https://doi.org/10.54361/ajmas.258169

Original article

Performance evaluation Innovative Modified Sand Filters with Biomass Integration for Effective Produced Water Treatment

Algathafi Eisay[1*], Azaldin Allafi[1], Almabrouk Almabrouk[1], Abdrabba Hassan[2], Suleiman Abdelrahim[3]

[1]*Department of Chemical Engineering, Tobruk University, Libya*
[2]*Department of Chemical Engineering, Omar Al-Mukhtar University, Libya*
[3]*Department of Mechanical Engineering, Tobruk University, Libya*
Corresponding E-mail. algaddafi.ragheb@tu.edu.ly

Abstract
This work has evaluated the efficiency of modified sand filters filled with biomass for the removal of chemical and physical contaminants from produced water. Also, this study aimed at designing, constructing, and evaluating a cost-effective modified sand filter was undertaken. The sand filter was modified with the addition of biomass (Sawdust SD), where the biomass formed the largest part of the filter media, which comprised of four layers. Cylindrical filters were constructed with PVC pipes 10.16 cm^2 in diameter and 70 cm in length, with inner layers composed of sand, gravel, and biomass. The filters were fed with produced water (PW) contaminated, which was brought from the Messla field. The filtered water was collected in a graduated glass cylinder, after which the samples were taken for analysis. Results indicated the removal of up to 5.25 % total suspended solids, 20% turbidity, 65% apparent color, 68.67% total organic matter, 2.2% total dissolved salt, and conductivity.
Keywords. Modified Sand Filter, Biomass, Sawdust, Produced Water, Turbidity Reduction.

Introduction

Oil and natural gas are fundamental to modern civilization, driving energy production, transportation, and manufacturing. However, their extraction generates substantial amounts of produced water (PW), a byproduct that poses significant environmental challenges. Produced water, often considered one of the largest waste streams in the oil and gas industry, has an average oil-to-water production ratio of 1:3, making its management critical [1- 2].

Produced water contains a complex mixture of contaminants, including hydrocarbons, heavy metals, salts, solids, and dissolved gases. Dispersed oil droplets, ranging in size from less than 10 microns to over 100 microns, are common [3]. Dissolved salts include cations such as Na^+, Ca^{2+}, and Ba^{2+}, as well as anions like Cl^- and SO_4^{2-}, in addition to heavy metals such as cadmium, lead, and mercury [4]. The environmental hazards associated with untreated produced water (PW) are complex and varied. The high salinity levels can negatively impact soil fertility and the quality of groundwater, while nitrogen compounds lead to the degradation of aquatic ecosystems. Additionally, the higher temperatures of PW relative to atmospheric water can impose thermal stress on aquatic life. Furthermore, the mineral content of PW, along with its ability to create sludge deposits, intensifies the risks faced by both land and water environments [5]. It may also contain trace amounts of chemical additives, such as demulsifiers and corrosion inhibitors, used during extraction processes [6]. Suspended solids, including scale, corrosion byproducts, and bacteria, as well as dissolved gases like CO_2, O_2, and H_2S, further contribute to the complexity of PW [7-4]. The variability of PW composition depends on geological formations, reservoir lifespan, and extraction techniques [8]. If untreated, these contaminants can lead to soil degradation, water pollution, and ecosystem disruption, posing risks to agriculture, aquatic life, and human health [9-10].

Effective treatment technologies are essential to mitigate these impacts, enabling the reuse or safe disposal of PW. This study develops and evaluates a cost-effective modified sand filter incorporating biomass (sawdust) as a filtration medium to enhance the removal of physical and chemical contaminants, offering a sustainable solution for produced water treatment [11]. In this study, a modified sand filter incorporating biomass (sawdust) as a primary filter medium was designed, constructed, and evaluated for its efficiency in treating produced water. The primary objective was to assess the filter's ability to remove physical and chemical contaminants, providing a cost-effective and environmentally sustainable treatment solution.

Hydrocyclones are mechanical devices designed to separate materials of different densities using centrifugal force. These are commonly employed in process industries, including PW treatment, to remove solids, sand, and oil from liquid streams. The design includes a cylindrical top section and a conical base, where the angle of the conical section critically impacts performance and separation efficiency [12-13].

