Science and Engineering Research Journal
ISSN: 2997-6227 |
Volume 12 Issue 2, April- June, 2024
Journal Homepage: https://ethanpublication.com/articles/index.php/E5
Official Journal of Ethan Publication

PERFORMANCE OF A NOVEL BIO-MEMBRANE IN SEAWATER DESALINATION FOR ARID CLIMATE APPLICATIONS

Chinedu Michael Okonkwo
Chemical Engineering Department, College of Technology, Federal University of Petroleum Resources, Effurun, Effurun, Delta State, Nigeria
DOI: https://doi.org/10.5281/zenodo.17242313

Abstract
This research involved extracting cellulose from sawdust, converting it into cellulose acetate (CA), and evaluating its performance as a bio-membrane for desalination of synthetic saline water. The experimental studies were conducted using a fixed-bed adsorption column setup, to the desalinate synthetic saline water. The CA biomembrane exhibited a high salt removal efficiency of up to 98.95%. Kinetic modeling was carried with the obtained results, using the Bohart-Adams and Thomas models. The Bohart-Adams model better described the adsorption behavior, with a higher correlation coefficient of 91.5%, as compared with the correlation coefficient of 85.7 % of the Thomas model. The results demonstrate the potential of the developed CA bio-membrane for seawater desalination. This innovative approach can help address the global portable water scarcity challenge in coastal communities, by providing potentially sustainable, cost-effective, and energy-efficient desalination technology, when compared to conventional technologies.

Keywords: Seawater, membrane, desalination, saline, synthetic, cellulose, sawdust.

Introduction

Water is an essential requirement for all living organisms on our planet and holds significance for humans in particular. In addition to its consumption as a beverage, water is utilized for agricultural, industrial, and hygienic purposes, playing a vital role in the advancement and progress of civilization. Although water is plentiful on earth, with approximately 70% of the planet's surface covered by it, the majority of this water is saline, making it unsuitable for direct human use. This issue of did not pose a significant challenge until the middle of the 20th century, as there was an ample supply of fresh water available for everyone. The rapid worldwide increase in human population, urbanization, industrialization, economic advancement, changes in lifestyle, and climate change have become a significant source of worry regarding the availability of fresh water for humanity. In many areas around the world, water stress (usually defined as having a yearly access of less than 1700m^3 fresh water per capita[1] has become a serious problem with natural sources being depleted, polluted, salted or otherwise no longer usable for the people depending on them. The potential succeeding risks for the environment, human health, security, peace and prosperity call for immediate and effective actions. Approximately 20% of the global population lacks access to clean drinking water. The World Health Organization reports that 3,900 children die daily because of diseases transmitted through contaminated water or inadequate hygiene. As stated in the U.N. World Water

Development Report, this concerning situation is expected to significantly deteriorate by 2050, with at least 25% of the global population residing in a country experiencing chronic or recurring scarcity of freshwater. Statistics such as these are likely to worsen further as water contamination from waterborne pathogens and discharge of pollutants (e.g. heavy metals, arsenic, pharmaceutical derivatives, agricultural chemicals, endocrine disrupters) increases[2].Aside from being directly consumed by humans, water is primarily used for agricultural purposes and irrigation, which constitutes around 70% of global freshwater usage. In certain industrialized countries, this percentage can even reach up to 90%. The escalating water scarcity poses a direct threat to the already burdened global food supply. In addition, the combination of existing geopolitical tensions and limited access to water can contribute to the emergence of regional conflicts that pose a threat to global peace and stability[3]. Desalination of seawater is a necessary and important option for ensuring water availability in dry and semi-dry areas, particularly coastal regions. This is because these areas have specific soil, land, and climate conditions that make them lack in surface water and fresh groundwater sources[4,5]. Desalination is the process of extracting salts and/or inorganic substances from seawater or salt-water. It can be used for treating various types of water, including process water, brackish water, waste water, and most commonly, seawater (which accounts for approximately 60% of global desalination activity)[6]. Seawater desalination has been implemented as a major industrial process since the 1960s, when it was first introduced in the Persian Gulf. Semiat[7] and Van der Bruggen[8] identify the primary desalination techniques as multi-stage flash distillation (MSF), multi-effect distillation (MED), and reverse osmosis (RO).

