

Design and Fabrication of a Low-Cost Laboratory-Scale Produced Water Treatment Apparatus

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Abstract

Produced water is a major waste stream generated during oil and gas extraction and contains a complex mixture of hydrocarbons, suspended solids, dissolved constituents, and trace elements. Conventional treatment technologies can achieve effective contaminant removal but may require significant capital investment, energy consumption, and technical expertise, limiting their application in small-scale and remote oil-producing areas. This study investigated the design, fabrication, and laboratory-scale performance of a low-cost, gravity-driven treatment system incorporating limestone, laterite, and coconut-shell-derived activated carbon. The system combined physical filtration and adsorption, with activated carbon serving as the primary adsorptive medium for hydrocarbon removal. Three glass columns with an internal diameter of 130 mm were arranged in series and packed with 800 g of limestone, 500 g of laterite, and 400 g of activated carbon. Approximately 2 L of produced water were treated under gravity flow, with a passage time of approximately 1 h 11 min. The filtration experiment was conducted in triplicate, and influent and effluent samples were evaluated for total suspended solids (TSS), total dissolved solids (TDS), hydrocarbons, pH, and selected elemental constituents. The system achieved removal efficiencies of 91.7% for hydrocarbons, 87.8% for TSS, and 83.0% for TDS. The total fabrication cost was ₦255,000, and the system operated without electrical input. The results demonstrate the potential of a locally fabricated, gravity-driven multi-media system as a preliminary produced-water treatment approach at laboratory scale. Further investigation is required to establish adsorption capacity, long-term performance, media saturation and regeneration, and scalability under higher flow conditions.

Keywords: Produced Water, Low-Cost Treatment, Adsorption, Laterite, Gravity Filtration.

1.0. Introduction

Produced water is a major wastewater stream generated during oil and gas production. It is a complex mixture of organic and inorganic constituents, including dispersed and dissolved hydrocarbons, suspended solids, dissolved salts, trace elements, and residual production chemicals. Its composition varies according to reservoir characteristics, geological conditions, and production practices [1], [2]. Effective management of produced water is therefore important because treatment requirements depend on the characteristics of the water and its intended disposal or reuse route [4], [11].

A range of conventional technologies is available for produced water treatment, including gravity separation, hydrocyclones, dissolved air flotation, membrane processes, chemical treatment, and other physical and biological methods [1], [3], [5], [6]. These technologies can be effective for removing specific contaminant groups, but their application may involve considerable capital investment, energy requirements, specialized equipment, and operational expertise. These considerations can be particularly important for smaller operations and locations where access to infrastructure and technical resources is limited [5], [6], [9], [10].

The selection of an appropriate treatment process depends on the contaminants present and the required effluent quality. Produced water may contain suspended particles, free and dispersed oil, dissolved organic compounds, inorganic constituents, and trace elements, meaning that a combination of treatment mechanisms may be required rather than reliance on a single separation process [1], [4], [11]. Consequently, hybrid or sequential treatment configurations have been investigated as a means of combining complementary physical and chemical treatment mechanisms [5], [6].

Adsorption is an important treatment mechanism for the removal of dissolved and dispersed organic contaminants from produced water. Its performance is influenced by factors such as adsorbent surface characteristics, pore structure, adsorbent dosage, contact time, pH, contaminant concentration, and operating conditions [12], [13]. Activated carbon is among the commonly investigated adsorbents because of its developed pore structure and surface properties. Carbon materials derived from biomass have also received attention because agricultural and other biomass residues can serve as precursor materials for adsorbent production [12], [14].

Coconut-shell-derived activated carbon has specifically been investigated for produced water treatment. Omoruwou *et al.* studied coconut-shell activated carbon for the removal of total hydrocarbons from oilfield produced water and examined the influence of adsorption conditions on its performance [15]. Emmanuel and Giegbefumwen also evaluated coconut-shell activated carbon for produced water treatment and reported reductions in several physicochemical parameters [16]. These studies provide a basis for investigating coconut-shell-derived carbon as the principal adsorptive medium in a treatment system. However, adsorption performance obtained from an isolated or batch system cannot necessarily be assumed to represent the behaviour of a sequential gravity-driven filtration system [12],[13],[14],[15],[16].

