

- Required Carrier Surface Area, C.S.A $_r$ = BOD_{LR} / SALR in m^2. SALR can be selected with Table 8

Table 1 Typical Design Values for BOD Removal

Treatment Target % of BOD Removal	Design SALR in g/m^2/ d
75-80	25
85-90	15
90-95	7.5

- Required Carrier Volume, C.V $_r$= C.S.A $_r$ / CSSA unit in m3

CSSA = Carrier Specific Surface Area in m^2 / m3

- Required Tank Volume, T.V $_r$ = C.V $_r$ / carrier fill % in m3
- Liquid Volume in Tank, L.V.T = T.V $_r$ – [C.S.A $_r$- (1- carrier % void space)]
- Assume depth, D = 0.3 m; L = 4B; B = $(L.V.T /4D)^{1/2}$
- Ave. HRT $_{des.\ ave.}$ =L.V.T / Q in hours
- Ave. HRT peak $_{hr.}$ = Ave. HRT $_{des.\ ave.}$ / 4 in hours

Estimation effluent Concentration:

- Slope = -0.007; Intercept = 0.975
- SARR/SALR = - (Slope) (SALR) + Intercept
- SARR = (SARR/SALR) x SALR in g/m^2/day
- BOD Removal Rate, BOD $_{RR}$ = SARR x C.S.A $_r$ in g/day
- BOD Effluent Concentration BOD $_{EC}$= (BOD_{LR} - BOD $_{RR}$) / Q in mg/l
- Percentage of BOD Removal = (BOD $_{EC}$ / BOD) x 100%

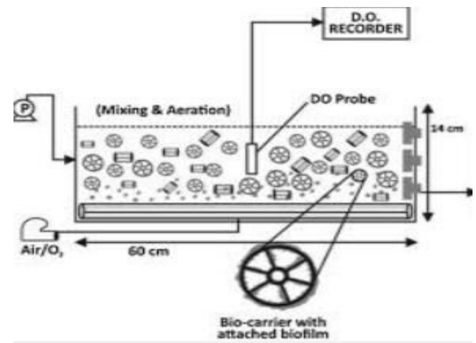

Fig. 1 Principles of MBBR

These are normally shaped as small cylinders with a cross inside and fin outside. The standard filling of carrier is below 70% with a maximum specific area not more than 465 m^2/m3. Generally, design load for COD-BOD removal is 20 g COD / m^2d. Smaller carriers need smaller reactor volume at a given loading rate (as g/m2d) when the carrier filling is same. HRT of the reactor is about 3 – 4 hours for effective BOD and nitrogen removal. It is advisable to use MBBR in combination with a septic tank or a pre-coagulation step as a pre-treatment unit, depending on the local conditions and input characteristics. It is a very robust and compact alternative for secondary treatment of municipal wastewater, having removal efficiency for BOD 90 – 95% (low rate) and that of 75 – 80% for high rate. Average nitrogen removal is about 85%. There is no need for sludge recirculation. Phosphorus and faecal coliform reduction is feasible with additional passive (non-mechanical) or active (mechanical) system components [3].

Characteristics of Carrier:

In this Paper the Moving bed biofilm reactor (MBBR) technology using eco-friendly carrier is introduced ridge gourd to astound the difficulties faced by conventional carrier used for wastewater treatment processes. The major advantage of this technology is the extraordinary treatment capacity due to the majority of the microbial biomass being retained for extended periods

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within the reactor on suspended eco-friendly carriers. However, much remains unknown about the microbial ecology of these biofilm-based systems. This research examined the full-lab scale MBBR systems treating industrial wastewater generated at Paper Manufacturing Industries in Salem, Tamilnadu. A subsequent study investigated biofilm succession on Conventional carriers (AnoxKaldnes™K1) from initial seeding to and comparing its efficiencies with the eco- friendly carrier (Ridge Gourdnut fibre). Comparisons of successional development of bacterial (biofilm) communities were also made between two carriers. The results provided in-depth knowledge of the development of bacterial biofilm of MBBR from initial attachment to maturation.