Water scarcity is a critical global issue, and the arid region faces significant challenges in accessing adequate potable water. With growing populations and changing climatic conditions, traditional water sources are insufficient to meet demand. Seawater desalination, a proven method for addressing water scarcity, has been limited by high energy consumption, environmental impact, and operational costs. A novel approach employing bio-membranes offers a sustainable, efficient, and cost-effective solution.

Materials and Methods

The materials used for this research were selected based on the functionality, reactivity, process requirements and availability of materials within the environment. Sawdust was obtained from a nearby sawmill. The chemicals used include n-hexane, ethanol, acetic acid (CH_3COOH), sodium hydroxide (NaOH), monochloroacetic acid are of analytical grades. Equipment used include electronic weighing balance, retort stand, hot plate magnetic stirrer, stirring rod, beakers, pipettes and filler, burettes, volumetric flasks, round bottom flasks.

Methods

Extraction of cellulose from sawdust: The sample should be grinded into smaller particles by a grinder. The acquired particles should be washed in Soxhlet apparatus with various solvents such as n-hexane, Ethanol, and deionized water for 3 hours to remove the polar, extractives and waxy materials. For drying the sample should be retained in oven at 80°C. Saw dust which is free from extractive was treated in

autoclave at 121°C and 2 atm of pressure, in a 1:100 for 30 min with an aqueous solution of sodium hydroxide 5 % (w/ v) for the separation of fiber and bond breaking.

Polar materials such as hemicelluloses, lignin and pectin were eliminated by bleaching process which was described previously for the straw of wheat[9]. The biomass was reacted with in the solution of hydrogen peroxide 2 % (v/ v) and ethylene diamine tetra-acetate 0.2 % (w/ v) in a 1:25 (g / ml) with stirring for 12 hours, at 48°C. The pulp was filtrated and neutralize with deionized water. The step is known as bleaching.

Preparation of cellulose acetate: Production of CA was carried out by two reactions: alkalization and carboxymethylation. The alkalization reaction begins after introduction of NaOH into 5g of pure cellulose and ethanol solution, under mechanical stirring, at room temperature for an hour. Then, the carboxymethylation reaction starts, under constant stirring, during which monochloroacetic acid (MCA) is slowly added. During this period, reaction temperature and reaction time were controlled. The product thus obtained was then filtered and suspended in 200 mL of methanol. The slurry was neutralized using glacial acetic acid. Then the sample was washed, using a 70% ethanol solution, to remove undesired product. Lastly, the sample was dried at 60 ℃ temperature by forced convection oven (model: FC-610,Toyo)[10].

CA yield was measured on a dry weight basis. The net weight of dried CA was divided by the weight of dried cellulose to get the yield value[11] as follows:

$$\text{CA Yield, (\%)} = \frac{\text{weight of CA obtained}}{\text{wight of dried cellulose}} \times 100 \qquad (2.1)$$

Laboratory analysis of cellulose acetate: The cellulose acetate was characterized for different physicochemical properties which include moisture content, carbon content, Sulphur content, ash content, cellulose and lignin percentage prior to the desalination process. All the properties were analyzed by standard laboratory procedures.

Determination of moisture content: The moisture content was quantitatively determined by oven drying method at 110˚C for 1 hour. 5g of sample was weighed in a crucible using the electronic mass balance. The weight of the crucible and oil obtained together was placed in an oven at 110 degrees. At time intervals of 10 minutes, the crucible with sample was taken out and weighed with a new mass for both oil and crucible obtained. The process was continued till constant weight of the sample was obtained respectively. The moisture content was calculated using the following equation;

$$\frac{W_m - W_d}{W_m} \times 100 \qquad (2.2)$$

W_m = weight of moist sample

W_d = weight of dry sample

Ash content: Exactly 2.0 g each of pulverized samples were weighed into three separate platinum crucibles and subjected to a temperature of 600°C in a muffle furnace for about 2 hours. The furnace was then switched off and the sample was left inside for about 60 minutes for the temperature to drop and then removed and place in a desiccator where the temperature was allowed to drop into ambient temperature.