In addition to adsorption, naturally occurring mineral materials can provide complementary treatment functions. Laterite contains iron- and aluminium-bearing mineral phases that may contribute to particle retention and interactions with selected dissolved constituents, while limestone can contribute to pH conditioning and precipitation-related processes. The use of locally available materials in water-treatment systems has also been investigated as a means of reducing dependence on more complex or costly treatment infrastructure [7], [8].

Despite the extensive investigation of individual treatment technologies and adsorbents, there remains a practical need to evaluate how locally available mineral and carbonaceous materials perform when integrated into a simple, gravity-driven treatment configuration. Such a system could combine physical filtration, adsorption, and conditioning processes while allowing the treatment media to be arranged in separate stages. The assessment of fabrication requirements and cost is also relevant when considering laboratory-scale systems intended for resource-constrained applications [7], [8], [9].

In this study, a laboratory-scale, gravity-driven produced water treatment apparatus was designed and fabricated using limestone, laterite, and coconut-shell-derived activated carbon arranged sequentially in separate columns. The system was designed to combine physical filtration, adsorption, and conditioning/precipitation-related processes. The study evaluated the characteristics of the selected media, the removal of total suspended solids (TSS), total dissolved solids (TDS), and hydrocarbons, and the fabrication cost of the apparatus.

2.0 Methodology

This section gives details of the methods used in this research. These include materials used and surveys, design and fabrication of apparatus, methods of characterizing different media, and method of experimentation on the fabricated device.

2.1 Material Selection and Survey

The treatment media were selected based on their expected complementary functions in the treatment of produced water, including physical filtration, adsorption, and pH-conditioning/precipitation-related processes. Activated carbon was selected as the principal adsorptive medium because of its porous structure and established application for the removal of organic contaminants from produced water. Previous studies have also reported the use of carbon-based and activated-carbon adsorbents for hydrocarbon and other contaminant removal from produced water. [12], [13], [14], [15].

Coconut shells were selected as the carbon precursor because biomass-derived carbon materials can provide a lower-cost alternative to conventional commercial adsorbents. In particular, coconut-shell-derived activated carbon has been investigated for total-hydrocarbon removal from oilfield produced water. [14], [15]. Laterite was selected as a granular mineral medium for physical filtration and for its potential interaction with selected dissolved constituents, while limestone was incorporated for its potential contribution to pH conditioning and precipitation-related removal. The use of multiple treatment media allows different treatment mechanisms to operate within the same treatment train rather than relying solely on adsorption. [5], [6], [10].

Coconut shells were obtained from a local market and used as the precursor for the carbonaceous adsorbent. The shells were washed to remove adhering impurities, dried, and broken into smaller pieces before grinding. The prepared coconut-shell material was subjected to thermal pyrolysis at 750 °C under oxygen limited conditions to produce the carbonaceous adsorbent used in the treatment system. The resulting material was subsequently ground and sieved to obtain a more uniform particle size.

Laterite was selected because of its granular nature and its content of iron- and aluminum-bearing minerals, which can contribute to physical retention of suspended particles and adsorption of selected dissolved constituents. Limestone was selected primarily for its calcium-carbonate composition and its potential contribution to pH stabilization and precipitation-related removal processes. Coconut-shell-derived carbon was selected as the principal adsorptive medium because its porous structure provides sites for the retention of dissolved hydrocarbons and other organic compounds.

Before packing, the three media were rinsed to remove dust and loose surface impurities, air-dried, ground where necessary, and sieved to obtain relatively uniform particle sizes. The selected materials and their functions in the treatment system are presented in Table 1.

