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Sensitivity Analysis of Microbial Desalination Cell (MDC) Technology and Comparison with Existing Biological Treatment Systems

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Abstract: -The present study was focused on the sensitivity analysis of UASBR, CAT, EAT, MBBR, RBC, biopiping, anoxic, and aerobic systems and their comparison with MDC technology. The infeed parameters were varied to check the system performance in terms of COD and BOD removal and system restoration with pH sensitivity. The experiment study showed a better performance in terms of COD reduction by RBC (92%) followed by UASBR (89%), biopiping (85%) and MDC system (82%) for substrate concentrations. However, variation of HRT showed, a maximum COD removal of 93% by RBC, 92% by UASBR and 72% by MDC systems. With variation in flow rate, RBC system (94%), followed by UASBR (91%), biopiping (88%) and MDC (in batch) 87% presented a better performance in terms of COD reduction. The study of pH variation showed a stability and resistivity of MDC system of sustaining 4 to 8 pH when compared to other biological systems tolerating pH range of 6.5 to 8.5. The organic loading to the MDC system was found to be maximum (12000 mg/L of COD) followed by UASBR (7500 mg/L), CAT (2000 mg/L) and remaining all the other systems (< 2000 mg/L). The feasibility matrix indicated that the MDC system exhibited strong performance in terms of high organic loading, TDS reduction, and power generation, surpassing all other biological treatment systems. The MDC system was promising towards treatability and potential for practical implementation highlighted its prospective contribution towards addressing wastewater treatment challenges and promoting sustainable solutions for various applications.

Keywords: *Biological treatment, COD, feasibility matrix, organic loading, sensitivity analysis*.

1. Introduction

In the present scenario of climate change and energy crisis, the endeavors aimed at achieving environmental targets hold significant importance [1]. Conversely, the issue of pollution, particularly from industrial effluents, has intensified in developing nations over the past few decades. The rapid industrialization has adversely impacted the environment at large, with water quality being particularly affected [2]. Nevertheless, there is an increasing consciousness regarding the impact of activities by human on the environment, leading to the development of numerous environmentally friendly strategies and technologies in recent decades [3]. From this standpoint, there remains a persistent necessity to employ a judicious management of both natural freshwater and energy resources, a need that is closely linked to the functioning of wastewater treatment plants [4].

Secondary treatment systems play a crucial role in wastewater treatment plants, as their efficiency significantly enhances the overall treatment efficacy. These systems are essential for further removal of organic matter and suspended solids, ensuring that the effluent meets stringent regulatory standards before discharge. Moreover, selecting the appropriate biological system is paramount to improving plant efficiency, as it directly impacts the effectiveness of treatment process and their operational costs.

Livingston and Abbassi [5] demonstrated the effectiveness of multi-criteria analysis (MCA) combined with scenario analysis in evaluating various petroleum refinery wastewater (PRWW) treatment technologies. The study found that advanced oxidation processes (AOP) consistently outperformed electrocoagulation and microbial fuel cell (MFC), scoring a maximum of 8.51 out of 10 across six scenarios. Narayanan and Narayan [6] highlighted the development of diverse bioreactors with favorable traits by researchers, emphasizing the importance of their industrial implementation. The study also advocated the integration of Liquid Phase Oxygen (LPO) system with conventional wastewater treatment processes, suggesting its significant potential for effective treatment.

Ceretta et al. [3] demonstrated that utilizing microbial consortia enables the biodegradation of complex compounds. The study emphasized the necessity of employing a combination of physical, chemical, and biological methods for effective treatment, not only in reducing dye concentration and COD but also in lowering pH, BOD, and toxicity. Shah and Ruparelia [2] found COD removal ranging from 61% to 86%, 27% to 73%, and 9% to 59% for textile processing, dyes, and dye intermediates, respectively. The study concluded that the scale of industries and treatment technologies did not significantly affect COD removal efficiency. Batch reactor studies indicated that Fenton's reagent outperformed the electrocoagulation process for most industries in the study. Bartha et al. [1] revealed that subjecting the active sludge suspension to an electric field notably reduced residual pollutant levels at the biological purification tank outlet. The study indicated a threefold decrease of COD and approximately twofold decreases of $N\text{-}NH_4$ and Pt. Analysis of dissolved oxygen (DO) content in aerobic and anaerobic periods highlighted that the electric field accelerated the denitrification process by approximately two times compared to the reference.

The comparative study of various biological treatments was crucial for comprehending water treatability, especially concerning pH sensitivity, substrate loading, HRTs, and flow rates. This analysis aided in identifying the most effective treatment method for diverse wastewater treatment requirements.

Despite notable advancements in standalone wastewater treatment and desalination technologies, there is a pressing need to effectively integrate these processes. Existing methods often result in higher energy consumption, operational expenses, and environmental repercussions. There is a clear demand for innovative solutions that can simultaneously tackle water scarcity and wastewater treatment issues, while minimizing energy usage and environmental impact.

Thus, the main objective was to analyze the sensitivity of the MDC technology as a sustainable solution for addressing water scarcity and wastewater concerns. This study comprehensively assessed the MDC technology, considering factors like COD and BOD removal efficiencies under various conditions, including high and low flow rates, hydraulic retention time, and substrate concentrations. The study also aimed to identify pH sensitivity and maximum loadings within the operational conditions to determine treatment efficiencies.