Science and Engineering Research Journal
ISSN: 2997-6227 |
Volume 12 Issue 2, April- June, 2024
Journal Homepage: https://ethanpublication.com/articles/index.php/E5
Official Journal of Ethan Publication

$$\%Ash = \frac{mass\ of\ ash}{mass\ of\ sample} \times 100 \quad (2.3)$$

Estimation of Cellulose, Hemicellulose and Lignin Content: To remove the hemicellulose content, about 10g of the sample was refluxed at 100°C with 500ml of 0.5M NaOH solution for 2 hours and the residue which is the cellulose and lignin content was filtered and washed with plentiful amount of distilled water until pH 7 was obtained and dried in oven at 105°C until completely removed of water. The lignin content was estimated from the dried residue by boiling in 100ml 4M CH_3COOH for 2 hours and allowed to remain soaked for 24 hours at ambient temperature. The undissolved residue was washed with plentiful amount of several times until pH 7 was attained. The residue was dried at 105°C for 4 hours, cooled in a desiccator and weighed. Hence, the cellulose content was calculated from equation 2.4:

$$C_m = B_m - H_m - L_m \quad (2.4)$$

Where;

C_m = mass of cellulose content

B_m = mass of biomass 10g

L_m = mass of lignin

H_m = mass of hemicelluloses

Preparation of synthetic saline water: The synthetic saline waters with an ionic composition similar to actual saline waters was prepared according to Zhao et al.,[12]. Exactly 2.0g NaCl was weighed into 1000ml flat bottom flask and added 100ml of distilled water and placed on a magnetic stirrer with constant heating and stirring at 80°C to enhance complete dissolution of any suspended solids of the salt. The mixture was stirred for 30minutes with constant stirring and allowed to cool. The solution was poured into a 1000ml volumetric flask and added distilled water to the mark.

Application of bio-membrane in fixed bed adsorption: Laboratory column experiments were conducted isothermally in a 500cm-long, 40mm-diameter glass column at 30°C. A 35.62g bio membrane cellulose acetate sample was filled to a height H = 5cm in the column. The funnel with a valve circulated the feeding solution of NaCl solution 100mg/l through the bed in down-flow mode at Q = 25cm^3/min throughout the process. To keep column material from shrinking or expanding, bed depth, temperature, pressure, and flow rate were kept constant. In the experiment, the effluent sample were periodically collected and analyzed for NaCl concentrations with the aid of salinity meter.

Mathematical description of FBAC studies: The performance of FBAC was explored by the nature of breakthrough curves. In general, a breakthrough curve is elucidated by the plot of C/C_o (ratio of effluent and initial concentration) versus operation time of column (min). The nature of the breakthrough curve and its parameters are function of the column operating conditions like adsorbent bed depth (Z), flow rate of influent (Q) and adsorbate concentration (C_o) in the influent. The evaluation of these parameters by experimentation is very essential to estimate the performance as well as the scale-up of the column[13]. The time equivalent to stoichiometric or total capacity and time equivalent to usable capacity are expressed by Eq. (2.5) and Eq. (2.6), respectively.

Science and Engineering Research Journal
ISSN: 2997-6227 |
Volume 12 Issue 2, April- June, 2024
Journal Homepage: https://ethanpublication.com/articles/index.php/E5
Official Journal of Ethan Publication

$$t_e = \int_0^{\infty} \left(1 - \frac{C}{C_0}\right) dt = A_1 + A_2 \quad (2.5)$$

$$t_b = \int_0^{3.33} \left(1 - \frac{C}{C_o}\right) dt = A_1 \quad (2.6)$$

where, t_e designates the exhaustion time, and t_b designates the breakthrough time. The C_o and C salt concentration of influent (inlet feed) and effluent (outlet filtrate), respectively.