Thermal technologies rely on heat to separate water from dissolved salts and contaminants. These processes are particularly suitable for regions with abundant and inexpensive energy resources, despite their higher energy demand compared to membrane-based systems [14]. Sand filters are widely used for the removal of metals and suspended solids in PW. Proper pretreatment of water and integration with other methods can enhance their efficiency, achieving up to 90% removal of contaminants [15-9]. The electrochemical method separates cations and anions using charged membranes positioned between two electrodes. Electrodialysis

Received: *28-01-2025* - ***Accepted***: *16-03-2025* - ***Published***: *22-03-2025*

https://doi.org/10.54361/ajmas.258169

(ED) is effective for PW reclamation with relatively low total dissolved solids (TDS) levels [16-17]. Adsorption processes utilize materials such as organoclay, zeolites, chitosan, and activated carbon to capture contaminants. Factors influencing adsorption efficiency include pH, temperature, salinity, and contaminant concentrations [18-19]. The volume and concentration of contaminants in Oil Field Produced Water (OFPW) vary throughout the lifespan of a reservoir. This variability requires comprehensive physicochemical analysis to effectively oversee field operations, assess the effectiveness of treatment processes, and reduce potential risks to public health and the environment [5-20]. Coagulation and flocculation effectively remove suspended oils, particles, and colloids, while advanced oxidation processes (AOPs), such as chemical oxidation, electrochemical oxidation, Fenton reaction, ozone treatment, and Photocatalytic oxidation, degrade organic pollutants, achieving significant reductions in biochemical oxygen demand (BOD) and chemical oxygen demand (COD) [21–22].

Methods

Study area and sample collection

Produced water samples were collected in January 2024 from the Messla oil field, operated by the Arabian Gulf Oil Company (AGOCO). The Messla field is located in the Al Wahat Area, Libya, and has been a significant oil producer since 1988 [23]. Approximately 50 liters of PW were collected and transported in plastic containers. The sample was collected from the same well. After that, the samples were promptly delivered to the engineering laboratories at Tobruk University to minimize changes in their physical and chemical properties (Figure 1).

Figure 1. The produced water collected and stored in plastic containers

Modified sand filter design

This research investigated options to modify the SF such that it can be used to improve the quality of contaminated water. The design process involved two main steps:

- Development of several design options, field testing of designs, and selection of one design for further testing.
- Optimization of selected design based on theoretical calculations and laboratory testing.
- This first stage of the design process involved theorizing design modifications that could improve the capability of the modified sand filter to operate under high contaminated raw water levels. The design options were then tested in a lot of areas, and the results were assessed to identify which design modifications achieved the greatest improvement in water quality. Tests were carried out in two phases:
- The modified filter operated as a control filter to give baseline performance data to enable comparison of produced water pre- and post-modification.
- Testing of modified filter and performance evaluation.

It was also desirable that the Modified Sand Filter (MSF) be entirely constructed of materials that are commonly and locally available. Regarding the good results obtained by [24]. The modified sand filter (MSF) was designed using a cylindrical PVC pipe with a length of 70 cm and a diameter of 10.16 cm. The filter medium consisted of six distinct layers, including fine sand (0.125 – 0.5 mm), fine gravel (1 – 2 mm), biomass (sawdust) (10 –12 mm), coarse gravel (2–4 mm), and drain gravel (8 – 9.5 mm). Sawdust biomass was collected from local carpentry workshops, washed with tap water, dried, and sterilized in an oven at 78°C before being sieved to the desired particle size (Figure 2).