Through comparisons with conventional and emerging treatment technologies, the study aimed to evaluate the feasibility of large-scale implementation of MDC in municipal and industrial contexts. Ultimately, the research findings offer valuable insights into the potential of MDC technology to transform wastewater treatment and contribute to sustainable water resource management in an ever-changing world.

2. Materials and Methods

A. General

Conducting sensitivity analysis aimed to determine the optimal performance of diverse treatment units across various operational conditions. The study encompassed multiple treatment technologies, including MDC, UASBR, CAT, EAT, MBBR, RBC, biopiping, anoxic, and aerobic systems. This section focused on examining sensitivity parameters such as flow rate, hydraulic retention time (HRT), substrate concentration, pH variations, and loadings.

B. Industry selection and data collection

The preliminary authorization for the feasibility study was obtained from the Karnataka State Pollution Control Board (KSPCB), which was subsequently communicated to the relevant industries. This was followed by the collection and analysis of samples. The experiments were conducted in collaboration with the plant operation team, and data were gathered at various time intervals. Design specifications of treatment units/ systems and historical data were also gathered to assess the variability of treatment units for comparison and sensitivity analysis.

C. Experimental procedure

The experiments were conducted based on the changes made in the operational conditions. During the experiments of feed flow variation, all the treatment units were operated its maximum, moderate and minimum flow conditions and checked for the output results i.e., COD and BOD. A similar study was also done for high and low HRT and substrate concentration. The data of COD and BOD were collected to check the system performance and reliability. The other study was done based on the pH sensitivity where feed water pH was varied and check the system performance. A similar study was also done for the maximum loading into the system to check the nutrient removal.

D. Methodology

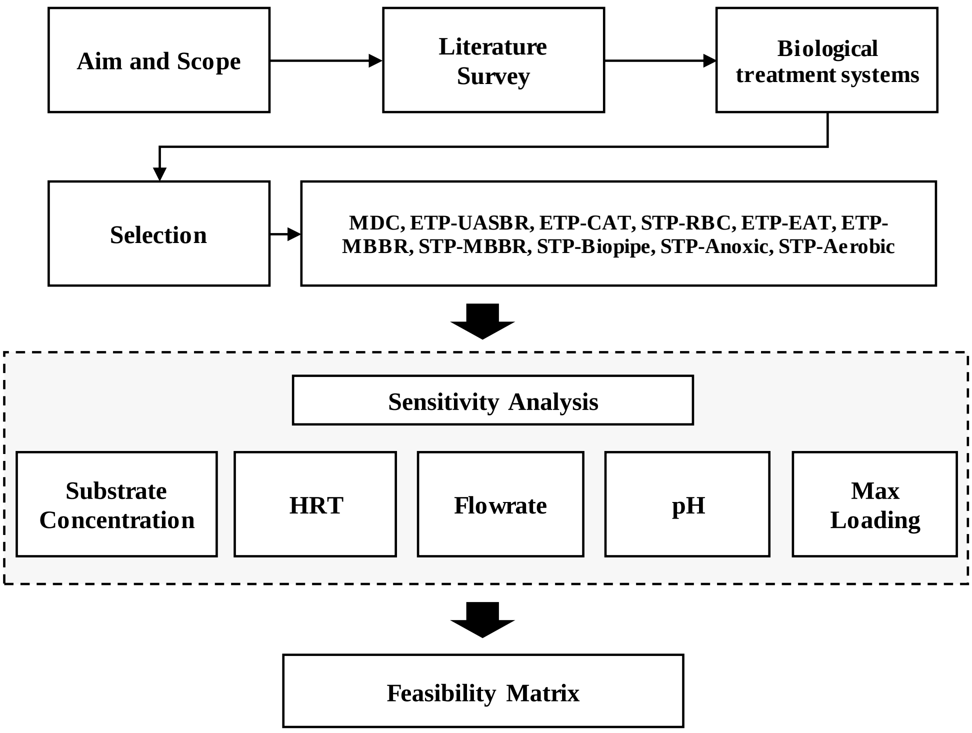

Figure 1. Methodology for the sensitivity and feasibility analysis considered in the present study.

This study aimed to evaluate the feasibility and perform a thorough cost-benefit analysis of different biological treatment systems. The scope encompassed assessing the effectiveness, operational feasibility, and financial considerations associated with the adoption of MDC, UASBR, CAT, EAT, MBBR, RBC, biopiping, aerobic, and anoxic systems (Figure 1).

E. Biological Treatments

The methodology comprised a thorough examination of pertinent literature and studies concerning the biological treatment of wastewater, with a focus on the applications and performance of different systems across varying wastewater compositions. This literature review delved into the fundamental principles, mechanisms, and processes of biological treatment, evaluating the effectiveness of each system in addressing particular pollutants and contaminants. Additionally, it explored technological advancements, recent progress, and emerging trends in the realm of biological wastewater treatment, contributing to a comprehensive grasp of the current advancements in this field and aiding in the selection of appropriate treatment systems.

F. Selection of Different Treatment Systems

The selection process involved a systematic comparison and evaluation of the MDC, ETP-UASBR, ETP-CAT, STP-RBC, ETP-EAT, ETP-MBBR, STP-MBBR, STP-Biopipe, STP-anoxic, and STP-aerobic systems. The analysis took into account the project's objectives, distinctive demands and challenges linked to the wastewater characteristics. It entailed evaluating the capability of each system to manage the wastewater's composition, fluctuations in loads, and potential contaminants, alongside their operational effectiveness and adherence to regulations. The criteria emphasized high performance, sustainability, and reliable operation, ensuring the identification of the most suitable biological treatment system for the feasibility analysis.