Kinetic Studies: The Thomas and Bohart-Adams models were employed to scrutinize the data in the fixed bed column. In the Thomas model, known for its extensive utilization in investigating the efficacy of adsorption columns, is derived from the mass conservation equation in a flow system. The Thomas model, it is assumed that the equilibrium of surface adsorption follows the Langmuir model, which has been shown in a previous study. The mathematical expression of the Tomas model Eq. (2.7) is as follows:

$$\ln\left(\frac{C_o}{C} - 1\right) = \left(\frac{Mq_oK_{TH}}{Q}\right) - C_oK_{TH}t \quad (2.7)$$

So that C, C_o, KT, Q, q_o, M and t are the concentration in the outlet and inlet stream, Thomas rate constant, flow rate, maximum adsorption capacity, dry adsorbent mass, and time, respectively.

Bohart-Adams model is usually used to describe the first part of the curve. The Bohart-Adams model is based on the surface reaction theory and states that the adsorption reaction is not immediate. The linear form of BohartAdams is given by the Eq. (2.8):

$$\ln\left(\frac{C_o}{C}\right) = \left[(K_{AB}C_o t) - \left(\frac{K_{AB}N_o Z}{U_o}\right)\right] \quad (2.8)$$ where N_o, Z, K_{AB}, and $U_o t$ are the saturation concentration, column bed height, Bohart-Adams rate constant, and linear flow rate.

III. Results And Discussion

Basic properties of sawdust

The sawdust was ground into smaller particles, and then it was tested for its physico-chemical properties.

Table 3.1: Physico-chemical properties of sawdust

Property	Value
Moisture content (%)	3.72
Ash content (%)	1.84
Carbon content (%)	52.78
Sulphur content (%)	1.63
Cellulose (%)	38.79
Lignin (%)	25.17

Properties of synthetic saline water

The property of the synthetic saline water is given in Table 3.2

Table 3.2: Properties of synthesized saltwater

Property	**Value**
DO (mg/L)	3.72
COD (mg/L)	132.56

Density (g/cm^3)	0.9783
pH	7.01
EC (µS/cm)	4317
Turbidity (NTU)	98.7
TDS (ppm)	2158.5
Salinity (ppt)	2.0

Results of adsorption process

The fixed bed adsorption method was used to carry out this process and the effect of contact time of the adsorbent (cellulose acetate) on the saline water was performed with varied adsorption time of 10 minutes interval in a packed bed at about 5.0cm of sorbent height of Sample and using a handheld salinity meter was immediately analyzed for salt content. It is observed from Table 3.3 that as the contact time increases, the salt removal percentage of the bio-membrane decreases.

Table 3.3: Results of the concentration of effluent and salt removal percentage

Time t (min)	Conc. of effluent, C (ppt)	Salt Removal (%)
0	0.021	98.95
10	0.021	98.95
20	0.026	98.70
30	0.031	98.45
40	0.038	98.10
50	0.045	97.75
60	0.053	97.35
70	0.062	96.90
80	0.089	95.55
90	0.278	86.10
100	0.472	76.40
110	1.767	11.65
120	1.858	7.10
130	1.967	1.65
140	1.975	1.25
150	1.982	0.90

Science and Engineering Research Journal
ISSN: 2997-6227 |
Volume 12 Issue 2, April- June, 2024
Journal Homepage: https://ethanpublication.com/articles/index.php/E5
Official Journal of Ethan Publication