Table 1: Materials used in the produced water treatment system

Material	Role / Function
Activated carbon (coconut shell)	Adsorption of hydrocarbons and organic compounds
Laterite	Physical filtration of suspended particles; adsorption of selected dissolved constituents.
Limestone	pH stabilization and precipitation-related removal
Glass columns (6 mm)	Housing for filtration media
PVC pipes, valves, fittings	Inter-column connections and flow regulation
Sealant adhesive	Prevention of leakage at joints

2.2 Apparatus Design and Fabrication

The treatment apparatus consisted of three glass columns connected in series using PVC tubing, valves, and fittings. Each glass column had an internal diameter of 130 mm and a wall thickness of 6 mm. The flow arrangement and column configuration were first developed using Autodesk Fusion 360 before fabrication. The treatment media were arranged sequentially as limestone, laterite, and coconut-shell-derived carbon, such that produced water first contacted the limestone bed, followed by the laterite bed and finally the activated-carbon polishing bed.

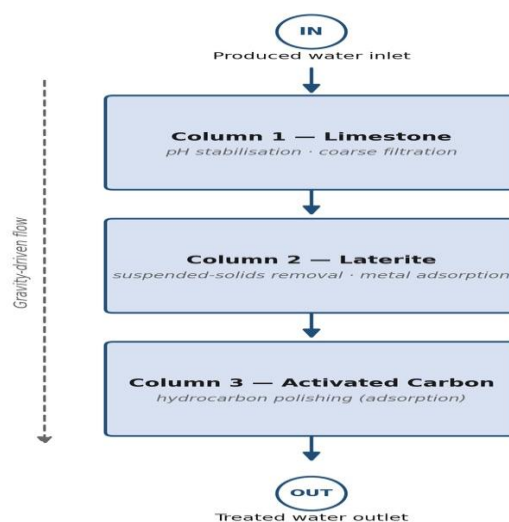


Figure 1: Schematic of the gravity-driven process flow through the limestone, laterite and activated-carbon columns

Figure 1 illustrates the treatment sequence and flow direction through the three media beds. Produced water enters the limestone column first, passes through the laterite column, and subsequently enters the activated-carbon column under gravity flow. The sequence was selected according to the intended functions of the individual media: limestone provides initial conditioning, laterite provides physical filtration and adsorption of selected constituents, and activated carbon provides the principal adsorptive polishing step for dissolved hydrocarbons and organic compounds.

The column dimensions were selected to provide adequate media depth and contact between the produced water and treatment media while maintaining a practical laboratory-scale configuration. The 130 mm internal diameter provided sufficient cross-sectional area for gravity-driven flow, while the selected bed heights provided media depth without making the apparatus unnecessarily large for laboratory handling. The laterite bed was given

a greater depth of 300 mm to provide additional filtration depth, while the limestone and activated-carbon beds were each 160 mm high.

The quantities of media loaded into the columns were 800 g of limestone, 500 g of laterite, and 400 g of coconut-shell-derived carbon. The system was designed to operate under gravity flow, thereby eliminating the need for a mechanical pumping unit. The column dimensions and corresponding media quantities are presented in Table 2.

Table 2: Column dimensions and media quantities

Column / Medium	Height / Quantity
Column 1 (Limestone)	160 mm / 800 g
Column 2 (Laterite)	300 mm / 500 g
Column 3 (Activated carbon)	160 mm / 400 g

Following the CAD design, the columns were fabricated and connected using PVC tubing, valves, and fittings. The connections were sealed to prevent leakage, and the arrangement of the columns and flow pathway was maintained according to the CAD design.

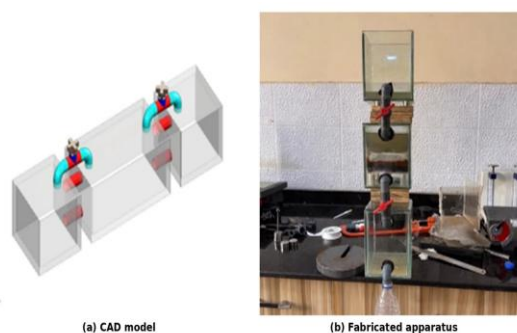


Figure 2: Apparatus design and fabrication: (a) CAD model of the column layout and flow pathway, developed in Autodesk Fusion 360; (b) photograph of the fabricated, gravity-driven filtration apparatus

Figure 2 presents the transition from the computer-aided design to the fabricated apparatus. Figure 2(a) shows the arrangement of the columns, interconnections, and flow pathway, while Figure 2(b) shows the assembled laboratory-scale apparatus.

