

Effect of Waste Engine Oil Treatment on Moisture Absorption and Hygroscopic Performance of Selected Tropical Hardwoods

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Abstract

The moisture sensitivity of wood-based reinforcement can restrict dimensional stability and durability in humid service environments. This study examined the effect of waste engine oil impregnation on the moisture-absorption behaviour of three tropical hardwoods—White Safari (*Triplochiton scleroxylon*), Opepe (*Nauclea diderrichii*) and Bush Mahogany (*Khaya ivorensis*)—considered for reinforcement in wood-based composite applications. Prepared specimens were separated into untreated controls and waste-engine-oil-treated groups. The treated specimens were immersed in filtered waste engine oil, drained and conditioned to stable mass before gravimetric moisture-absorption assessment. Moisture transport was interpreted using Fickian diffusion principles, while treatment effects were evaluated statistically at a 95% confidence level. Waste engine oil treatment reduced equilibrium moisture absorption in all three species. White Safari decreased from 11.80% to 6.20%, Opepe from 10.50% to 5.70%, and Bush Mahogany from 10.30% to 5.50%, corresponding to reductions of 47.46%, 45.71% and 46.60%, respectively. The treated specimens also showed slower moisture uptake and lower equilibrium values than the untreated controls. These findings are consistent with partial occupation of pores and lumens by a hydrophobic oil phase and reduced accessibility of water-binding sites. The results demonstrate that waste engine oil impregnation can substantially reduce hygroscopic response in the selected hardwoods. However, environmental safety, contaminant leaching, long-term weathering and application-specific durability require evaluation before engineering deployment.

Keywords: Hygroscopicity, Moisture Absorption, Tropical Hardwoods, Waste Engine Oil, Wood Composites, Chemical Modification, Moisture Resistance

1. INTRODUCTION

Renewable lignocellulosic materials continue to attract interest as reinforcement and structural constituents because of their comparatively low density, renewable origin and useful specific properties. Wood and other natural fibres are consequently considered in products ranging from building components and furniture to transport and packaging applications (Jayan et al., 2021; Mohammed et al., 2022; Khan et al., 2024). Their engineering use, however, depends not only on strength but also on stability during exposure to the environment.

Moisture sensitivity is one of the principal limitations of wood-based materials. Cellulose and hemicellulose contain hydroxyl groups that interact readily with water. Moisture uptake can therefore produce swelling, dimensional change and deterioration in the mechanical integrity of wood-containing systems, particularly when exposure is repeated or prolonged (Cai et al., 2021; Awais et al., 2021). In humid tropical environments, where materials may experience sustained atmospheric moisture and frequent wetting, reducing hygroscopic response is important for maintaining dimensional consistency and service performance.

Several modification routes have been investigated to reduce the affinity of lignocellulosic materials for water. These include alkali and silane treatments, acetylation, furfurylation and polymer impregnation. Although such approaches can be effective, the cost of reagents, processing requirements and need for specialised equipment may constrain their use in some settings (Awais et al., 2021). This creates interest in treatment media that are locally available and capable of restricting moisture transport without complex processing.

Waste engine oil is a hydrophobic petroleum-derived residue generated during routine vehicle and machinery maintenance. Its non-polar constituents can potentially enter accessible voids in wood, coat internal surfaces and obstruct pathways through which water penetrates the material. From a materials perspective, this suggests a possible impregnation treatment for reducing moisture uptake. From an environmental perspective, however, waste engine oil is not an inherently benign material. Any proposed reuse must therefore be considered alongside contaminant content, worker exposure, leaching, end-of-life management and applicable environmental controls.

Published studies have examined moisture transport and chemical modification in a wide range of natural-fibre and wood-based systems, but evidence concerning waste-engine-oil treatment of Nigerian tropical hardwoods remains limited. Direct comparison of White Safari (*Triplochiton scleroxylon*), Opepe (*Nauclea diderrichii*) and Bush Mahogany (*Khaya ivorensis*) under a common treatment and exposure approach is particularly useful because wood anatomy, density and pore structure can influence both liquid penetration and moisture transport.