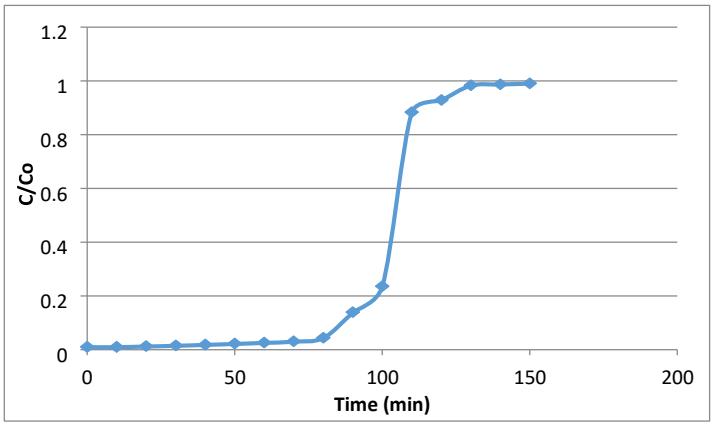

Figure 3.1: Plots of ratio of effluent and initial concentration (C/C_o) vs. time

Using the equation 2.5 and 2.6, we can get the exhaustion time, (t_e) and the breakpoint time, (t_b) from the breakthrough curve above, the exhaustion time, t_e was determined to be 120 minutes, the breakpoint time, $t_b$was determined to be 90 minutes.

The Fraction of total capacity to breakthrough is given as$\frac{t_b}{t_e}$, which was then determined to be 0.75. Also, the length of the used bed is $H_B = \frac{t_b}{t_e} H_T$, where the H_T is the total height which was given as 5.0cm, so the length of the used bed was calculated to be 3.75cm. The unused bed is given by$H_{UNB} = \left(1 - \frac{t_b}{t_e}\right) H_T$, the length of unused bed was calculated to be 1.25cm

Investigation of Kinetic Models in Fixed Bed Column

The investigation is carried out for the kinetic study of saltadsorption on CA adsorbent. Figure 3.2 and 3.3 presents the salt adsorption with the Thomas model and Bohart-Adams model. The kinetic parameters were calculated from the linear plot of the Thomas model ($\ln(C_o/C - 1)$ vs t) and Bohart-Adams model ($\ln (C_o/C)$ vs.

t). It is evident that the experimental value fits better withthe Boharts-Adams model. The kinetic parameters (K_{TH} and K_{AB}), along with the correlation coefficient, are recorded in Table 3.4. The correlation coefficients obtained for Thomas Model and Boharts-Adams model 85.7 and 91.5, respectively. All these results suggest that the Boharts-Adams model is more convenient for describing salt adsorption on the CA bio-membrane.

Science and Engineering Research Journal
ISSN: 2997-6227 |
Volume 12 Issue 2, April- June, 2024
Journal Homepage: https://ethanpublication.com/articles/index.php/E5
Official Journal of Ethan Publication