2.3 Characterization of Filtration Media

Before packing, samples of coconut-shell-derived carbon, laterite, and limestone were examined for visible impurities, rinsed with clean water to remove dust and loose surface materials, air-dried, ground where necessary, and sieved to obtain relatively uniform particle sizes.

The three-treatment media were characterized using Scanning Electron Microscopy (SEM), and Energy-Dispersive X-ray Spectroscopy (EDX). SEM was used to examine the surface morphology and structural features of the media, particularly the presence of pores, surface irregularities, and particle structure. EDX was used to determine the elemental composition of the media and identify the major elements associated with their expected treatment functions.

The characterization was performed on all three-treatment media, coconut-shell-derived carbon, laterite, and limestone, prior to their use in the filtration experiment. The characterization results were subsequently used to relate the physical and chemical properties of the media to their respective roles in filtration, adsorption, and pH/precipitation-related treatment.

2.4 Experimental Procedure

Produced water samples were obtained from an oil well location and stored in sealed containers prior to analysis. Before treatment, the influent sample was characterized for total suspended solids (TSS), total dissolved solids (TDS), total hydrocarbons, pH, and selected elemental constituents. The initial concentrations obtained were used as the baseline for evaluating treatment performance.

Approximately 2 L of produced water were introduced into the settling chamber and allowed to pass through the three treatment columns under gravity flow. The flow was regulated at the inlet valve, and the observed passage

time through the complete treatment system was approximately 1 h 11 min. The treated water was collected at the outlet of the third column for subsequent analysis.

The influent and effluent samples were analyzed using the same laboratory analytical procedures to allow direct comparison before and after treatment. TSS, TDS, and total hydrocarbons were determined using the laboratory's established analytical procedures. The pH of the samples was measured using a calibrated pH meter, while TDS was measured using a calibrated TDS meter. Selected elemental constituents were determined using Atomic Absorption Spectroscopy (AAS). The analytical equipment was calibrated before each analytical session.

Clean sampling bottles were used for sample collection, and appropriate laboratory handling procedures were followed during sample preparation and analysis. The filtration experiment was conducted in triplicate, and the reported treatment values represent the mean of the replicate measurements.

3.0 Theoretical Foundation

This section presents the theory behind the treatment apparatus design and the approach adopted to analyze its efficiency. It includes the physics of contaminants' removal and mathematical expressions used to calculate the efficiency of the process and its economic feasibility.

3.1 Physical Mechanism of Contaminant Removal

Three principal mechanisms contribute to contaminant removal in the treatment system: sedimentation, physical filtration, and adsorption. These mechanisms operate sequentially as produced water passes through the treatment columns.

Sedimentation occurs in the settling chamber and during flow through the system as suspended particles and relatively large free oil droplets separate under gravity because of differences in density between the contaminants and the water. For spherical particles under laminar conditions, the settling velocity can be described using Stokes' law:

$$V_s = \frac{d^2 (\rho_p - \rho_f) g}{18\mu} \quad (1)$$

where d is particle diameter (m), ρ_p and ρ_f are particle and fluid densities (kg/m^3), g is gravitational acceleration (9.81 m/s^2), and μ is fluid dynamic viscosity ($\text{Pa}\cdot\text{s}$). Larger particles and free oil droplets generally settle more readily under gravity, whereas smaller suspended particles and dissolved contaminants require additional removal mechanisms.