The present study involves the applicability of ridge gourdnut fibre an adsorbent (carrier) for the removal of BOD (Biochemical Oxygen Demand) from the industrial wastewater. The eco-friendly were prepared from the ridge gourd fruit, as it matures, the fruit becomes increasingly fibrous, which makes it unfit for consumption. A major motivation of this study was to identify the carrier in eco centric & econo centric point of waste management, as they reduce the environmental degradation. Totally 3 Reactors (MBBR-A, MBBR-B, MBBR-C) are installed on 15th February, 2018 by varying the percentage of eco-friendly carrier fill fraction as 40%, 50%, 60% volume of the reactor respectively with the Hydraulic Retention Time as 15 days[8].

Fig. 2 Eco- Friendly Carrier (Ridge gourd fibre)

Fig. 3 Conventional Carrier (AnoxKaldnes™K1)

Eco- Friendly Carrier (Ridge gourd fibre)

- Ridge gourd fibre is originated from the fruit of a sub-tropical vine that belongs to the cucumber family and is native to central and eastern Asia, including the Indian subcontinent.
- The plant is quite hardy and easy to cultivate and is even grown indoors in regions with colder climates.
- Ridge gourd is popular as a vegetable in various regional cuisines in Asia, but the fruit is only edible before it ripens.
- As it matures, the fruit becomes increasingly fibrous, which makes it unfit for consumption.

Conventional Carrier (AnoxKaldnes™K1)

- AnoxKaldnes™K1 MBBR technology is our implementation of the biofilm principle. Carriers are of course a vital ingredient in AnoxKaldnes™ MBBR technology.
- On their protected surfaces different microorganisms ranging from bacteria to ciliates and rotifers are established in a biofilm.
- These carriers are kept in motion either by the blast air injection in aerobic systems or by stirrers in anoxic or anaerobic systems.
- By these motion impurities in the water is transported to the biofilm and are reduced by it.

Sample Collection: As per the Bureau of Indian Standard, the industrial wastewater has been collected as a sample from the paper manufacturing industry by sampling procedure.Sampling is the act of selecting a representative part of a water sample for the purpose of determining parameters of the whole water sample.

Simple Random Sampling Systematic Sampling

Cluster Sampling Multistage Sampling

The following Wastewater characteristic has been analyzed as per the Bureau of Indian Standard.

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- **pH:** pH is measured by a pH meter using a glass electrode which generates a potential varying linearly with the pH of the solution in which it is immersed. It is a Nernstain concentration cell with potential controlled by the activities of H on either side of a very thin glass membrane. The latter bottom part of a bulb at the end of a glass tube containing a reference solution of fixed a_H^+.
- **Turbidity:** When light is passed through a sample having suspended particles, some of the light is scattered by the particles. The scattering of the light is generally proportional to the turbidity. The turbidity if the sample is thus measured from the amount of light scattered by the sample taking a reference with standard turbidity suspension.
- **Total solids** are determined as the residue left after evaporation and drying of the unfiltered sample.
- **Total dissolved solids** are determined as the residue left after evaporation and drying of the filtered sample.
- **Total volatile solids and fixed solids** are determined as residue remaining after evaporation, drying at 103°C and ignition at 600°C.
- **Chloride** ion is determined by Mohr's method, titration with standard silver nitrate solution in which silver chloride is precipitated at first. The end of titration is indicated by formation of red silver chromate from excess $AgNO_3$ and potassium chromate used as an indicator in neutral to slightly alkaline solution.
- **Hardness:**In alkaline condition, EDTA reacts with Ca and Mg to form a soluble chelated complex. Ca and Mg ions develop wine- red color with Erio Chromo black T under alkaline condition. When EDTA is added as a titrant, Ca and Mg divalent ions get complexed resulting in sharp change from wine – red to blue which indicates end point of the reaction.
- **Biological Oxygen Demand**is an empirical biological test. This BOD test may be considered as wet oxidation procedure in which the living organisms serve as the medium for oxidation of the organic matter to carbon-dioxide and water.
- **Chemical Oxygen Demand**The organic matter present in sample gets oxidized completely by $K_2Cr_2O_7$ in the presence of H_2SO_4 to produce CO_2 and H_2O. The excess $K_2Cr_2O_7$ remaining after the reaction is titrated with Fe $(NH_4)_2$ $(SO_4)_2$. The dichromate consumed gives the O_2 required to oxidation of the organic matter.
- **Fluoride** The test is based on the fact that fluoride ion combines with zirconium ion to form a stable complex ion, ZrF5 and these results in bleaching the reddish color of Zirconium and alizarin combination. The decrease in intensity of color is directly proportional to fluoride concentration.