G. Sensitivity Analysis

The sensitivity analysis was conducted to identify the system performance in various condition and to optimize the operation. In this regard, the feed parameters such as substrate concentration, flow rate and HRT was varied with time. The variability of in-feed pH was checked with the system performance. However, the maximum loading was also checked for the various biological treatment units.

H. Feasibility Matrix

The feasibility matrix was made considering different factors such as flowrate, HRT, substrate concentration, maximum loading, TDS reduction, pH variation, and power generation. The ranking of the factors was derived from the direct performance study conducted in the experimental procedure and operational criteria. The ranking had been set based on the lower as high performance and high rank when there is low performance.

3. Results and Discussion

A. Performance of different treatment systems and sensitivity towards substrate concentration

The impact of high and low substrate concentrations on COD and BOD removal efficiencies vary depending on the specific wastewater treatment system being used (Figure 2). Investigating how different influent concentrations affect removal rates provided the insights into a system's capacity to handle fluctuations in wastewater strength. In the case of MDC, the relatively higher initial substrate concentration of 12,000 mg/L resulted in a COD and BOD removal efficiencies of 47% and 50%, respectively. At this elevated concentration, there might have been a limited capacity of the microbial community to effectively degrade the organic pollutants, possibly due to inhibition or competition among microorganisms. Conversely, at the lower initial substrate concentration of 4,000 mg/L, MDC exhibited an improved COD and BOD removal efficiencies of 82% and 85%, respectively, as the microbial community could readily metabolize the organic matter without encountering inhibitory levels.

On the other hand, in ETP-UASBR, a COD and BOD removal efficiency of 86% and 77%, respectively were observed at 4,500 mg/L initial substrate concentration, showcasing the reactor's efficiency in organic matter removal under anaerobic conditions. At a slightly lower initial concentration of 3,250 mg/L, UASBR achieved an even higher COD and BOD removal efficiencies of 89% and 80%, respectively likely because the microbial consortium was well-adapted to metabolize the available organic substrate efficiently.

In the case of the STP-RBC, it exhibited the highest COD removal efficiencies of 90% at 800 mg/L substrate concentration and 92% at 600 mg/L substrate concentration. This can be attributed to the high surface area provided by the rotating discs, which fosters the attachment and growth of a diverse microbial community capable of efficiently metabolizing organic matter across a range of substrate concentrations. STP-Biopiping, with COD removal efficiencies of 80% at 800 mg/L and 85% at 600 mg/L substrate concentrations, also demonstrated favorable performance. The design of the biopiping system allowed for effective contact between wastewater and biofilm-encrusted surfaces, facilitating organic matter removal. The STP-Anoxic system exhibited moderate COD removal efficiencies of 68% at 800 mg/L and 75% at 600 mg/L substrate concentrations. Anoxic conditions promote denitrification but may have limited the full utilization of organic substrates for COD removal. In contrast, the STP-Anaerobic system displayed the lowest COD removal efficiencies, reaching only 32% at 800 mg/L and 40% at 600 mg/L substrate concentrations. This can be attributed to the absence of oxygen, which restricts the metabolic pathways available for organic matter breakdown, resulting in lower COD removal rates.

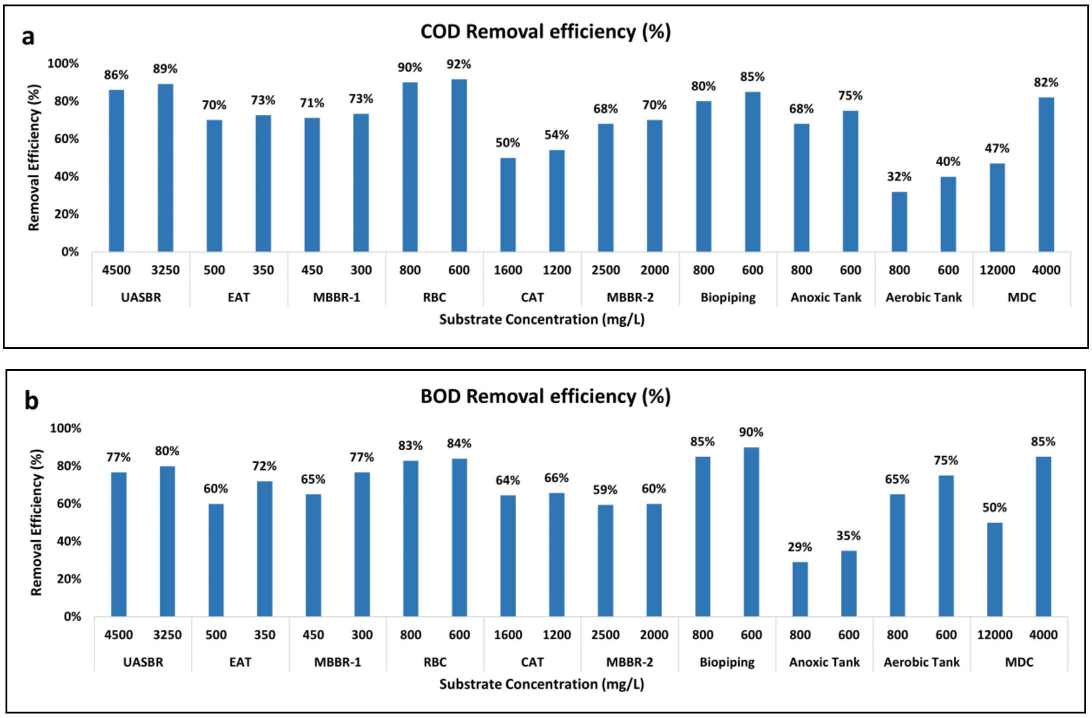

Figure 2. Performance of different treatment systems with the variation of substrate concentration (a) COD removal efficiencies (b) BOD removal efficiencies.

