Development of an Environmentally Friendly Energy Efficient Biofiltration System for Brackish Water Desalination

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***Abstract*—Desalination has garnered significant interest as a means of addressing the demand for freshwater; nonetheless, traditional desalination methods can prove expensive and have adverse environmental effects. Hence, this study aimed to design and develop a 'brackish water desalination system, that integrates marine algae and a biofilter liner system composed of mature compost, clay-polyethylene-clay composites. To begin, marine algae samples were gathered from Negombo, "Thalpe" beach, and Baticoloa lagoon and cultivated in a controlled laboratory environment. A well-developed sample was then chosen for the treatment system. Next, a portable trapezoidal pit-shaped model was constructed, measuring 90 cm across the top square, 30 cm across the bottom square, and with a depth of 30 cm. This structure was encased with steel wire mesh, with the bottom layer of mesh serving to release the water. The biofilter system was constructed with a 20-cm clay polythene-clay composite liner along with a mature compost layer. Algae have shown great potential in desalination processes due to their unique biological properties. The incorporation of algae-abundant Negombo Lagoon water in the final layer of the biofilter system serves a crucial role in desalinating the water. Characterization of brackish water of Negombo lagoon electrical conductivity, salinity %o, total dissolved solids and pH was 17,910mS/cm, 35%, and 8,957ppm, 7.76 respectively. Hydraulic conductivity of the liner was 2.64 × 10^{-7} cm/sec. Parameters were taken from both filtrate and inside the bioreactor regularly at 4.00pm. The collaborative efforts of mature compost, algae, and the microalgal community proved successful in achieving a 90% reduction in salinity.**

Keyword—Brackish water, desalination, water scarcity, algae, biofilter

I. INTRODUCTION

Water scarcity is an ever-growing global challenge, intensified by the increase in population, urbanization, and industrial expansion. These factors contribute to the unsustainable exploitation and mismanagement of freshwater resources[1]. In this context, the demand for freshwater sources has driven widespread adoption of desalination as a feasible method for generating potable water. Nonetheless, conventional desalination techniques are frequently cost-prohibitive and may carry environmental risks [2]. Therefore, it is crucial to explore low-cost and sustainable desalination techniques.

Clay-polyethylene-clay composite liner system developed by the University of Peradeniya which is a live biofilter as a bottom liner of a reactor to make the system biological[3, 4]. The importance of vertical movement through dissimilar surfaces provides ideal conditions for both mineralization and conversion of ammonia to nitrate. The mineralized compounds are formed within the narrow passages and above the liner as solid phase reactions [3, 4]. On the other hand, compost is rich in beneficial microorganisms that can help break down and metabolize organic matter in the water. These microorganisms play a key role in the biological filtration process, as they can remove contaminants and help in the breakdown of organic material in the water[3][4][5]. Algae are characterized as a group of plants that lack roots, stems, and leaves, but they do contain chlorophyll [6]. Moreover, algae can be classified into a diverse range of organisms, varying in size from microscopic species smaller than certain bacteria to seaweeds that can reach lengths of several feet. Various types of algae thrive in different aquatic environments, be it in saltwater or freshwater, and under diverse climatic conditions throughout the year, where they can synthesize their components and food through photosynthesis. Algae, as a group, demonstrate an exceptionally broad tolerance for salt levels in their surroundings [6]. Algae can effectively reduce salinity levels in water through a process known as bioremediation. Algae can absorb and accumulate salt ions, such as sodium and chloride from the surrounding water.

As a result, this research project was initiated with the main goal of designing and developing a 'brackish water biofilter' system that incorporates algae, mature compost, and a clay-polyethylene-clay liner. This innovative system seeks to reduce salinity levels in brackish water, providing a sustainable and cost-effective solution to the increasing water scarcity challenges experienced by coastal cities in Sri Lanka.

II. Methodology

The laboratory plant was located on the rooftop of the Research building, Sri Lanka Technological Campus (SLTC), Paddukka Premises, it was operated under natural conditions including average temperature (25 ºC – 27ºC), sunlight duration (12 hrs), and humidity (86%). The experiment was divided into four stages: a) Macro algae and microalgae sampling, b) algae growth experiments, c) performance assessment of the compost layer, and the d) laboratory-scale setup implementation and evaluation. Initially, the algae growth experiment took place at the Environmental Technology Laboratory of Sri Lanka Technological Campus, while the performance testing of the compost layer was conducted in Negombo (7°12'14.67"N, 79°51'11.51"E) an area with convenient access to the lagoon. The laboratory analysis was done at Environmental Technology laboratory and Civil Engineering Laboratory, Sri Lanka Technological Campus. In the pursuit of a comprehensive study on algae diversity and nutrient dynamics, four distinct locations within Sri Lanka were strategically selected: Negombo Lagoon, "Morawala" in Negombo, Batticaloa Lagoon, and "Thalpe" Beach in Galle, each representing urbanized, high-nutrient-rich environments[3][4]. As for the first step, further growing experiments for selected algae samples were conducted at the Environmental Technology Laboratory, Sri Lanka Technological Campus. The required waste polythene was collected from the university canteen and the required clay was collected from the paddy field located inside the university. Before introducing the algae to the setup hydraulic conductivity[5] test for the clay-polythene-clay liner was conducted with saline water and evaluated the performances at the Department of the Environmental Technology, SLTC. And the laboratory scale biofilter based desalination system was established and its performances were assessed.