***Received**: 28-01-2025 - **Accepted**: 16-03-2025 - **Published**: 22-03-2025*

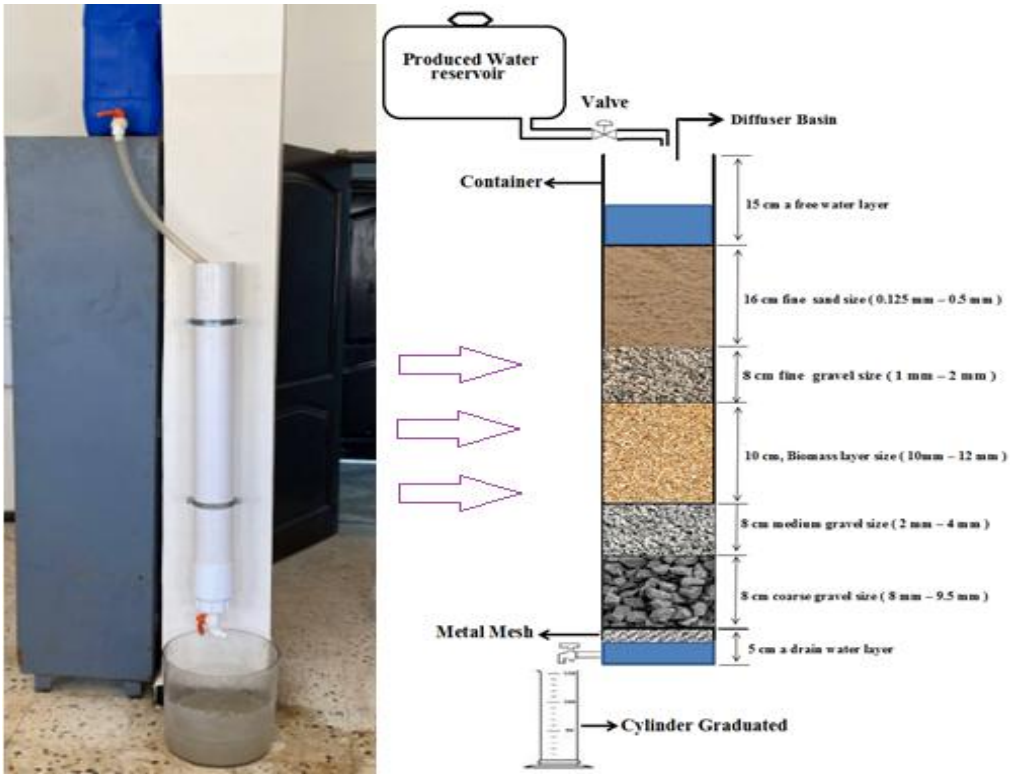

Figure 2. The Modified Sand Filter Design

Preparation of biomass

The sawdust SD was collected from a local carpentry workshop at the industrial area in Tobruk City, as shown in figure 3.

Figure 3: The sawdust.

The sawdust was firstly washed with tap water to remove dust, fungus and other foreign materials and sun dried for a full day. The sawdust was oven-dried at 78 ° C for two hours to completely remove any water still present. Then dried sawdust is pounded using mortar and pestle and sieved using a sieve shaker model 160 to different sizes, we selected only one size (10 - 12 mm), the selected sizes was wash well with distilled water after that dried in electric oven at 78^{o}C to completely remove any water still present for two hours [25], this is the only treatment was carried out for the adsorbent (i.e., sawdust), as shown in Figure 4.

Received: *28-01-2025* - ***Accepted***: *16-03-2025* - ***Published***: *22-03-2025*

https://doi.org/10.54361/ajmas.258169

Figure 4. The sawdust size (10 - 12 mm).

Experimental setup

The experimental system included a 6-liter water tank connected to the MSF (Figure 5). This tank contains a valve that controls the amount of water flowing and also calculates the flow rate and prevents the filter from being flooded. After opening the valve to the required flow rate (48 liters/hour), during this time, the water begins to flow through the layers of the modified sand filter (MSF). The time for the water to pass through the modified sand filter (MSF) is calculated as 6 minutes. The amount of water absorbed is also calculated by calculating the amount of water flowing through the modified sand filter (MSF) at the end of the experiment and the amount of water in the tank.

Figure 5. The Modified Sand Filter (MSF) with biomass of Sawdust (SD).

Received*: 28-01-2025 -* ***Accepted****: 16-03-2025 -* ***Published****: 22-03-2025*

Finally, the water is collected in a graduated cylinder. After that, the filtered water is stored in sterile bottles to conduct the required tests on it, as shown in figure 6.

Figure 6. The produced water before and after treatment by MSF (SD)

The removal ratio represents the efficiency of the treatment process in removing the pollutant from the produced water, such as to study the efficiency and ability to remove and calculate the pH, Conductivity, Total dissolved salt TDS, Turbidity, Total suspended solid TSS, and Total organic matter. The removal percentages were calculated using the following equation [26]:

$$\textit{The percentage of reduction } \mathbf{R}\,(\%) = \left[\frac{T_0 - T_f}{T_0}\right] \times 100$$

Where:
% R.......represents the percentage of reduction (%),
T_0.........represents the initial value before filtration and
T_f.........represents the final value after filtration.