In a similar comparative study by Basset et al. [7], it was observed that in terms of the capability to remove organic matter, laboratory-scale tests showed that the granular sequencing batch reactor (GSBR) could manage significantly higher organic loading rates (OLR), reaching up-to 15 kg COD per cubic meter per day, surpassing that of the Anaerobic Membrane Bioreactor (AnMBR). On the other hand, according to the study by Minhas and Bakshi [8], the biological process resulted in a reduction of BOD, where aerobic process did not generate any excess sludge. Factors such as the population of microorganisms, the types of plants utilized, the configuration of the reactor bed, and the duration for initiating the process were identified as critical considerations. The current study presented a good agreement with the experiments conducted by the other researchers. The order of COD removal efficiencies aligned with the system's design and the availability of suitable environmental conditions for microbial communities to efficiently metabolize organic substrates.

B. Performance of different treatment systems and sensitivity towards HRT

The examination of different HRTs was crucial as it helped to determine the optimal residence time for efficient pollutant removal (Figure 3). By assessing the impact of variation in HRTs on treatment performance, one can identify the most cost-effective and environmentally sound approach. This information is helpful in designing systems that balance treatment efficiency with operational costs, ensuring long-term sustainability. The impact of high and low HRT can vary depending on the specific wastewater treatment technology being used. The STP-RBC exhibited the highest COD and BOD removal efficiencies, with 93% and 86% at 4.8 hours; 92% and 84% at 3 hours; and 89% and 81% at 2 hours of HRT, respectively. RBCs are known for their excellent performance in providing a large surface area for biofilm growth, allowing for effective organic matter removal even at shorter HRTs. The STP-Anoxic system, with 83% COD removal at 7.68 hours, 80% at 4.8 hours, and 73% at

3.5 hours of HRT, also performed well. Anoxic conditions promote denitrification and the removal of nitrogen compounds, contributing to its efficiency.

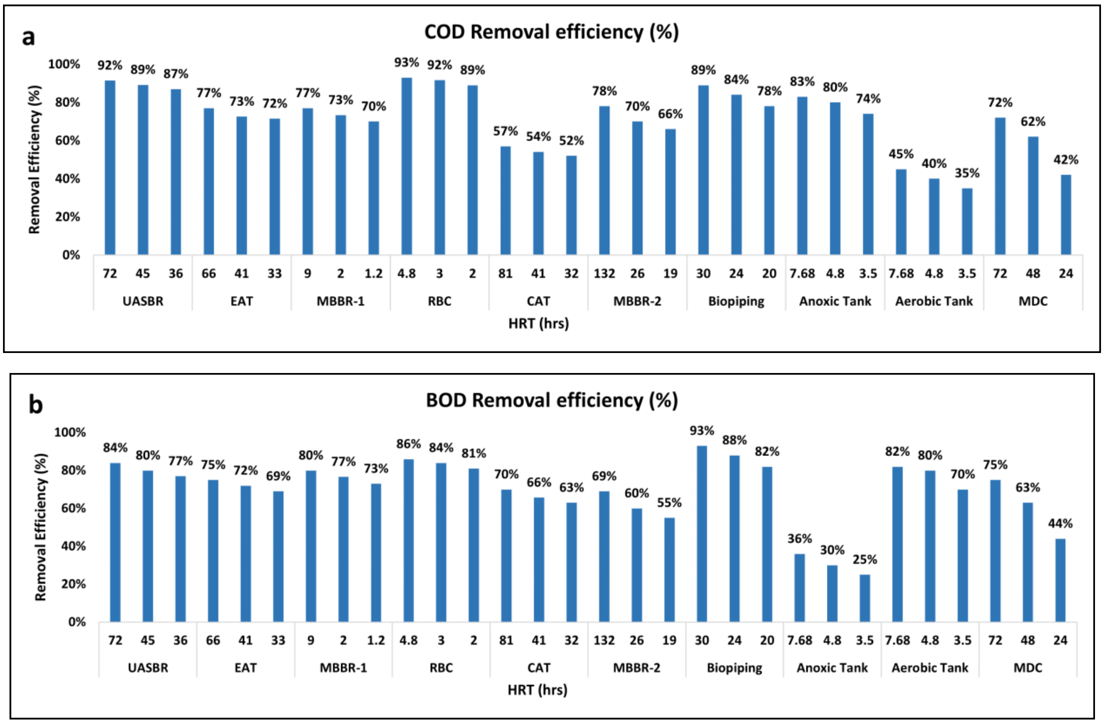

Figure 3. Performance of different treatment systems with the variation of hydraulic retention time (a) COD removal efficiencies (b) BOD removal efficiencies.