Physical filtration occurs as the produced water passes through the granular limestone, laterite, and carbon beds. Suspended particles are retained through mechanisms including straining, interception, and attachment to the surfaces of the porous media. Flow through the fixed beds is governed by the hydraulic properties of the media and can be described using Darcy's law:

$$Q = \frac{kA\Delta P}{\mu L} \quad (2)$$

where Q is flow rate (m^3/s), k is media permeability (m^2), A is cross-sectional area (m^2), ΔP is pressure drop (Pa), μ is fluid viscosity ($\text{Pa}\cdot\text{s}$), and L is bed thickness (m). Flow through the columns was maintained under gravity, and the bed arrangement and flow were controlled to promote contact between the produced water and the treatment media while minimizing preferential flow or channelling.

Adsorption provides an additional mechanism for removing dissolved contaminants that cannot be effectively removed by physical filtration alone. It involves the accumulation of dissolved molecules or ions at the surface of a solid adsorbent. In the present system, coconut-shell-derived carbon serves as the principal adsorptive medium for dissolved hydrocarbons and organic compounds because of its porous structure and available surface area. Laterite may also contribute to the adsorption of selected dissolved constituents through interactions with its iron- and aluminium-bearing mineral surfaces.

The treatment system therefore combines sedimentation, physical filtration, adsorption, and precipitation/pH-conditioning effects rather than relying on filtration alone. Limestone provides initial conditioning and may contribute to precipitation-related removal, laterite provides physical filtration and adsorption of selected constituents, while the coconut-shell-derived carbon provides the principal adsorption step for dissolved hydrocarbons and organic compounds.

3.2 Performance and Cost Evaluation Framework

Treatment efficiency was evaluated based on the percentage reduction in contaminant concentration between the influent and effluent samples. The removal efficiency for each measured parameter was calculated using the following mass-balance relationship:

$$n = \frac{C_i - C_o}{C_i} \times 100 \quad (3)$$

where C_i represents concentration of influent contaminants, C_o refers to concentration of effluent contaminants and η represents efficiency of removal (%).

4.0 Results and Discussions

The outcomes of this study are presented and analyzed below based on the objectives stated in Section 1. They include characterization of the filtering media, performance of filtration treatment, cost estimation, as well as comparison with previous works and their practical applications.

4.1 Characterization of Filtration Media

The SEM images in Figure 3 show distinct surface characteristics among the three treatment media. The coconut-shell-derived carbon exhibited a porous structure with cavities and channels formed during the carbonization process. These structural features provide surface and pore spaces that can contribute to the adsorption of dissolved contaminants. Laterite exhibited a heterogeneous structure with irregular particles and surface features, which can contribute to both physical retention of suspended particles and adsorption of selected dissolved constituents. Limestone exhibited a relatively dense, angular to sub-angular structure with rough surface features.

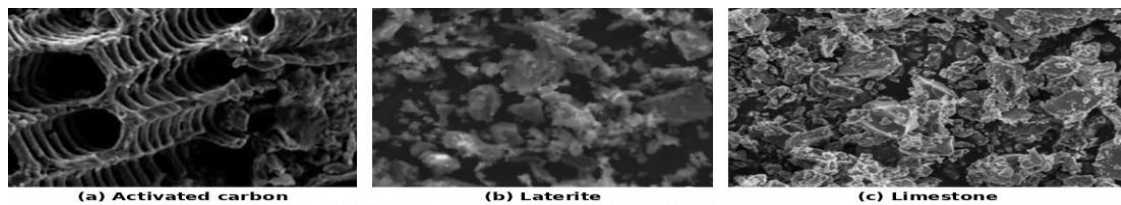


Figure 3: SEM images of (a) activated carbon, (b) laterite, and (c) limestone

The EDX spectra in Figure 4 further showed differences in the elemental composition of the treatment media. The coconut-shell-derived carbon was predominantly composed of carbon and oxygen, with smaller signals associated with other elements. Laterite showed prominent iron, aluminium, silicon, and oxygen signals, consistent with its mineral composition. The limestone spectrum showed prominent calcium, oxygen, and carbon signals, consistent with a calcium-carbonate-rich material.