Result and discussion

pH values of produced water

The results of this study demonstrate the effectiveness of the modified sand filter (MSF) filled with biomass (sawdust) in treating produced water by improving various quality parameters. The pH of the untreated produced water was measured at 5.6, reflecting an acidic environment. After treatment with the MSF, the pH increased to 6.4, approaching a neutral value (Figure 7). This adjustment indicates a reduction in acidity, which can be attributed to the interactions between contaminants and the filter media, including the biomass's buffering capabilities. This shift toward a more neutral pH enhances the suitability of the treated water for various applications, such as reuse or safe discharge.

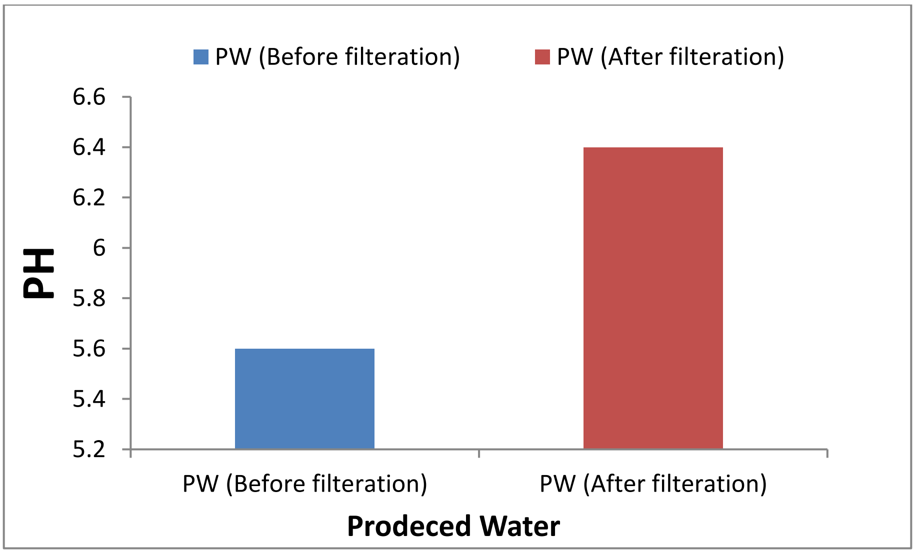

Figure 7. The pH of the produced water before and after filtration.

***Received**: 28-01-2025 - **Accepted**: 16-03-2025 - **Published**: 22-03-2025*

https://doi.org/10.54361/ajmas.258169

Total suspended solids TSS and turbidity reduction

The MSF also demonstrated a significant ability to reduce total suspended solids (TSS). The TSS value of the raw produced water, initially at 6.3%, decreased to 5.25% following treatment, representing a reduction rate of 16.67% (Figure 8). This improvement highlights the efficiency of the filter layers in physically trapping suspended particulate matter, thereby improving water clarity. Similarly, turbidity was reduced from 10 NTU to 8 NTU, achieving a 20% reduction (Figure 9). Furthermore, the MSF removed approximately 65% of the apparent color from the water. These results suggest that the physical properties and adsorptive capacity of the biomass play a critical role in enhancing water clarity and reducing visible contaminants.