Comparative study by Ambriz et al. [9] demonstrated that moving bed biofilm reactors serve as a viable substitute for activated sludge systems in treating biowaste effluents. During the experiments, the total removal of COD reached 53%, while the removal of dissolved COD amounted to 40%. Further, an impressive 99% reduction in ammonia concentration was achieved in the same study. In contrast, the STP-MBBR demonstrated moderate COD and BOD removal efficiencies across different HRTs, likely due to its reliance on suspended and attached biomass. Finally, the STP-Anaerobic system exhibited lower COD removal efficiencies, reaching 77% at 9 hours, 73% at 2 hours, and 70% at 1.2 hours of HRT. Anaerobic systems are typically less efficient at organic matter removal compared to aerobic processes and may require longer HRTs to achieve comparable results.

The ETP-UASBR exhibited higher COD and BOD removal efficiencies, achieving 92% and 84% at 72 hours, 89% and 80% at 45 hours, and 87% and 77% at 36 hours of HRT, respectively. This could be attributed to the UASBR's well-established efficiency in anaerobic organic matter degradation. The longer HRT allowed for more extensive microbial contact with the wastewater, enabling effective COD removal through anaerobic digestion processes. Ahmad et al. [10] found that the optimum HRT for the activated sludge process was 8 hours. They had reported an average removal efficiency of 87% for both COD and BOD, 96% for TSS, and 75% for TOC achieved using an 8-hour HRT.

Conversely, the MDC displayed lower COD removal efficiencies, reaching 72% at 72 hours, 62% at 48 hours, and 42% at 24 hours of HRT. Despite the higher initial substrate concentration in the MDC, its performance was comparatively better. This can be explained by the MDC's dual focus on both organic matter removal and desalination, which combined microbial activity and energy towards salt removal processes, and COD removal efficiencies. However, the shorter HRT in the MDC restricted the contact time between microorganisms and wastewater, affecting the COD removal rates.

C. Performance of different treatment systems and sensitivity towards flowrate

An experimental study was conducted to understand the BOD and COD removal efficiency for specified treatment units with the varying flow rates and the result of which presented in Figure 4. The treatment efficiencies were based on the COD loadings in the respective treatment system and based on the designed flow rates of the systems. Each treatment systems were different and meant for treating wastewaters of different characteristics. STP-RBC displayed a noteworthy pattern, with COD and BOD removal efficiencies increasing order when the flow rate decreased. At 2.4 m^3/hr, the RBC achieved COD and BOD removal efficiencies of 87% and 80%, while at 2 m^3/hr and 1.5 m^3/hr, the efficiencies improved to 91% and 83%, 94% and 85%, respectively. This trend can be attributed to the increased hydraulic residence time available at lower flow rates, allowing more contact time for microorganisms to metabolize organic pollutants effectively.

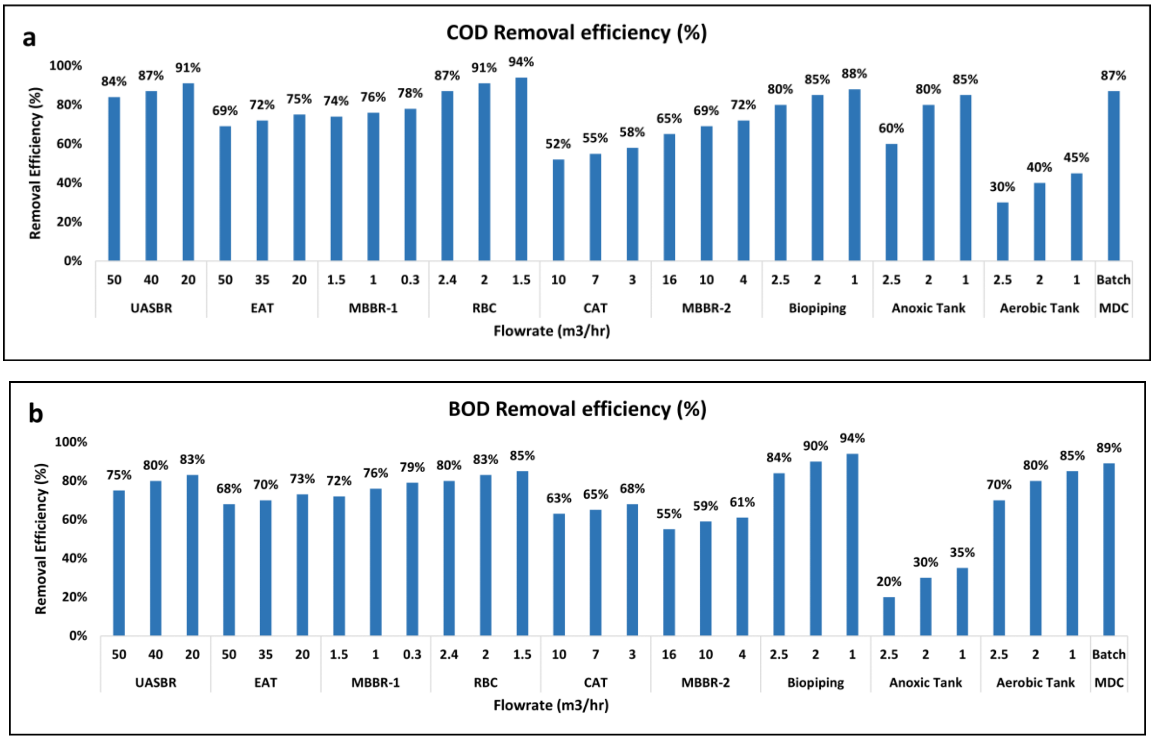

Figure 4. Performance of different treatment systems with the variation of influent flowrate (a) COD removal efficiencies (b) BOD removal efficiencies.