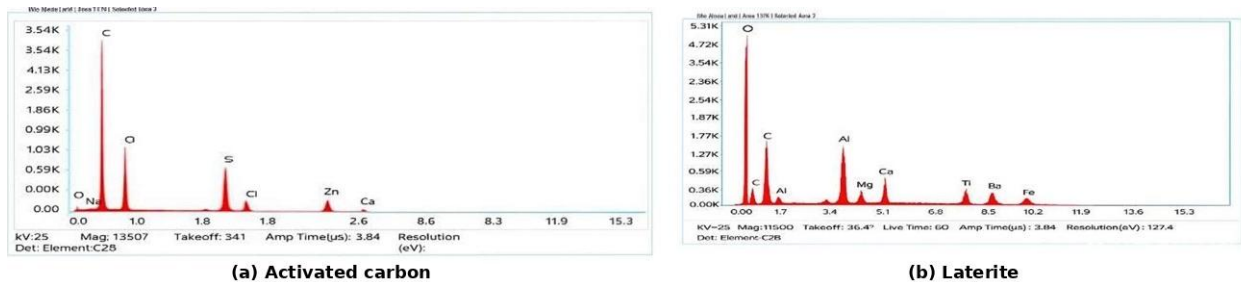


Figure 4: EDX spectra of (a) activated carbon and (b) laterite

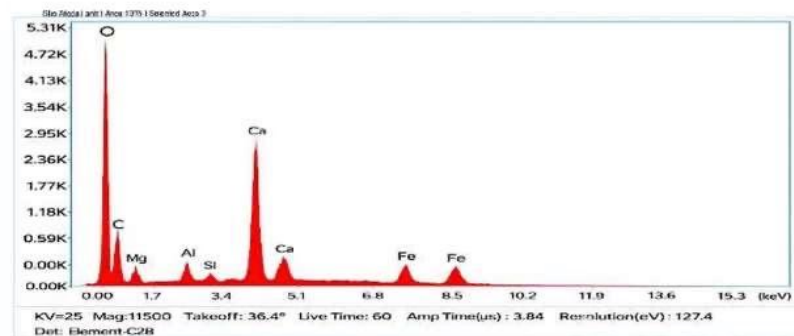


Figure 5: EDX spectrum of limestone

The characterization results provide supporting evidence for the complementary functions of the treatment media within the system. The porous structure observed for the coconut-shell-derived carbon provides surface

and pore spaces suitable for adsorption of dissolved organic contaminants. The heterogeneous mineral structure of laterite supports its role in physical filtration and may provide sites for adsorption of selected dissolved constituents. The calcium- and oxygen-rich composition of limestone is consistent with its intended role in pH conditioning and precipitation-related processes. Collectively, the SEM and EDX results support the use of the three media as complementary components in the combined filtration and adsorption treatment process.

4.2 Treatment Performance

The treatment performance was evaluated by comparing the characteristics of the produced water before and after treatment. The measured parameters included pH, total dissolved solids (TDS), total suspended solids (TSS), total hydrocarbons, and selected elemental constituents. The results obtained from the treatment experiments are presented in Table 3.

Table 3: Physiochemical and elemental characteristics and removal efficiency of produced water before and after treatment

Parameter	Before Treatment	After Treatment	Removal Efficiency (%)
pH	7.30	7.25	—
TDS (ppm)	1,885	320	83.0
TSS (ppm)	22	2.68	87.8
Total hydrocarbons (ppm)	40.48	3.36	91.7
Fe (ppm)	1.50	<0.01	>99
Zn (ppm)	0.01	<0.005	>50
Pb (ppm)	0.01	<0.005	>50
Cu (ppm)	0.01	0.01	0
Na (ppm)	13.82	0.25	98.2
Ca (ppm)	7.00	1.10	84.3
Mg (ppm)	2.12	0.20	90.6

The results show noticeable reductions in TDS, TSS, total hydrocarbons, and most of the selected elemental constituents after treatment, while the pH remained relatively stable, changing from 7.30 to 7.25. TDS decreased from 1,885 ppm to 320 ppm, while TSS decreased from 22 ppm to 2.68 ppm. Total hydrocarbon concentration also decreased substantially from 40.48 ppm to 3.36 ppm. Among the selected elements, reductions were observed for Fe, Zn, Pb, Na, Ca, and Mg, whereas Cu remained unchanged at 0.01 ppm.