4. Results & Discussion

Wastewater Characteristics: The wastewater generated from paper & pulp industry at Salem, Tamilnadu has been taken as sample, this sample has been as asses and compared with the effluent discharge limits as per Tamilnadu Pollution Control Board, 2017.

Table 2 Industrial Wastewater Quality Assessment

Parameter	Industrial Waste Water Quality	Industrial Discharge Standards as on

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		land for irrigation as per TNPCB January 2017
pH	8.2	5.5 to 9.0
Turbidity in NTU	186	No limits
Alkalinity in mg/l	3600 as $caco_3$	No limits
Total Solids in mg/l	2160	No limits
Total Suspended Solids in mg/l	450	200
Total Dissolved Solids in mg/l	2710	2100
Total Volatile Solids in mg/l	3720	No limits
Total Settable Solids in mg/l	220	No limits
Calcium in mg/l	400 as ca^{2+}	75
Magnesium in mg/l	72 as mg^{2+}	No limits
Hardness in mg/l	1000 as $caco_3$	No limits
Chlorides in mg/l	1019 as cl^-	600
COD in mg/l	8200	No limits
BOD in mg/l	4300	100
ODOUR	HIGHLY ODOUR	No limits
Temperature	33ºC	No limits

From the Table.2 it clearly shows that the organic pollutant like Total Dissolved Solids, Total Suspended Solids, Total Fixed & Volatile Solids, BOD, COD, are excess from the effluent Discharge Limits and

Theoretical Design of Moving Bed Biofilm Reactor

Based on the design procedure detailed in the chapter 3 the Moving Bed Biofilm Reactors are theoretically designed by varying the percentage of carrier fill fraction as 40%, 50% & 60% of the total volume of the reactor.

Table 3 Theoretical DesignValues for Moving Bed Biological Reactor – Lab Scale

Design Parameters	MBBR-A	MBBR-B	MBBR -C
Carrier Fill in %	40	50	60
BOD in mg/l	4300	4300	4300
Specific Surface Area of Carrier, SSA in m^2/ m^3	500	600	700
Surface Area Loading Rate, SALR in g/ m^2/d	25	7.5	15
BOD Loading Rate in g BOD/day	21.5	21.5	21.5
Carrier Surface Area in m^2	0.86	2.86	1.43
Carrier Volume in m^3	0.00172	0.00477	0.00204
Tank Volume Required in m^3	0.0043	0.00955	0.00341
Required Liquid Volume in m^3	0.003612	0.000952	0.002594
Depth of the Tank, D in cm	30	30	30
Width of the Tank, B in cm	5.4	2.8	4.64
Length of the Tank, L in cm	21.94	11.26	18.29
BOD Removal Rate in g/d	17.2	19.78	18.66
BOD Effluent Conc. In mg/l	900	340	567.7

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BOD Removal in %	20.9	7.9	13.02

Table 3 shows the target limits for the organic pollutant which are excess from the effluent discharge limits.

Experimental Analysis of MBBR using Eco- Friendly Carrier (Ridge gourd fibre) – First Cycle

Characteristic of Eco- Friendly Carrier (Ridge gourd fibre)

Parameters	**Unit**	**Value**
Length	Cm	2-3
Diameter	Cm	3-5
Surface Area	cm^2	19.63
Carrier Shape	No Unit	Circular
Moisture Content	Percentage	58.6
Carrier Density	g/cm^3	1
Carrier fill fraction	Percentage	40, 50, 60

Fig. 4 Preparation of Eco-friendly Carrier

Fig.5 Working of Lab scale MBBR using Eco-friendly Carrier

Fig. 4 & Fig.5 involves the applicability of ridge gourdnut fibre an adsorbent (carrier) for the removal of BOD (Biochemical Oxygen Demand) from the industrial wastewater. The eco-friendly were prepared from the ridge gourd fruit, as it matures, the fruit becomes increasingly fibrous, which makes it unfit for consumption. A major motivation of this study was to identify the carrier in eco centric & econo centric point of waste management, as they reduce the environmental degradation. In the first cycle, totally 3 Reactors (MBBR-A, MBBR-B, MBBR-C) are installed on 15th February, 2018 by varying the percentage of eco-friendly carrier fill fraction as 40%, 50%, 60% volume of the reactor respectively with the Hydraulic Retention Time as 15 days as shown in Table 4.