Conversely, the performance of the STP-Biopiping system demonstrated higher COD removal efficiencies at higher flow rates, with 80% at 2.5 m^3/hr, 85% at 2 m^3/hr, and 88% at 1 m^3/hr. Biopiping systems were characterized by their ability to foster biofilm growth within the pipes, and higher flow rates may enhance the detachment of excess biomass, resulting in better treatment performance. Similarly, the STP-Anoxic system exhibited improved COD removal efficiencies at higher flow rates, with 60% at 2.5 m^3/hr, 80% at 2 m^3/hr, and 85% at 1 m^3/hr. In case of STP-MBBR, COD removal efficiencies remained relatively consistent across the flow rate variations, suggesting that this system was less sensitive to hydraulic loading changes. The STP-Anaerobic system demonstrated lower COD removal efficiencies overall, with slight improvements at higher flow rates, reaching 30% at 2.5 m^3/hr, 40% at 2 m^3/hr, and 45% at 1 m^3/hr. This may be due to the hydraulic conditions impacting anaerobic microbial activity and organic matter degradation.

The UASBR exhibited higher COD and BOD removal efficiencies at all flow rates, with 84% and 75% at 50 m^3/hr, 87% and 80% at 40 m^3/hr, and 91% and 83% at 20 m^3/hr, respectively. This is because UASBR are well-suited for anaerobic organic matter degradation, and their efficiency was less affected by changes in flow rate. In contrast, the ETP-EAT demonstrated lower COD removal efficiencies, with 69% at 50 m^3/hr, 72% at 35 m^3/hr, and 75% at 20 m^3/hr. The UASB's anaerobic nature and ability to maintain efficient COD removal across varying flow rates contributed to its superior performance in this context. On the other hand, the MDC system performed 87% COD removal and 89% of BOD removal in a batch mode with higher substrate concentration of 5000 mg/L. Due to the presence of the active micro-organisms and concentration gradient, MDC performed well in comparative to other treatment technologies.

According to Mandloi et al. [11], the study revealed that the efficiency of BOD removal varied in the sequence MBR > SBR > UASB > EA > MBBR. Additionally, the COD removal was in the order MBBR > MBR > SBR > EA > UASB, while the TSS removal efficiency followed the pattern UASB > MBR > MBBR > SBR > EA. However, Denisov et al. [12] informed that the technology and scheme improved biological treatment quality by optimizing parameters and enabling automatic operation of the rotary machine, with the design facilitating adjustments of parameters like duty cycle pulse and pulse duration during operation.

D. Sensitivity towards pH

pH was an important parameter to consider in the sensitivity analysis of biological systems. pH played a crucial role in maintaining the proper functioning of biological processes such as, enzyme activity, protein structure and function, cellular membrane potential, buffering capacity, metabolic pathways, biological reactions. In the present study it was observed that, most of the biological process work better in the neutral pH of 7. However, system variability was observed in between pH 6.5 to 9. Figure 5 represented the MDC system was able to handle the pH variation from 4 to 8 which was found to be the maximum tolerable variation among the other technologies.

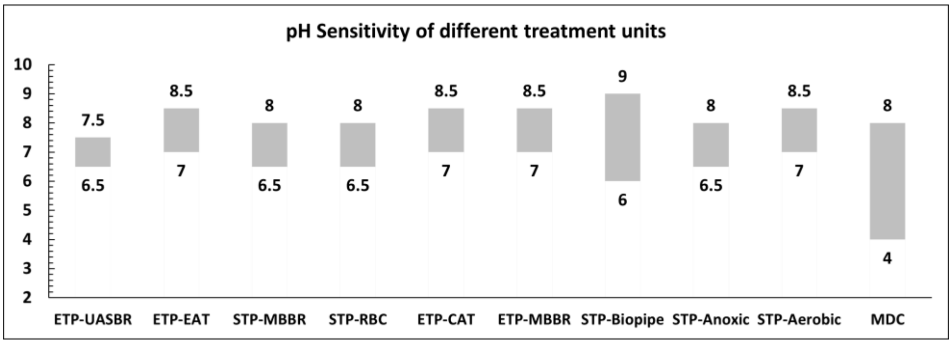

Figure 5. pH sensitivity towards the operation of different biological systems.

Unlike many other treatment technologies that heavily rely on specific pH ranges to sustain microbial activity and chemical reactions, the MDC predominantly operated on electrochemical processes. The MDC system was having electrochemical reactions along with electrodes which drive ion exchange and desalination. These electrochemical reactions were inherently less pH-sensitive compared to the biological processes observed in systems like ETP-UASBR and ETP-MBBR. Consequently, the MDC's functionality was not as severely constrained by pH fluctuations. Furthermore, MDCs were often equipped with built-in pH buffering mechanisms, which help stabilize and regulate the pH within the system. Goli et al. [13] outlined that the high tolerance to pH variations, decreased sludge generation, and consistent COD removal performance of the UASBR and Anaerobic Filter Bed (AFB) system which renders it advantageous for the biological treatment of moderately polluted industrial wastewaters.