Based on the calculated removal efficiencies, the system achieved 87.8% TSS removal, 83.0% TDS removal, and 91.7% hydrocarbon removal. The reduction in TSS is primarily associated with physical filtration and particle interception within the granular media, while hydrocarbon removal is consistent with the adsorption function of the coconut-shell-derived activated carbon. The reduction in TDS may involve interactions with the mineral media, including adsorption and precipitation-related processes. However, since the media were operated together in a sequential configuration, their individual contributions to the overall removal efficiency could not be separately quantified.

The overall reduction in the measured parameters is illustrated in Figure 6.

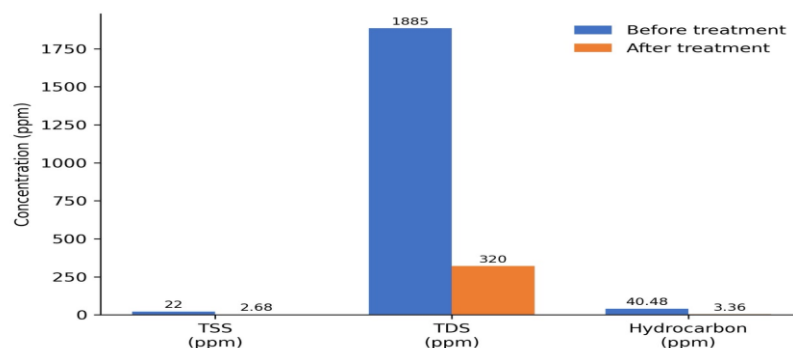


Figure 6: Comparison of produced water contaminant concentrations before and after treatment

Figure 6 provides a direct comparison of the influent and effluent concentrations of TSS, TDS, and hydrocarbons. The results show a substantial reduction in all three measured parameters following passage through the treatment system. The observed reductions indicate that the combination of physical filtration and adsorption, together with the conditioning and precipitation-related functions of the media, contributed to the overall treatment performance.

4.3 Cost Analysis

The total cost of materials and fabrication for the laboratory-scale produced water treatment apparatus was ₦255,000, as presented in Table 4. The major cost components were the coconut-shell-derived activated carbon and the glass columns, which accounted for ₦135,000 and ₦68,000, respectively. Other costs included PVC pipes and valves, fittings and sealants, and limestone. Laterite was obtained locally at no cost.

Table 4: Cost of materials used for fabrication

Item	Cost (₦)
Glass columns (6 mm)	68,000
Pipes and valves	25,000
Fittings and sealants	12,000
Activated carbon	135,000
Limestone	15,000
Laterite	0
Total	255,000

The cost distribution indicates that activated carbon represented the largest individual cost component, accounting for approximately 53% of the total fabrication cost, while the glass columns accounted for approximately 26.7%. The relatively low-cost contribution of laterite reflects its local availability. These results indicate that the choice and sourcing of the adsorptive medium can have a substantial influence on the overall fabrication cost of the system.

The distribution of the fabrication cost among the different components is illustrated in Figure 7.

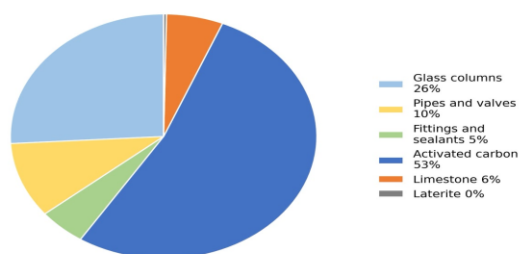


Figure 7: Distribution of total fabrication cost by component

For the laboratory-scale system, the cost analysis provides an estimate of the resources required to construct the apparatus. However, the reported fabrication cost should not be interpreted as a direct field-scale treatment cost, since larger-scale operation would involve additional factors such as media replacement, maintenance, column sizing, flow capacity, and operating lifetime. Further economic assessment would therefore be required before evaluating the cost performance of the system under field conditions.