Table 4 Experimental Analysis of MBBR using Eco-Friendly Carrier (Ridge gourd fibre) – First Cycle

Parameter	MBBR – A(60%)	MBBR – B(50%)	MBBR – C(40%)
pH (no unit)	7.5	8.0	7.0
Temperature (°C)	41.0	41.1	41.2
Fluoride (mg/l)	1.5	1.0	1.0
Alkalinity (mg/l)	600	400	350
Chloride (mg/l)	1250	500	400
Hardness (mg/l)	750	350	300
Total Dissolved Solids (mg/l)	3120	1500	1260
BOD (mg/l)	862.5	350	559
COD (mg/l)	6979	7018	7380
Total Suspended Solids (mg/l)	500	423	378

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Total Volatile Solids (mg/l)	3800	3500	3478
Total Settable Solids (mg/l)	240	178	150

Table 4 shows the Experimental Analysis of MBBR using Eco-friendly Carrier (First Cycle) with the HRT of 15 days, the removal efficiency of organic pollutant was better when the MBBR has been working with the carrier load of 40%.

Experimental Analysis of MBBR using Conventional Carrier (AnoxKaldnes™K1) – Second Cycle

The first cycle reactors has been monitored as first cycle and based on the performance of the 3 reactors, second cycle is started on 5th March, 2018 by varying the percentage of conventional carrier (AnoxKaldnes™ K1) fill fraction as 40%, 50%, 60% volume of the reactor and the analysis results are shown in Table 5

Characteristic of Conventional Carrier (AnoxKaldnes™K1)

Parameters	**Unit**	**Value**
Length	cm	1.5
Diameter	cm	2
Carrier Shape	No Unit	Circular
Carrier Density	g/cm^3	1
Carrier fill fraction	Percentage	40, 50, 60

Fig.6 Working of Lab scale MBBR using Conventional Carrier (AnoxKaldnes™K1)

Table 5 Experimental Analysis of MBBR using Conventional Carrier (AnoxKaldnes™K1) – Second Cycle

Parameter	MBBR – A (60%)	MBBR – B (50%)	MBBR – C (40%)
pH (no unit)	8.0	8.0	7.5
Temperature (^oC)	40.1	41.2	41.9
Fluoride (mg/l)	2.5	2.0	1.5
Alkalinity (mg/l)	1200	700	450
Chloride (mg/l)	1000	950	500
Hardness (mg/l)	900	450	350
Total Dissolved Solids (mg/l)	2672	2520	1560
BOD (mg/l)	1100	2565	2667
COD (mg/l)	7221	6373	6487
Total Suspended Solids (mg/l)	414	400	365
Total Volatile Solids (mg/l)	3600	3569	3029
Total Settable	209	195	185

Solids (mg/l)			

4. Conclusion

In the present study we designed and developed a simple, low cost and eco-friendly carrier for Moving Bed Biofilm Reactor. In this regard Paper Industry Wastewater has been collected as sample by random sampling. The water samples were analyzed for various parameters as per Bureau of Indian Standard, before and after the wastewater using the eco-friendly and conventional carrier for MBBR. Investigation continues with the design of Carrier with theoretical design. Lab scale MBBR has been designed and analyzed by varying the carrier fill of 40%, 50%, 60% of Eco-friendly Carrier (Ridge gourd fibre) and Conventional Carrier (AnoxKaldnes™K1) respectively for the inflow rate of 8L/day. The system was operated with the Hydraulic Retention Time as 15 days in order to evaluate the lab scale performance. According to the experimental results, the BOD removal efficiency was about 50% of carrier fill of MMBR using Eco- friendly Carrier whereas the BOD removal efficiency was about 60%of carrier fill fraction of MBBR using Conventional Carrier.

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