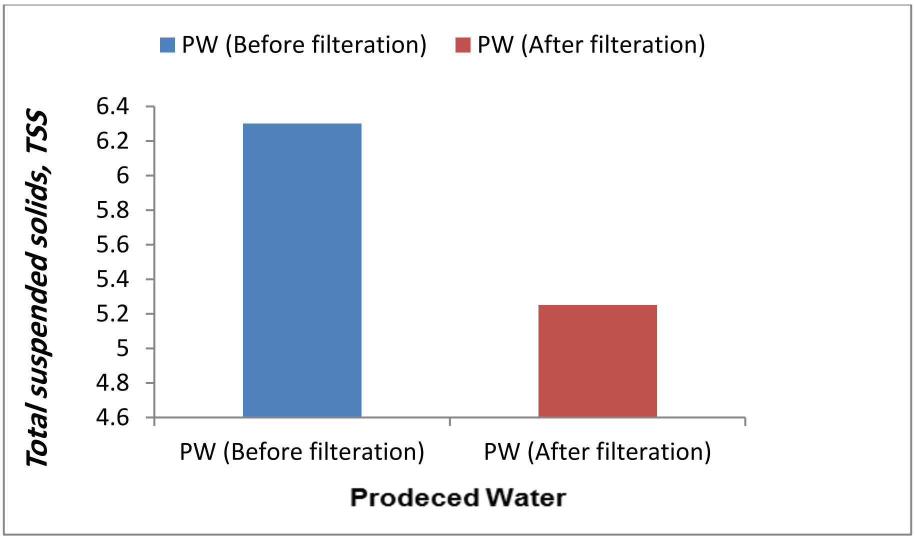

Figure 8. The TSS of the produced water before and after filtration

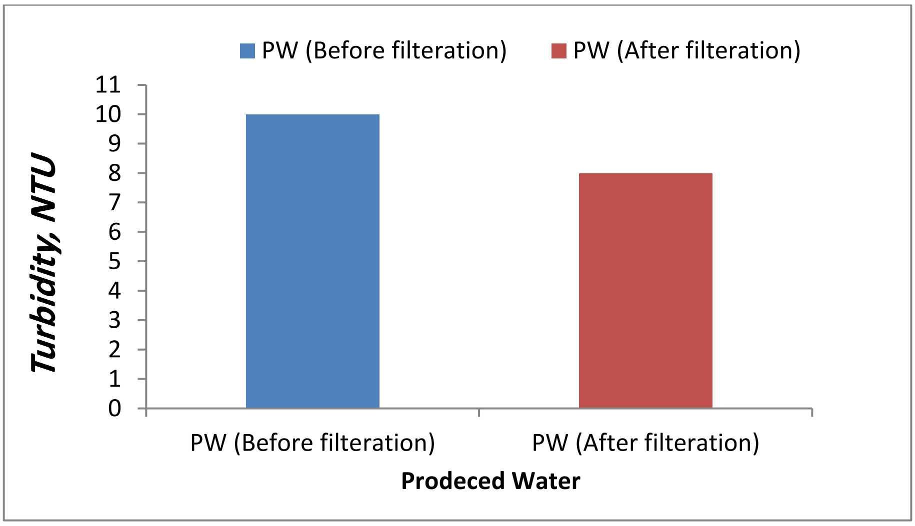

Figure 9. The turbidity of the produced water before and after filtration,

Total dissolved salt, TDS reductions, and conductivity

The filter's impact on dissolved contaminants, however, was more limited. Total dissolved solids (TDS) in the produced water decreased from 137,800 ppm to 134,800 ppm, corresponding to a modest reduction of 2.2% (Figure 10). Similarly, the conductivity of the water was reduced by 2.2%, from 206,597 µS/cm to 202,099 µS/cm (Figure 11). These results highlight the MSF's limited effectiveness in addressing dissolved ionic species, suggesting the need for complementary treatment methods, such as advanced oxidation processes or reverse osmosis, to achieve significant reductions in dissolved salts.