A. Macroalgae and MicroAlgae Sampling

The sampling location may significantly affect the accuracy and application of the results, particularly in places with highly variable climatic conditions where samples were collected. Understanding the complex biological processes of algal populations and how they respond to environmental factors requires careful consideration of the best locations to gather samples. Each of these areas demonstrates different urbanized and nutrient-rich characteristics. The study sites selected for the sampling were the Negombo "Mora Wala" (7°12'14.73"N, 79°49'2.49"E) (November 2022), "Thalpe"beach (5°59'53.24"N, 80°16'58.82"E)(March 2023), Baticoloa lagoon (7°42'40.52"N, 81°41'22.39"E)(May 2023).

B. Algae Growing Experiments

The lab space was kept clean and free from contaminants that could have affected the experiment. Algae require major essential elements (Carbon (C), Nitrogen (N), Phosphorus (P), Sulphur (S), Potassium (K), Magnesium (Mg) and Calcium (Ca)) for their maximum growth [7]. Thus, 1g of "Eppawala" rock phosphate (ERP) was used as the nutrient source of the algae thrice a week throughout the experiment period since ERP has high phosphate content. Aeration provided the algae with a steady supply of carbon dioxide, which was essential for photosynthesis, and helped prevent the buildup of excess oxygen, which could have hindered algae growth. The aeration was done using a two-way aerator pump (SDA-2800). The samples were positioned near a window to provide natural sunlight. Light was a crucial factor in photosynthesis, and the intensity and duration of light exposure could have affected the growth rate and pigment production in algae. pH, temperature, total dissolved solids (TDS) concentration, salinity and electrical conductivity (EC) were monitored every day at 4 pm.

C. Performance Evaluation of Mature Compost in Desalination Process

In order to evaluate the effectiveness of mature compost in the desalination process, an experimental filter bed was meticulously constructed and rigorously tested. The apparatus consisted of a plastic bucket measuring 45 cm in height and 35 cm in diameter, equipped with an outlet fixed at the bottom to facilitate water drainage. The selected filter medium for this study was mature compost, which was sourced from the municipal council in Negombo. And the brackish water was taken from the Negombo "Morawala". The filter bed was designed with a specific layering approach. At the base of the bucket, a 5 cm thick layer of fine metal particles, each approximately 2 cm in diameter, was meticulously arranged. On top of this metal layer, a generous 10 cm thick layer of mature compost was carefully placed. The experiment was conducted over a duration of two weeks, during which salinity levels in the filtrate samples were assiduously measured. This vital data collection process done daily at 4. 00 pm.

D. Laboratory Scale Bioreactor Setup

A potable trapezoidal pit shape model was constructed 90 cm top square and 30 cm bottom square with 30 cm depth as shown in Figure 1 [5]. This structure was covered with steal wire mesh. Bottom steal wire mesh was used to release the water. The biofilter system was fabricated with a 15-cm clay polythene clay composite liner and 5 cm mature compost layer and algae layer as shown in Figure 1(a, b). The research was conducted for a period of two weeks, during which various water quality parameters were systematically measured both inside the biofiltration system and the filtrate. These measurements included pH (using pH meter Thermo Scientific, model Orion 2 star), Electrical conductivity (EC), total dissolved solids (TDS)(EC and TDS meter, Thermo Orient Model 145 A), total suspended solids (TSS) using Gravimetric method (using APHA Method 2540-G), salinity (using Refractometer RHA-100ATC) , and total solids using oven dried method (using APHA Method 2540-G) (Table 1). Measurements were consistently taken daily at 4.00 pm. Removal efficiency was calculated using Eq. 1.

$$Removal\ efficiency\% = \frac{C_{in} - C_{out}}{C_{in}} \times 100 \qquad (1)$$

Where, C_{in} = inlet concentration, C_{out} = outlet/filtrate concentration

III. Results and Discussion

The brackish water in Negombo "Morawala", which used as the source water to the laboratory scale setup had specific starting characteristics, with an EC of 17,910 ms/cm, a salinity of 35‰, a TDS concentration of 8,957 ppm, and a slightly alkaline pH of 7.76. For the laboratory-scale setup of this study, the location of choice was the Negombo "Morawala" area, which provided convenient accessibility for in-depth analysis and observation of algae abundance. The research extended from November to March, a period during which the Negombo Lagoon exhibited richness in macroalgae populations. However, it is noteworthy that after the month of April, a significant decline in the presence of macroalgae blooms was observed in the Negombo "Morawala" area, this decline may be related to seasonal variations, with the period from November to March being characterized by favorable conditions such as temperature, light availability, and nutrient levels, which are conducive to the growth and proliferation of macroalgae. As these conditions change with the onset of spring and the transition into warmer months, macroalgae populations may naturally recede.

