Design Of Pilot Scale Moving Bed Biofilm Reactor

Mr. Satya Ranjan Barik[1], Mr. Amitkumar Dilip Khandare[2], Mr. Vishal Bharat Shinde[3],
Mr. Aniket Dashrath Kulhadkar[4], Prof. V. S. Poman[5], Prof. Pratiksha Sanas[6]
[1,2,3,4]Student, Dept. of Civil Engineering, Trinity Polytechnic, Kondhawa, Pune
[5,6]Assistant Professor, Dept. of Civil Engineering, Trinity Polytechnic, Kondhawa, Pune

Abstract—**The objective of this project is to design a pilot-scale Moving Bed Bioreactor (MBBR) and to evaluate its short-term performance using sewage water samples collected from the Indrayani River. The design calculations were carried out based on key parameters obtained from the analysis of local sewage wastewater, along with standard values of activated sludge kinetic coefficients. These parameters helped in establishing a reliable design framework for efficient biological treatment. Important process parameters such as bioreactor volume, biomass loading (F/M ratio), oxygen demand, and hydraulic retention time were determined based on the actual characteristics of the wastewater. These calculations ensured that the system was tailored to handle real conditions effectively. Based on the finalized design considerations, a pilot-scale MBBR unit was constructed and integrated with laboratory testing facilities. The reactor was designed with a hydraulic volume of approximately 54 litters and incorporated specially designed plastic carrier media available in the market to support biofilm growth. Performance testing of the developed MBBR system was carried out over a specified period using sewage wastewater to assess its functionality and treatment efficiency. The results obtained from the experimental study were used to evaluate the effectiveness of the reactor design, including its ability to remove organic pollutants and maintain stable operation. Overall, the study demonstrates the practical applicability of the pilot-scale MBBR system for wastewater treatment and provides a foundation for further optimization and scale-up in real-world applications.**

Index Terms—**Moving Bed Biofilm Reactor (MBBR), Pilot-Scale Design, Wastewater Treatment, Sewage Water, Indrayani River.**

I. INTRODUCTION

Moving bed bio-reactor (MBBR) technology is a combination of the conventional biological sludge process, a wastewater treatment process characterized by a suspended growth of biomass. The biological unit is responsible for the biodegradation of the waste compounds and the membrane module for the physical separation of the treated water from the mixed liquor. The MBR offers the advantage of higher product water quality and low footprint. Due to its advantages, membrane bioreactor technology has great potential in wide ranging applications including municipal and industrial wastewater treatment (e.g. textile) and process water recycling.

Wastewater reclamation and reuse are effective tools for sustainable industrial development programmes. Increase kingly stringent environmental legislation and generally enhanced intensity, efficiency and diversity of treatment technologies have made the reuse of water more viable in many industrial processes. Membrane bioreactors (MBRs) technology will be an essential part of advancing such water sustainability because they encourage water reuse and open up opportunities for decentralized treatment. Moreover, membrane bioreactor (MBR) technology is recognized as a promising technology to provide water with reliable quality for reuse and is very attractive for industrial, e.g. textile wastewater treatment. But the performance of MBR technology depends on the proper design of the plant considering different factors required for optimum outcome.

This paper deals with the design of a pilot-scale MBR to obtain optimum performance of this kind of technology, and the trial was done for 6 weeks using textile wastewater. The optimum design of the technology can prove the viability of the technology and open up a door of a reliable technology for industrial wastewater treatment and reuse.

A. State of development

Membrane Filtration is defined as the separation of two or more components from a fluid stream. In conventional usage, it usually refers to the separation of solid or insoluble particles from a liquid stream. Membrane filtration extends this application further to include the separation of dissolved solids in liquid streams, and hence membrane processes in water treatment are commonly used to remove various materials ranging from salts to microorganisms.

The moving bed bio-reactor (MBBR) concept is a combination of conventional biological wastewater treatment plant and membrane filtration. The concept is technically similar to that of a traditional wastewater treatment plant, except for the separation of activated sludge and treated wastewater. In an MBBR installation, this separation is not done by sedimentation in a secondary clarification tank, but by membrane filtration.