The present study therefore evaluates the effect of waste engine oil treatment on the hygroscopic behaviour of the three selected tropical hardwoods. The emphasis is deliberately placed on the moisture-absorption evidence reported for treated and untreated specimens. The specific objectives are to compare equilibrium moisture uptake, quantify the percentage reduction associated with treatment, interpret the observed response using moisture-transport principles, and discuss the engineering relevance and limitations of the treatment. This focus avoids extending the conclusions beyond the moisture data directly reported in the experimental programme.

2. MATERIALS AND METHODS

2.1 Materials

The investigated wood species were White Safari (*Triplochiton scleroxylon*), Opepe (*Nauclea diderrichii*)

and Bush Mahogany (*Khaya ivorensis*). Condemned engine oil used as the treatment medium was obtained from automobile service workshops within Calabar Metropolis, Nigeria.

The use of three species provided a comparative basis for assessing whether the response to oil impregnation was common across woods with different anatomical characteristics. The waste engine oil was filtered before treatment so that the impregnation medium used for the specimens was free from readily removable particulate debris.

2.2 Specimen Preparation and Experimental Groups

Wood specimens were cut and sanded for moisture-absorption testing and conditioned at room temperature until constant mass was attained. The prepared specimens were assigned to two experimental conditions: untreated specimens, which served as controls, and waste-engine-oil-treated specimens.

The experimental record identifies the sample preparation as following the ASTM procedure adopted for the study. Because the exact ASTM designation, specimen dimensions and detailed conditioning parameters are not contained in the available manuscript record, the present paper does not introduce values that were not experimentally documented. This limitation is considered when interpreting reproducibility and is identified explicitly in Section 3.5.

2.3 Waste Engine Oil Treatment

For treatment, each specimen was fully immersed in filtered waste engine oil for the treatment period used in the experiment. After immersion, specimens were removed from the oil, allowed to drain and then cured under laboratory conditions until their masses stabilised. Untreated controls did not undergo oil impregnation.

2.4 Moisture Absorption Assessment

Moisture absorption was determined gravimetrically from the change in specimen mass relative to the initial dry mass. The percentage moisture absorption, $M\%$, was calculated as:

$$M\% = [(W_t - W_0) / W_0] \times 100 \quad (1)$$

where W_t is the specimen mass after exposure at time t and W_0 is the initial dry mass. Moisture-uptake behaviour was interpreted within a Fickian diffusion framework. In one-dimensional form, moisture transport may be expressed as:

$$\partial C / \partial t = D(\partial^2 C / \partial x^2) \quad (2)$$

where C is moisture concentration, t is time, D is the effective diffusion coefficient and x is the diffusion distance. The diffusion framework was used to interpret the shape and relative rate of the uptake response rather than to claim diffusion coefficients not reported in the available dataset.

2.5 Statistical Analysis

The measured data were evaluated using analysis of variance (ANOVA) at a 95% confidence level ($\alpha = 0.05$). Statistical significance was assessed using $p < 0.05$ as the decision criterion. The interpretation in this paper is restricted to the reported treatment effect and does not introduce unreported F statistics, degrees of freedom or post-hoc comparisons.

2.6 Use of Generative Artificial Intelligence

Generative artificial intelligence was used only to assist with language refinement, structural editing and journal-format preparation of the manuscript. It was not used to generate experimental measurements or replace the authors' interpretation and verification of the research data. The authors remain responsible for

the accuracy, integrity and final content of the manuscript.

3. RESULTS AND DISCUSSION

3.1 Effect of Waste Engine Oil Treatment on Equilibrium Moisture Absorption

Waste engine oil treatment reduced equilibrium moisture absorption in each of the three investigated species. White Safari decreased from 11.80% in the untreated condition to 6.20% after treatment. Opepe decreased from 10.50% to 5.70%, while Bush Mahogany decreased from 10.30% to 5.50%. The corresponding percentage reductions were 47.46%, 45.71% and 46.60%, respectively (Table 1).