However, this adaptability to diverse pH conditions made the MDC an attractive solution for treating a wide array of wastewater sources, including those with highly acidic or alkaline characteristics, which might challenge other treatment systems. The system can take care of the pH fluctuation, and this will help to reduce the requirement of the buffer tank in the effluent treatment plant. A high range of pH variation system can handle shock loading to the treatment unit. This will also ensure the requirement of low chemical usage in the treatment system. MDC system can be best suited with the incoming effluent having the pH fluctuations.

E. Sensitivity towards loadings

The observed existing substrate handling capacity among these wastewater treatment processes could be explained by examining the inherent design, operational characteristics, and treatment objectives. Of each method in relation to their capability to remove and degrade organic pollutants (Figure 6), MDC system with a COD and BOD handling capacity of 12,000 and 4800 mg/L, respectively exhibited the highest capacity due to their specialized design to simultaneously remove salts and metabolize organic matter, making them highly efficient at handling elevated COD concentrations.

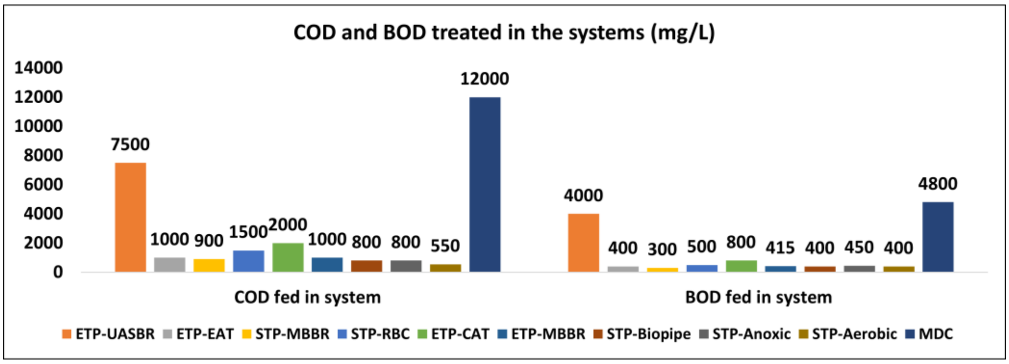

Figure 6. Operational maximum loads of the different biological systems considered in the present study.

ETP-UASBR with a capacity of 7,500 and 4000 mg/L, also had a substantial COD and BOD handling capacity, respectively. These reactors operate under anaerobic conditions, which were particularly effective for the degradation of organic pollutants, allowing them to handle higher COD levels. ETP-CAT at 2,000 and 800 mg/L, prioritize oxygenation over COD and BOD removal, respectively, resulting in a lower COD handling capacity. These can support biological treatment; their primary function was not optimized for high COD concentrations.

STP-RBC with a capacity of 1,500 mg/L, and ETP-EAT at 1,000 mg/L, had even lower COD handling capacities. These processes focused on organic matter removal but may be less efficient at handling elevated COD levels, especially when compared to anaerobic processes. STP-MBBR, with a capacity of 900 mg/L, exhibited a lower COD handling capacity, possibly due to its smaller reactor volume and design characteristics that might limit its efficiency in handling higher COD loads.

According to Mandloi et al. [11], in terms of footprint area, the MBR necessitates the smallest area, approximately 0.48 m² per KLD. Thus, if space is a significant limitation, MBR could be the preferred option. Their research indicated the following hierarchy: EA > USAB > SBR > MBBR > MBR. According to Bajpai [14], the aerobic process primarily revolved a single species. It also demonstrated a high biomass yield, typically ranging from 0.35 to 0.45 kg VSS per kg of COD and the biomass yield remains relatively consistent.

However, in the present study, STP-Biopiping and STP-Anoxic systems, both with a capacity of 800 mg/L, shared a similar COD handling capacity, likely because they rely on biofilm formation and biological processes that might have limitations in handling very high COD concentrations efficiently. Aeration systems had the lowest COD handling capacity at 550 mg/L. These systems primarily focused on oxygenation and may not be as effective at COD removal as other processes specifically designed for organic matter degradation.

Table 1: Feasibility matrix ranking for different treatment systems.

Parameters	ETP-UASBR	ETP-EAT	STP-MBBR	STP-RBC	ETP-CAT	ETP-MBBR	STP-Biopipe	STP-Anoxic	STP-Aerobic	MDC
Flow rate	2	6	5	1	8	7	3	4	9	Batch
HRT	2	6	7	1	9	5	3	4	10	8
Substrate concentration	2	7	6	1	9	8	3	5	10	4

Maximum loading	2	5	6	4	3	5	7	7	8	1
pH Variation	5	3	3	3	4	4	2	3	4	1
TDS reduction	6	2	3	5	4	3	4	4	4	1
Power consumption	1	5	7	4	7	7	3	3	6	2
Power generation	2	NG	NG	NG	NG	NG	NG	NG	NG	1
*NG = No Generation										

F. Feasibility matrix

The feasibility matrix ranking is presented in Table 1. It was observed that MDC system was found to perform the best on maximum loading, pH variation, TDS reduction and power generation. However, UASB system performed well in terms of flow rate, HRT, substrate concentration, and maximum loading. Both UASB and MDC system had the advantages of generating revenue in terms of biogas generation and electricity generation, respectively. In the comparative study, the Rotating Biological Contactor (RBC) secured the top feasibility ranking (Rank 1) for handling variations in flow rate, hydraulic retention time, and feed substrate concentration due to its effective adaptability to fluctuating operating conditions. Its efficient design allowed better tolerance to these variations resulting in the optimal performance. However, its feasibility ranking was moderate (Rank 3) for maximum loading capacity, indicating that it was moderately capable of accommodating higher loads. The system also attained a relatively lower ranking (Rank 4 and Rank 5) for pH variation and TDS reduction, highlighting its comparatively less robust performance in these areas.