In this context, mature compost proved to be a valuable asset due to its rich microbial community. These microorganisms played a pivotal role in breaking down and metabolizing the organic matter present in the water. Remarkably, Thus, 65±12% salt reducing efficiency was observed in the compost.

The liner system in use exhibited a hydraulic conductivity of 2.64 × 10^{-7} cm/sec. This set the stage for an innovative approach to salt removal. Within the bioreactor situated above the liner system, the presence of algae was noteworthy. Despite the moderate salinity (35‰), the algae not only survived but also actively participated in reducing the salt content. It achieved a commendable 60% reduction through the uptake of salts, demonstrating its remarkable adaptability to challenging conditions.

The EC of the bioreactor, averaging 18,084 ± 1,612.68 mS/cm, contrasted markedly with the much lower EC observed in the filtrate, which averaged 2,116.5 ± 1,036.39 mS/cm. This substantial decrease in EC within the filtrate highlights the effectiveness of the desalination process in reducing the concentration of ions and total dissolved solids, further emphasizing its application in producing low-conductivity water. Salinity levels within the bioreactor remained relatively constant at 24 ± 0.08%, while in the filtrate, salinity was substantially reduced to an average of 4 ± 0.02% (Table 1). This remarkable reduction in salinity emphasizes the potential of the biofilter system for desalination, indicating its suitability for generating low-salinity water, which can be crucial in regions with freshwater scarcity. The bioreactor contained a substantial concentration of total dissolved solids (TDS), averaging 8,991.2 ± 780.66 ppm, whereas the filtrate exhibited significantly lower TDS levels, averaging 1,296.6 ± 508.20 ppm. This pronounced decrease in TDS in the filtrate underscores the bio-filter's capability to effectively remove dissolved solids from the water. TSS concentration within the bioreactor measured 14,100 ± 3,446 mg/l, whereas the filtrate showed lower TSS levels, averaging 3,200 ± 1,475 mg/l. This discrepancy between the two indicates that some suspended solids may still be present in the bioreactor, suggesting the need for additional post-treatment methods, such as sedimentation or enhanced filtration, to further clarify the water. TS concentration within the bioreactor were significantly higher, with an average of 93,800 ± 44,842 mg/l, compared to the lower TS values in the filtrate, averaging 44,300 ± 28,771 mg/l. The substantial reduction in TS within the filtrate reinforces the efficiency of the biofilter system in reducing the concentration of solid particulates in the water. The overall success of the system became even more evident when a laboratory-scale biofiltration setup, incorporating algae, mature compost, and clay polyethylene clay liners, was put to the test. This integrated approach resulted in an impressive 90% removal of salt from the saline water, as clearly illustrated in the accompanying figures and graphs. In essence, the collaborative actions of mature compost, algae, and the microbial community allowed for a highly effective and sustainable approach to tackling the salinity issue in the water, marking a promising advancement in brackish water treatment. The development of sustainable algae harvesting techniques for large-scale applications is imperative. This necessitates a comprehensive focus on optimizing the kinetics of harvesting processes and exploring the potential integration of carbon sources.

TABLE 1: PERFORMANCES OF THE BIOFILTER SYSTEM DURING THE STUDY PERIOD

Parameter	Inside the Bioreactor	Filtrate	Removal efficiency (%)
pH	8.96 ±0.73	9.32±0.27	-
Temperature(°C)	29.54 ±1.40	30.46±2.31	-
EC (ms/cm)	18084±1612.68	2116.5±1036.4	88.29±5.4
Salinity (‰)	24±0.08	4±0.02	80.55±9.47
TDS (ppm)	8991.2±780.66	1296.6±508.20	85.63±5.29
TSS (mg/l)	14100±3446	3200±1475	75.96±10.84
TS (mg/l)	93800±44842	44300±28771	32.38±36.30

IV. CONCLUSION

This study narrows down to combine; mature compost, algae and the liner system to remove 90% of the salinity. The findings from this study demonstrate the potential of naturally grown microalgae to effectively reduce salinity levels in brackish water. This approach not only minimizes the need for energy-intensive cultivation processes but also maintains the ecological integrity of the lagoon ecosystem. The microalgae, adapting to the local conditions, showcased their resilience and ability to thrive in the given environmental constraints, thereby offering a practical solution for saline water treatment. However, it is clear that a more controlled and efficient culturing system for microalgae is essential. While our experiment successfully utilized the natural environment, a dedicated culturing system would offer advantages in terms of scalability, optimization, and reliability. Therefore, it is recommended that future studies and applications incorporate a controlled microalgae culturing system that can be tailored to the specific needs of the brackish water treatment process. And the hydraulic conductivity of the liner system should be increased by modifying the compaction densities and increasing the amount of waste polythene in the composite liner. In essence, brackish water with the required combination of treatment methods can be used for irrigation of salt loving crops as well as crop requiring good quality water, industrial use or even for domestic use.

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