4.4 Comparison with Previous Studies and Engineering Implications

The treatment performance observed in this study is consistent with previous research demonstrating the potential of adsorption-based processes for produced water treatment. Adsorption has been investigated for the removal of hydrocarbons and other dissolved organic contaminants from produced water, with activated carbon among the commonly studied adsorbent materials [12], [13]. The effectiveness of adsorption is influenced by factors including adsorbent characteristics, contact time, contaminant concentration, and operating conditions; therefore, removal performance obtained from one treatment configuration cannot be directly assumed to represent another configuration [12], [13].

The 91.7% reduction in hydrocarbon concentration observed in the present study is also relevant to previous work on coconut-shell-derived activated carbon. Omoruwou *et al.* specifically investigated coconut-shell activated carbon for total-hydrocarbon removal from oilfield produced water and reported that adsorption performance

was affected by process variables such as adsorbent dosage and contact time [15]. Similarly, Emmanuel and Giegbefumwen reported improvements in hydrocarbon-related and other physicochemical parameters after treatment of produced water using coconut-shell activated carbon [16]. These studies support the relevance of coconut-shell-derived carbon for hydrocarbon-containing produced water, although the present study used the carbon as part of a sequential multi-media system rather than as an isolated adsorbent.

The 83.0% reduction in TDS requires more cautious interpretation. Dissolved solids are not generally removed by simple particle straining, and the observed reduction may involve a combination of adsorption, precipitation-related processes, and interactions with the mineral media. The present experimental design did not include media-specific control experiments or detailed ionic-speciation analysis; consequently, the proportion of TDS removal attributable to limestone, laterite, activated carbon, or individual mechanisms cannot be established. This limitation is important because produced water contains a complex mixture of dissolved inorganic and organic constituents whose behaviour depends on their individual chemical properties [5], [12], [13].

From an engineering perspective, the results demonstrate the feasibility of integrating different treatment mechanisms within a gravity-driven laboratory-scale system. The sequential arrangement allows the water to pass through the treatment media without an external pumping requirement, while the separate columns provide an arrangement that can be modified or replaced as individual media become exhausted. However, the laboratory-scale results should not be interpreted as evidence that the apparatus can replace conventional primary, secondary, or tertiary produced-water treatment systems. Conventional treatment trains involve different unit operations and are normally designed according to specific influent characteristics, required effluent quality, hydraulic loading, and regulatory requirements [5], [6].

The principal engineering implication of the present study is therefore the potential use of locally fabricated, gravity-driven treatment as a preliminary or polishing treatment option where appropriate, rather than as a direct substitute for industrial treatment systems. Further investigation under controlled flow conditions, higher treatment volumes, longer operating periods, and media-specific experiments would be required to establish adsorption capacity, breakthrough behaviour, media lifespan, regeneration requirements, and scale-up performance. Such studies would also help determine the contribution of individual media and mechanisms to the overall treatment efficiency.

5.0 Conclusion

A laboratory-scale, gravity-driven produced water treatment apparatus was successfully designed, fabricated, and evaluated using limestone, laterite, and coconut-shell-derived activated carbon as sequential treatment media. SEM and EDX characterization provided supporting information on the morphology and elemental composition of the media and their potential complementary roles in the treatment process.

The treatment system achieved removal efficiencies of 91.7% for hydrocarbons, 87.8% for TSS, and 83.0% for TDS, based on the average results obtained from the experimental runs. The observed performance indicates that the combined system provided substantial reduction in the measured contaminants through the interaction of physical filtration, adsorption, and conditioning/precipitation-related processes. The total fabrication cost was ₦255,000, and the system operated under gravity without electrical pumping.

Further studies should investigate longer operating periods, media-specific performance, adsorption capacity and breakthrough behaviour, regeneration or replacement requirements, and scale-up under controlled hydraulic conditions before application beyond the laboratory scale.

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