***Received**: 28-01-2025 - **Accepted**: 16-03-2025 - **Published**: 22-03-2025*

https://doi.org/10.54361/ajmas.258169

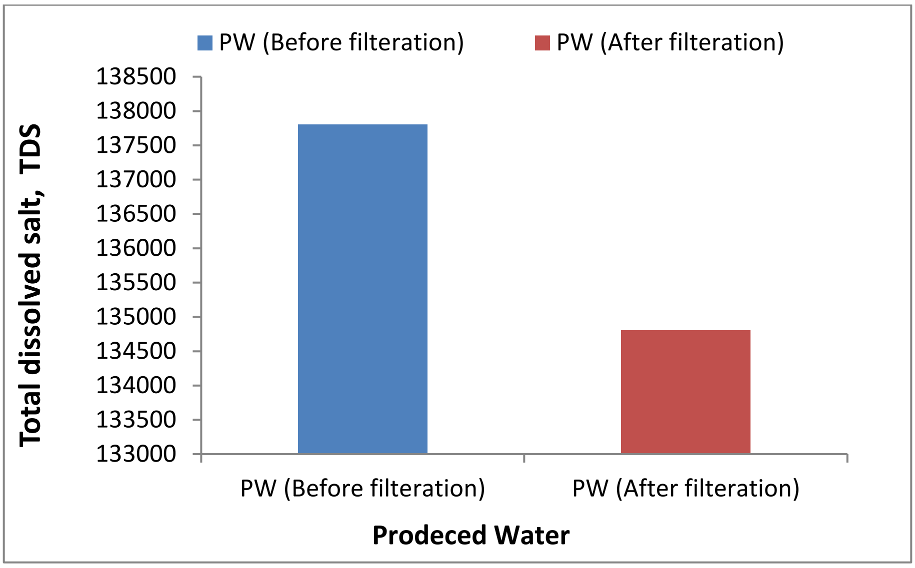

Figure 10. TDS of the produced water before and after filtration

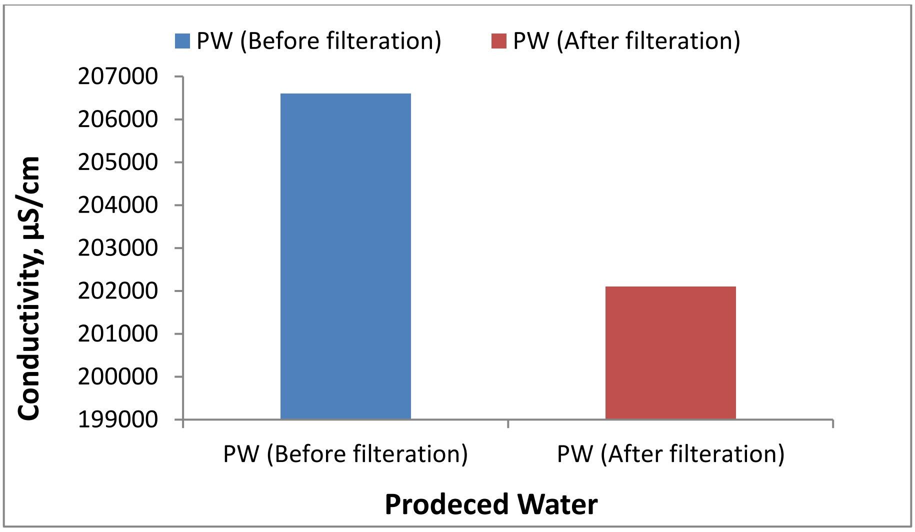

Figure 11. Conductivity of the produced water before and after filtration.

Total organic matter reductions

The removal of total organic matter (TOM) was notably effective, with concentrations decreasing from 1.995 g/100 ml to 0.625 g/100 ml, representing a reduction rate of 68.67% (Figure 12). This significant decrease underscores the strong adsorptive properties of sawdust biomass, which effectively captures organic contaminants. The high reduction rates of organic and suspended solids reflect the MSF's potential as a cost-effective solution for improving produced water quality.

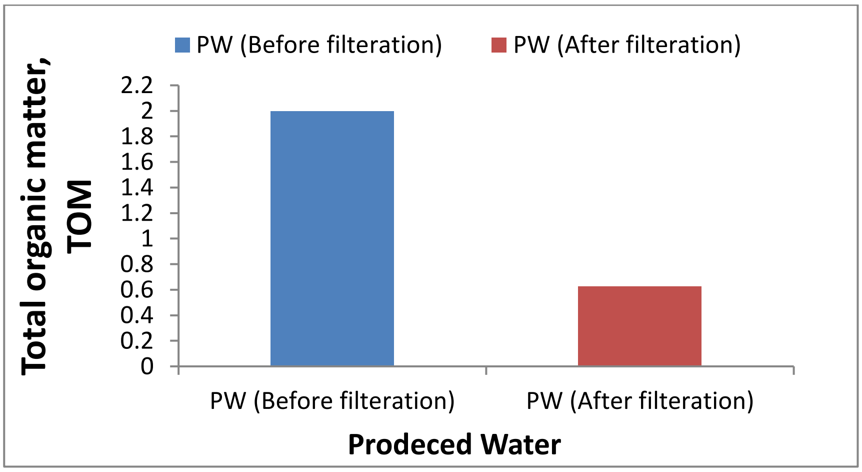

Figure 12. The TOM of the produced water before and after filtration.