Membranes processes can be categorized in various, related categories, three of which are: their pore size, their molecular weight cut-off; or the pressure at which they operated. As the pore size gets smaller or the molecular weight cut-off decreases, the pressure applied to the membrane for separation of water from other material generally increases

II. SYSTEM ANALYSIS AND DESIGN

Aeration is important part of MBBR for providing oxygen to microorganisms and keeping media in suspension by distributing it homogenously. So, a network of lateral and longitudinal pipes connected to aerators with 1–2 mm orifices are used at the bottom of reactor. Air moves upwards from orifices in the form of bubbles. Size of bubble depends on the diameter of orifice provided.

A. Media

Media is the important component of MBBR system. Media provides surface area to the microorganisms for growth as biofilm. These media move freely into the wastewater and increase contact between substrate available in wastewater and microorganisms present on the media. Generally, this media is made by polyethylene and specific gravity of media is between the ranges of 0.90-0.98 g/cm3. There are different types of media which can be used as a space for the microbial growth. In aerobic processes, the movement of media is caused by the agitation set up by the air, while in anoxic and anaerobic processes a mixer keeps the media moving. Special sieve arrangements to retain the media within the reactors have also been developed. In reactor, for biomass to adhere 30–70 % media is introduced, in which 67 % is optimal. The specific surface area of the media found on the market range from 350–1000 m2 /m3.

Figure shows the photographic view of the media. Commercially available media was used in the study. Media is collected from media manufacturing company Pune. Density of media was less than water to move the media easily in the reactor. Corrugation was made on the media to increase surface area.

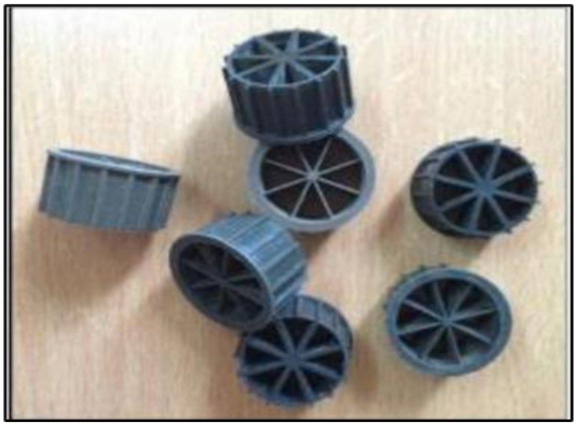


Fig. 1 Filter Media

B. Theory of attached growth process

In this process wastewater is contacted with microbial films attached to surface. Surface area for biofilm growth is increased by placing media in reactor. As shown in figure given below organisms attach themselves to the medium and grow into the dense films of a viscous, jellylike nature. Wastewater and biofilm come in contact due to movement of media. Dissolved and colloidal organics passes into the biofilm due to concentration gradients within the film. Oxygen from the wastewater and from air in the void spaces of the medium provides oxygen for aerobic reactions at the biofilm surface. End products from the metabolic processes diffused outward and are carried away by the water or air currents moving through the voids of the medium.

As the biofilm grows thicker, concentration gradients of both oxygen and food develop. Eventually, both anaerobic and endogenous metabolism occurs at the biofilm and media surface interface. The attachment mechanism is weakened, and the shearing action of the wastewater flowing across the film pulls it out and washes it away. This process is known as sloughing. Biofilm can be quickly re-established in places cleared by sloughing.

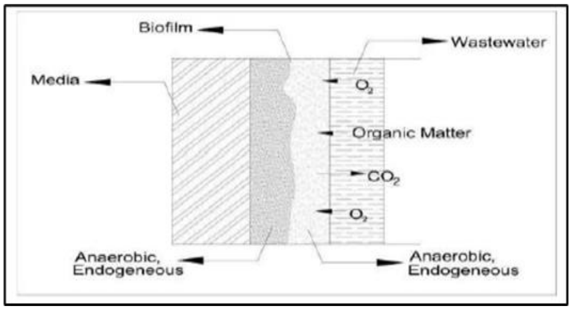


Fig 1 Biofilm on Media

C. Development of an activated sludge for MBBR

Active biomass is very important for developing biofilm on media. Cow dung is rich with microorganisms therefore it was used for sludge development. Jaggery is the best source of nutrients so slurry of jaggery was used for providing nutrients to the microorganisms. Following steps were adopted to develop an activated sludge.