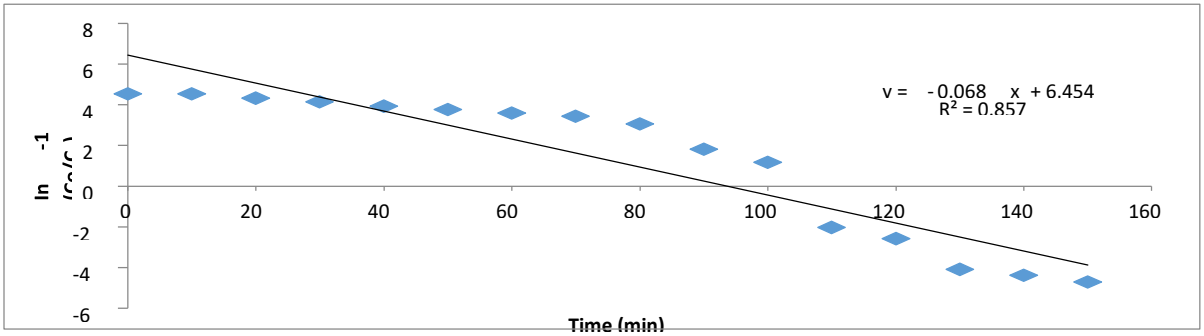

Figure 3.2 : Linear plot of the Thomas model with experimental data

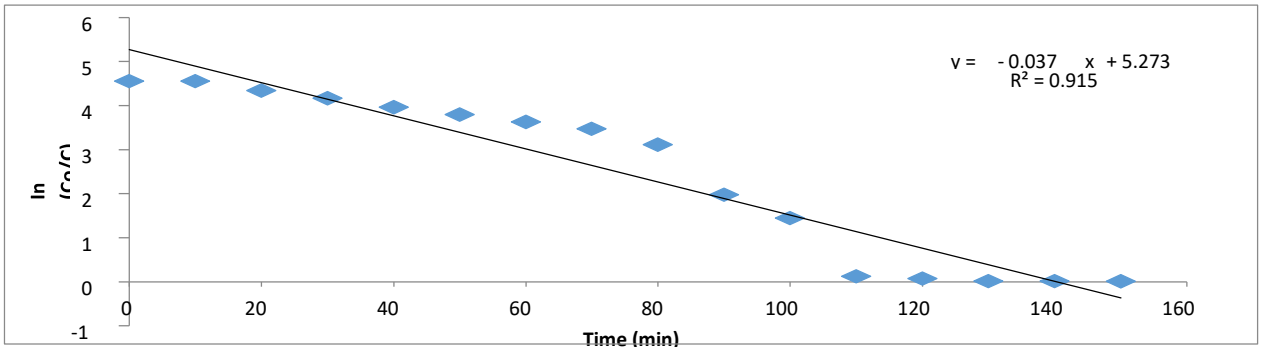

Figure 3.3: Linear plot of the Bohart – Adams model with experimental data

Table 3.4: Kinetic fitting constants of CA bio-membrane

Kinetic Models	
Thomas Model	
qo	133.34
K_{TH}(L mg^{-1} min^{-1})	0.034
R2	85.7
Bohart-Ada ms Model	
N_o (mg L^{-1})	1425.1
KAB	0.0185
R2	91.5

According to the findings of the linear graphs of the two models (the Bohart-Adams and Thomas), the fixed bed system can be effectively described by the Bohart-Adams model. The Thomas model is unsuitable for predicting the laboratory data of salt adsorption with CA adsorbent due to the low correlation coefficient (R^2 less than 0.9).

IV. Conclusion

Seawater desalination using a novel bio-membrane represents a transformative opportunity for addressing water scarcity in the arid region. By combining innovative technology with community-

centered deployment, this solution has the potential to improve water access sustainably and affordably. Future work will focus on refining the bio-membrane design, expanding its application, and fostering international collaboration to tackle global water challenges.

In this research, the desalination of saltwater was carried out in FBAC by using cellulose acetate adsorbent. The experiments were carried out to investigate the desalination efficiency of the cellulose acetate bio-membrane. The bio-membrane displayed good stability and high adsorption performance. The adsorption results revealed a supreme salt removal efficiency (98.95%). It was also revealed that the percentage salt removal decreases as time increases. The fixed bed column's performance was assessed using the breakthrough curve and the kinetic models of Thomas and Bohart-Adams. The kinetic results show that under identical experimental conditions, the BohartAdams model's correlation coefficient (R^2= 91.5) was higher than that of the Thomas model correlation coefficient (R^2= 85.7).

Hence, collaboration among researchers, policymakers, and local communities is vital to realize the full potential of bio-membrane desalination technology. Investment in research and development, along with knowledge-sharing platforms, can accelerate the transition toward a water-secured future for the arid region and beyond.

References

Shannon, M. A., Bohn, P. W., Elimelech, M., Georgiadis, J. G., Mariñas, B. J., & Mayes, A. M. (2008). Science and technology for water purification in the coming decades. Nature, 452(7185), 301-310.

Eliasson, J. (2015). The rising pressure of global water shortages. Nature, 517(7532), 6-6.

Pankratz, T. M. (2010). IDA DESALINATION YEARBOOK. MEDIA ANALYTICS Limited.

Semiat, R. (2000). Present and future. Water international, 25(1), 54-65.

Van der Bruggen, B. and Vandecasteele, C. (2002) Distillation vs. Membrane Filtration: Overview of Process Evolutions in Seawater Desalination. Desalination, 143, 207-218.