***Received**: 28-01-2025 - **Accepted**: 16-03-2025 - **Published**: 22-03-2025*

Overall, the MSF proved highly effective in reducing physical and organic contaminants, although its performance in addressing dissolved solids was limited. While the treated water meets many quality parameters for reuse or safe disposal, the integration of additional treatment technologies could further enhance its effectiveness, particularly in reducing dissolved salts and improving overall water quality. These findings emphasize the potential of the MSF as an environmentally friendly and economical approach to produced water treatment.

CONCLUSION

This study demonstrated the efficiency of a modified sand filter (MSF) incorporating biomass (sawdust) for treating produced water. The MSF effectively reduced key contaminants, achieving a 16.67% reduction in TSS, 20% in turbidity, 65% in apparent color, and 68.67% in TOM. Additionally, it improved the pH of produced water from 5.6 to 6.4, making it more suitable for reuse or safe discharge. While the MSF showed limited performance in reducing dissolved salts (2.2% reduction in TDS and conductivity), its strong filtration and adsorption capabilities for physical and organic pollutants make it a cost-effective and environmentally friendly solution. Future integration with advanced technologies could address these limitations, enhancing its overall efficiency. In summary, the MSF offers a practical and sustainable approach to produced water treatment, with significant potential for broader application in environmental management within the oil and gas industry.

REFERENCES

1. Sirivedhin, T., Dallbauman, L. Organic matrix in produced water from the Osage-Skiatook Petroleum Environmental Research site, Osage county, Oklahoma. Chemosphere J. 2004; 57(6): 463-469.
2. Munirasu, S., Mohammad, A. H., Banat, F. Use of membrane technology for oil field and refinery produced water treatment – A review. PSEP J. 2016; (100): 183-20.
3. Ojo Samuel , Mohd Hafiz Dzarfan Othman, Roziana Kamaludin, Oulavanh Sinsamphanh, Huda Abdullah, Mohd Hafiz Puteh, Tonni Agustiono Kurniawan, Tao Li, Ahmad Fauzi Ismail, Mukhlis A. Rahman, Juhana Jaafar, Tijjani El-badawy, Stanley Chinedu Mamah. Oilfield-produced water treatment using conventional and membrane-based technologies for beneficial reuse: A critical review. JEM. 2022; (308): 114556.
4. Hansen B and Davies S. Review of Potential Technologies for the Removal of Dissolved Components from Produced Water. ChERD J.1994; 72(2): 176–188.
5. Khaled Aghow and Salah Idris. Characterization and Environmental Impact of Produced Water from Oil Fields in the Sirte Basin, Libya. AJMAS. 2025;8(1):67-72
6. Al-Ghouti, M. A., Al-Kaabi, M. A., Ashfaq, M. Y., Da´na, D. A. Produced water characteristics, treatment and reuse: A review. JWPE. 2019; 28(3): 222-239
7. Deng S, Yu G, Chen Z, Wu D, Xia F and Jiang N. Characterization of Suspended Solids in Produced Water in Daqing Oilfield. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2009; 332(1):63-69.
8. Utvik, T. I. R. Chemical characterization of produced water from four off-shore oil production platforms in the North Sea. Chemosphere J. 1999;39(15): 2593–2606.
9. Ahmadun Fakhru'l-Razi , Alireza Pendashteh, Luqman Chuah Abdullah, Dayang Radiah Awang Biak, Sayed Siavash Madaeni, Zurina Zainal Abidin. Review of technologies for oil and gas produced water treatment. Journal of Hazardous Materials. 2009;(170): 530–551.
10. Ebenezer T. Igunnu and George Z. Chen. Produced water treatment technologies. IJLCT. 2014; 9(3): 157–177.
11. Ahmad K. Badawi, Karim Kriaa, Randa M. Osman, Raouf Hassan. Modified Rice Husk Waste-Based Filter for Wastewater Treatment: Pilot Study and Reuse Potential. Chem. Eng. Technol. 2024; 47(7): 968–975.
12. Delfos R. S. Murphy D. Stanbridge Z. Olujic P. J. Jansens, A design tool for optimizing axial liquid-liquid hydrocyclones. Minerals Eng. 2004;17(5): 7211-731.
13. Puprasert C, G. Hebrard, L. Lopez, Y. Aurelle, Potential of using hydrocyclone and hydrocyclone equipped with grit as a pre-treatment in run-off water treatment. Chem. Eng J. 2004;43 (1): 67-83.
14. Kargari A, M.M.A. Shirazi, Application of membrane separation technology for oil and gas produced water treatment, in: Advances in Petroleum Engineering (Volume 1: Refining), Studium Press LLC (2014c).
15. Zhixiong Cha, Cheng-Fang Lin, Chia-Jung Cheng, P.K. Andy Hong. Removal of oil and oil sheen from produced water by pressure-assisted ozonation and sand filtration. Chemosphere J. 2010; 78(5): 583-590
16. Pismenskiy A, M. Urtenov, A. Kovalenko, S. Mareev. Electrodialysis desalination process in conditions of mixed convection. Desalination and Water Treatment. 2015; 56(12): 3211–3213.
17. Tongwen Xu, Chuanhui Huang. Electrodialysis-based separation technologies: A critical review. AIChE J. 2008; 54 (12): 3147-3159.
18. Masooleh M.S., S. Bazgir, M. Tamizifar, A. Nemati, Adsorption of petroleum hydrocarbons on organoclay. JACR. 2010; 4(14): 19-23.
19. Tajar A.F., T. Kaghazchi, M. Soleimani. Adsorption of cadmium from aqueous solutions on sulfurized activated carbon prepared from nut shells, Hazardous Materials j. 2009; 165(1-3): 1159-1164.
20. Onur G Apul and Tanju Karanfil. Adsorption of synthetic organic contaminants by carbon nanotubes. Water Res. 2015; 68(1):34–55
21. Ghernaout D. Advanced oxidation phenomena in electrocoagulation process: a myth or a reality. Desalination and Water Treatment. 2013; 5(40-42): 7536-7554.