The magnitude of reduction was therefore similar across the three woods. All three values lie within a narrow interval of approximately 46–47%, indicating that the treatment response was not confined to a single species. White Safari showed the largest proportional reduction, whereas Bush Mahogany recorded the lowest treated equilibrium moisture value. These are different measures of performance: proportional reduction describes the treatment-induced change relative to the untreated state, while the treated equilibrium value describes the final moisture level under the reported exposure conditions.

The results support the central proposition of the study: impregnation with waste engine oil can substantially restrict the amount of moisture taken up by the selected tropical hardwoods. This finding is consistent with the general observation that hydrophobic modification or occupation of accessible pore space can reduce water interaction with lignocellulosic materials (Awais et al., 2021; Chen et al., 2021).

Table 1. Effect of waste engine oil treatment on equilibrium moisture absorption

Species	Untreated (%)	Treated (%)	Reduction (%)
White Safari	11.80	6.20	47.46
Opepe	10.50	5.70	45.71
Bush Mahogany	10.30	5.50	46.60

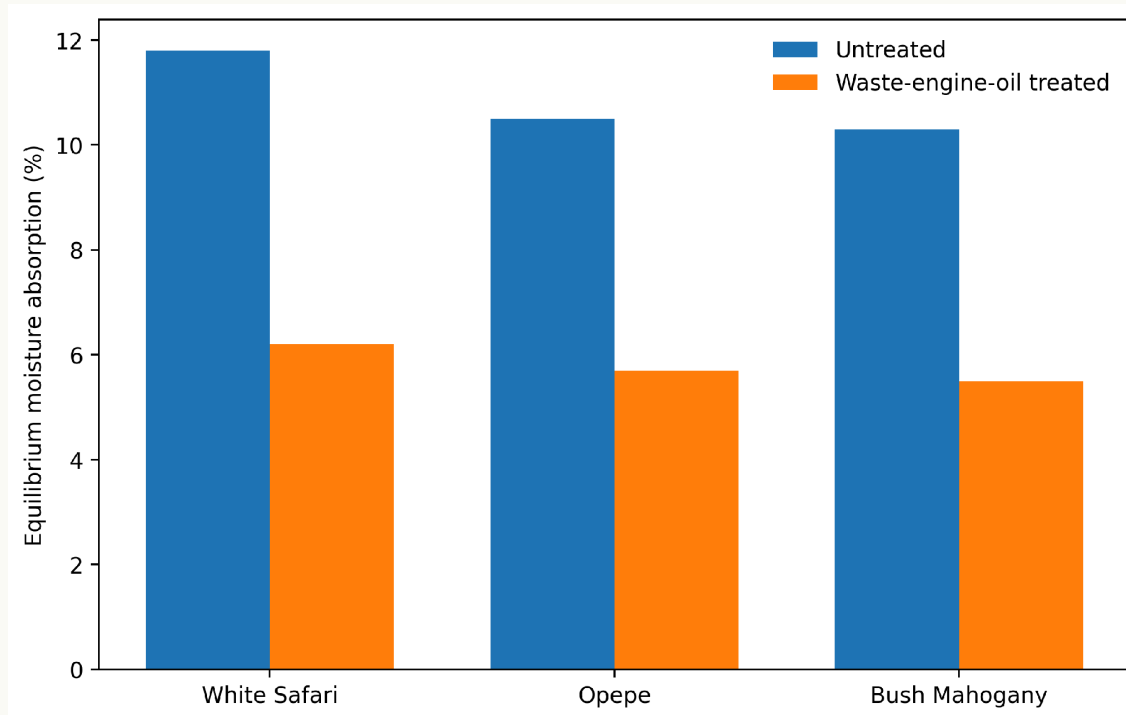


Figure 1. Equilibrium moisture absorption of untreated and waste-engine-oil-treated specimens for the three tropical hardwood species.