Initially, around 5 % of reactor was filled with cow dung slurry.

Then, about 2 % jaggery slurry was added in the reactor.

Remaining volume of the reactor was filled with the fresh domestic wastewater and sufficient aeration was provided.

Aeration was switched off after decided time interval and sludge was allowed to settle completely. Then around 50 % of wastewater (supernatant of settled wastewater) was replaced with the fresh domestic wastewater. Wastewater was replaced thrice a day.

Phosphate buffer, magnesium sulfate, calcium chloride and ferric chloride were added as nutrients each time after replacement of wastewater.

After development of sufficient quantity of active sludge, it was filled in the MBBR to get desired MLSS.

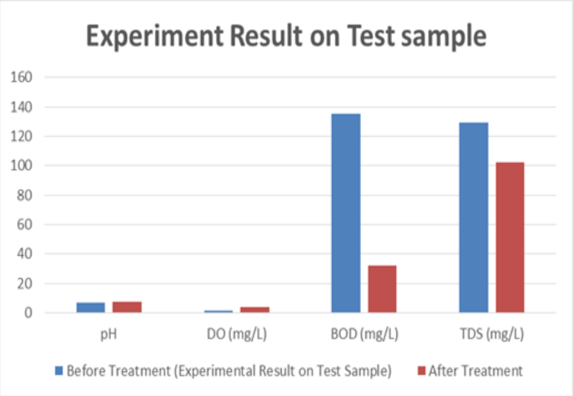
III. RESULT AND DISCUSSION

A. Observation Table for Bod Test.

Different analysis of wastewater sample is to done at inlet and outlet to understand the chemical and biological characteristic. Following tests are conducted i.e. pH, Total Suspended Solids, BOD, and DO.

Table 1 Observation Table for BOD Test

Sr. No.	Parameter	Before Treatment (Experimental Result on Test Sample)	After Treatment	CPCB Standard Values
1	pH	6.64	7.14	5.5 – 9.0
2	DO (mg/L)	1.3	3.7	4.0 mg/L
3	BOD (mg/L)	135	32	30 mg/L
4	TDS (mg/L)	129	102	100 mg/L



Graph 1 Observation Table for BOD Test

pH:

The pH value increased from 6.64 to 7.14, indicating that the treated water became more neutral. Both values fall within the acceptable CPCB range (5.5–9.0), showing that the treatment process maintained proper chemical balance.

Dissolved Oxygen (DO):

DO improved from 1.3 mg/L to 3.7 mg/L, which indicates better oxygen availability after treatment. However, it is still slightly below the CPCB standard of 4.0 mg/L, suggesting that further aeration may be required.

Biochemical Oxygen Demand (BOD):
BOD reduced significantly from 135 mg/L to 32 mg/L, showing effective removal of organic pollutants by the MBBR system. Although there is a major reduction, the final value is slightly higher than the CPCB limit of 30 mg/L.

Total Dissolved Solids (TDS):
TDS decreased from 129 mg/L to 102 mg/L, indicating partial removal of dissolved impurities. The treated value is very close to the CPCB limit of 100 mg/L, but still slightly exceeds it.

IV. CONCLUSIONS

The applied aeration rate of 1.0 m³/h was significantly higher than the originally designed aeration rate. However, this increased aeration was not solely intended for oxygen transfer; it also played a crucial role in creating cross-flow conditions within the system. The cross-flow helps in reducing membrane fouling by scouring the membrane surface and preventing the accumulation of suspended particles. As a result, the higher aeration rate contributed to maintaining stable system performance and improving the overall efficiency of the membrane bioreactor (MBR) process.

The MBBR system shows good treatment efficiency, especially in reducing BOD and improving DO levels. Most parameters are close to or within CPCB limits, but slight improvements in aeration and filtration are needed to fully meet all standards.

Overall, the testing results suggest that the design of the pilot-scale MBR plant is largely effective and close to optimal. Despite the higher-than-planned aeration rate, the system demonstrated satisfactory operation in terms of oxygen transfer, membrane performance, and treatment efficiency. The findings indicate that the design is robust and capable of handling practical operational variations, thereby confirming its suitability for pilot-scale applications with minor scope for further optimization.

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