***Received**: 28-01-2025 - **Accepted**: 16-03-2025 - **Published**: 22-03-2025*

22. Zhang H, L. Xiang, D. Zhang, H. Qing. Treatment of landfill leachate by internal microelectrolysis and sequent Fenton process, Desalination and Water Treatment. 2012; 47(1-3): 243-248.
23. Alfageh, Z. A. Increasing the production of Messla Oil field, Sirte basin-Libya. IJCR. 2021; 13(8): 18515-18517.
24. Shams Ali Baig, Qaisar Mahmood, Bahadar Nawab, Mustafa Nawaz Shafqat, Arshid Pervez. Improvement of drinking water quality by using plant biomass through household biosand filter. JEE. 2010; 37(11): 1842– 1848.
25. Algathafi R. A. Eisay, Abdrabba I. Hassan, Almabrouk M. Almabrouk. Removal an Oil Spill from Seawater by Using Natural Sorbent Material, Case Study: Tobruk, Libya. International Conference on Renewable and Sustainable Energy. 2021; 5(1):16-24.
26. Aluigi, F. Rombaldoni, C. Tonetti, L. Jannoke. Study of methylene blue adsorption on keratin nanofibrous membranes. Hazardous Materials J. 2014; 268: 156-165.

المستخلص
قيّم هذا العمل كفاءة مرشحات الرمل المعدلة المملوءة بالكتلة الحيوية في إزالة الملوثات الكيميائية والفيزيائية من المياه المنتجة. كما هدفت هذه الدراسة إلى تصميم وبناء وتقييم مرشح رمل معدل فعال من حيث التكلفة. عُدِّل مرشح الرمل بإضافة الكتلة الحيوية (نشارة الخشب)، حيث شكلت الكتلة الحيوية الجزء الأكبر من وسط الترشيح، والذي يتكون من أربع طبقات. صُممت المرشحات الأسطوانية باستخدام أنابيب بلاستيكية بقطر 10.16 سم‌سلطان وطول 70 سم، مع طبقات داخلية مكونة من الرمل والحصى والكتلة الحيوية. غُذِّيت المرشحات بالمياه المنتجة الملوثة، والتي جُلبت من حقل مسلة. جُمعت المياه المفلترة في أسطوانة زجاجية مُدرّجة، ثم أخذت العينات للتحليل. وأشارت النتائج إلى إزالة ما يصل إلى 5.25٪ من إجمالي المواد الصلبة العالقة، و20٪ من العكارة، و65٪ من اللون الظاهري، و68.67٪ من إجمالي المواد العضوية، و2.2٪ من إجمالي الأملاح المذابة، والتوصيل.

***Received**: 28-01-2025 - **Accepted**: 16-03-2025 - **Published**: 22-03-2025*