3.2 Moisture Uptake and Diffusion Behaviour

The reported moisture-uptake profiles showed a relatively rapid initial increase followed by a progressively smaller rate of gain as exposure continued. This type of response is consistent with moisture transport in porous lignocellulosic materials: readily accessible surfaces and connected voids contribute strongly at early exposure, whereas transport becomes progressively constrained as the material approaches an equilibrium state (Chen et al., 2021).

Across the reported profiles, untreated specimens gained moisture more rapidly than oil-treated specimens and approached higher equilibrium values. The direction of this change is consistent with a reduction in the effective accessibility of transport pathways after impregnation. Within a Fickian interpretation, slower uptake is associated with a lower effective transport rate. The present dataset, however, should not be used to assign numerical diffusion coefficients unless the required time-dependent specimen dimensions and fitted diffusion data are available.

The reduction in uptake can be interpreted through two complementary mechanisms. First, oil entering vessels, capillaries and lumens can partially occupy spaces that would otherwise contribute to water ingress. Second, an oil phase coating accessible to internal surfaces can reduce direct interaction between water and hydrophilic cell-wall constituents. Both mechanisms increase resistance to water penetration without requiring the assumption that the chemical structure of the wood has been permanently altered.

This distinction is important. The moisture results directly demonstrate a change in hygroscopic response after treatment, but they do not by themselves establish a specific chemical reaction between the oil and wood polymers. Confirmation of chemical modification would require appropriately documented spectroscopic evidence, while direct visualisation of lumen filling would require experimental microscopy. The present interpretation therefore treats pore occupation and hydrophobic shielding as plausible mechanisms consistent with the observed moisture response rather than as independently proven microstructural facts.

3.3 Species-Dependent Response

Although treatment reduced moisture absorption in every species, the untreated starting values and treated equilibrium values were not identical. White Safari had the highest untreated moisture absorption at 11.80% and remained highest after treatment at 6.20%. Opepe and Bush Mahogany had lower untreated values of 10.50% and 10.30%, respectively, and their treated values were correspondingly lower.

Bush Mahogany recorded the lowest treated equilibrium moisture absorption, 5.50%. Differences among species may be associated with anatomical structure, density, permeability and the distribution of accessible voids, all of which can influence water movement and retention in wood materials (Poletto et al., 2021). The available experiment, however, does not provide direct measurements of density, porosity, permeability or oil retention for the tested specimens. Those characteristics should therefore be regarded as possible explanatory variables rather than measured causes of the observed differences.

White Safari's 47.46% reduction was marginally larger than the reductions for Bush Mahogany and Opepe. This demonstrates that a species can show a large relative response to treatment while still retaining a higher final moisture value. Material selection should consequently consider both the untreated baseline and the treated equilibrium condition rather than relying on percentage reduction alone.

3.4 Engineering Significance and Environmental Considerations

An approximately one-half reduction in equilibrium moisture uptake is potentially important for wood-containing engineering products exposed to humid conditions. Lower moisture uptake can reduce

the magnitude of moisture-driven swelling and shrinkage and may therefore contribute to improved dimensional consistency. Moisture management is also relevant to the durability of natural-fibre and timber-based systems because repeated moisture cycling can promote interface deterioration and cracking (Bazli et al., 2020; Cai et al., 2021).

The findings are most directly relevant to applications in which hygroscopic stability is a design concern, such as interior building products, furniture and protected composite components. They should not be interpreted as proof of suitability for automotive, marine, structural or exterior construction service without additional testing. Those applications impose requirements extending beyond moisture absorption, including mechanical performance, weathering resistance, fire behaviour, coating compatibility, emissions and, where relevant, salt-water exposure.