The moderate feasibility ranking (Rank 3) of the moving bed bio reactor (MBBR) for pH and TDS reduction stemmed from its moderate capability in effectively managing pH levels and reducing total dissolved solids. Moreover, the system obtained lower rankings (Rank 5 to 7) for substrate concentration, loadings, flow rate, and hydraulic retention times (HRTs), suggesting its limited efficiency in handling higher substrate concentrations and varying flow rates and HRTs. These limitations could be attributed to the design constraints and operational parameters of the MBBR, which impacted its overall performance in these specific aspects. The biopipe system exhibited notable performance in handling pH variations and maintaining system stability, resulting in a high ranking for these aspects. Its moderate ranking in flow rate, hydraulic retention time (HRT), and substrate concentration underscored its effective yet not exceptional capabilities in these areas. However, issues concerning maximum loading and total dissolved solids (TDS) reduction impacted its lower ranking in these specific aspects.

Eckenfelder et al. [15] had reported that the capital costs of the aerobic system were more responsive to the escalation of wastewater strength compared to those of the anaerobic system. This was due to the requirement of a proportionally increasing aeration volume for aerobic treatment at the same Food-to-Microorganism ratio (F/M). However, Mandloi et al. [11] emphasized that after considering overall investment, area requirements, and removal efficiency, the SBR was determined to be the most economical and efficient technology for small STPs, followed by MBBR. They also concluded that SBR, MBR, and MBBR are the most effective technologies for the biological treatment of sewage in India.

4. Conclusion

The present study focused on the treatability of different aerobic and anaerobic biological systems installed in various industries. A comparative approach was made to understand the feasibility of the MDC system with respect to the other treatment technologies. The sensitivity analysis of the variation of different substrate concentration provided an insight regarding system's stability towards the treatment. The RBC system performed best (83 to 92 %) in terms of COD and BOD reduction for the specified design, followed by UASBR (77 to 89%) and biopiping (80 to 90%). However, MDC system performed well (47 to 85%) when compared to the feed water characteristics. MDC was able to degrade the organic components and generating power from the wastewater even with higher concentrations. On the other hand, the variability of HRTs showed a better performance of RBC system i.e., 81 to 93% in terms of COD and BOD reduction. This was due to the surface area and the better aeration availability in the system, followed by UASBR (77 to 92%), MBBR (70 to 80%). The MDC system performed 42 to 72% COD removal for highly concentrated effluent reduction, power generation and desalination simultaneously.

For the sensitivity with the flow variation RBC (94%) showed the best performance, UASBR (91%) followed by Biopiping (88%) and MDC (87%) in terms of COD reduction. Owing to active microorganisms and concentration gradients, MDC performance was better when compared to anoxic, anaerobic, EAT and CAT systems. It was also observed that, COD and BOD removal efficiencies increased when flow rate was decreased. The pH sensitivity showed a wide range of sustaining capability of MDC system i.e., 4 to 8, followed by biopiping (6 to 9) and other biological systems (6.5 to 8.5). Compared to biological processes seen in systems such as ETP-UASBR and ETP-MBBR, the electrochemical reactions in MDC showed lower sensitivity to pH variations.

The feasibility ranking showed MDC system having a good agreement with the maximum loading, pH variation, TDS reductions and power generation. MDC system had the advantage of sustaining well in high concentration effluents and also generating power by degrading the organic matter. In the same process, TDS from the desalination chamber also reduced. However, UASBR system performed well with minimum required maintenance and highly efficient with BOD, COD reduction and methane gas generation. The rest of all the systems were found to be moderate in the feasibility ranking based on the site conditions and influent characteristics. Finally, MDC technology was well-suited for treating wastewater with high TDS levels, making it applicable in various industrial processes where salinity reduction is critical.

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Nomenclature List

AFB	Anaerobic Filter Bed
AnMBR	Anaerobic Membrane Bioreactor
AOP	Advanced Oxidation Processes
BOD	Biological Oxygen Demand
CAT	Conventional Aeration Tanks
COD	Chemical Oxygen Demand
EA	Extend Aeration
EAT	Extended Aeration Tank
ETP	Effluent Treatment Plant
GSBR	Granular Sequencing Batch Reactor
HRT	Hydraulic Retention Time
LPO	Liquid Phase Oxygen
MBBR	Moving Bed Bioreactors
MBR	Membrane Bio Reactor
MDC	Microbial Desalination Cell
MFC	Microbial Fuel Cell
OLR	Organic Loading Rates
RBC	Rotating Biological Contractors
STP	Sewage Treatment Plant
UASBR	Up-flow Anaerobic Sludge Blanket Reactor
VSS	Volatile Suspended Solids