Environmental qualification is particularly important because the treatment medium is waste engine oil. Reuse may appear attractive as a route for diverting a waste stream from improper disposal, but environmental benefit cannot be inferred from moisture performance alone. Waste oil can contain degradation products and contaminants acquired during service. Before treated wood is adopted commercially, the composition of the oil, potential contaminant migration, leaching under wet conditions, occupational exposure during processing, fire and emissions behaviour, and end-of-life handling should be evaluated.

Accordingly, the present work should be understood as a materials-performance investigation of hygroscopic response rather than a complete environmental endorsement of waste-oil treatment. The strong reduction in moisture absorption establishes a basis for further study, while environmental and durability testing will determine whether the treatment can be translated responsibly into practical engineering applications.

3.5 Statistical Interpretation, Study Limitations and Reproducibility

The reported ANOVA indicated a statistically significant treatment effect at $\alpha = 0.05$. This statistical result is consistent with the large separation between untreated and treated equilibrium moisture values across all three species. Statistical significance, however, should be considered together with practical magnitude. In this case, reductions of 45.71–47.46% are sufficiently large to be relevant to material behaviour, subject to confirmation under repeated and service-specific exposure.

The available manuscript record does not contain the exact ASTM standard designation, specimen dimensions, number of replicates, numerical standard deviations for the equilibrium values, precise conditioning temperature and relative humidity, exposure medium and schedule, or the duration of oil impregnation. These omissions limit independent replication and prevent more detailed statistical reporting. They also mean that comparisons with other studies should be made cautiously because specimen geometry, conditioning history and exposure protocol can materially influence moisture-absorption results.

These limitations do not change the reported direction or magnitude of the observed treatment response, but they define the boundary within which the findings should be interpreted. Future experimental reporting should retain the exact test standard, specimen geometry, replicate count, conditioning environment, treatment duration, oil characterisation and complete ANOVA output so that the work can be reproduced and compared quantitatively with other modification methods.

A further limitation is that the moisture data alone cannot establish long-term durability. Repeated wet–dry cycling, outdoor weathering and leaching tests are required to determine whether the oil remains within the wood and whether the reduction in hygroscopicity persists over service time. These tests are also necessary

to assess whether any performance benefit is offset by contaminant release or changes in surface compatibility.

Taken together, the moisture results provide a coherent basis for treating hygroscopic performance as the principal contribution of the study. The three species responded in the same direction, yet retained distinct equilibrium values, showing why both treatment effect and species response should be considered in material selection. The reported data are therefore most useful as comparative evidence under the stated experimental conditions. Broader claims concerning chemical modification, microstructural change, thermal stability or mechanical enhancement require their own documented experimental methods and measurements and are intentionally not used as evidence for the conclusions of this paper.

4. CONCLUSION

This study examined the effect of waste engine oil impregnation on the hygroscopic behaviour of White Safari, Opepe and Bush Mahogany. Under the reported test conditions, treatment reduced equilibrium moisture absorption from 11.80% to 6.20% for White Safari, from 10.50% to 5.70% for Opepe, and from 10.30% to 5.50% for Bush Mahogany. These changes correspond to reductions of 47.46%, 45.71% and 46.60%, respectively.

The consistency of the response across the three species indicates that waste engine oil impregnation can substantially restrict moisture uptake in the investigated tropical hardwoods. The lower treated equilibrium values and slower reported uptake are consistent with hydrophobic shielding and partial occupation of accessible moisture-transport pathways. Bush Mahogany produced the lowest treated equilibrium value, while White Safari showed the largest proportional reduction.

The findings support further investigation of waste engine oil as a low-cost hydrophobic treatment medium, but they do not establish environmental safety or service qualification. Long-term weathering, repeated moisture cycling, leaching, oil characterisation, fire and emissions behaviour, and application-specific mechanical testing should precede practical deployment. Future work should also report the complete test standard and experimental parameters required for independent replication.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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