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# From Water Rejection to Oil Affinity: Comparative Adsorption of Petroleum Liquids, Water, and Xylene on Modified Sawdust

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ABSTRACT

This study evaluated hardwood unmodified sawdust (UMSD) chemically modified with 0.5 M succinic acid (0.5MSD) as a low-cost sorbent for the selective removal of organic liquids from water. The specific gravities of the tested adsorbates decreased in the order, water > lube oil > m-xylene > diesel > kerosene > gasoline. Batch adsorption and Foster swelling tests were carried out on the adsorbents with the adsorbates. On UMSD, equilibrium capacities (mg $g^{-1}$) followed dual-purpose kerosene (DPK) ≈ premium motor spirit (PMS) (0.23 and 0.227) > xylene (0.15) > water (0.14) > AGO ≈ lube oil (0.09 and 0.089). Modification of sawdust with succinic acid enhanced hydrocarbon uptake while preventing water sorption: the adsorbates DPK, PMS, xylene, AGO, lube oil, and water were identified to be adsorbed to the treated adsorbents with batch adsorption values of 0.32, 0.29, 0.28, 0.27, 0.26, and −0.07 mg $g^{-1}$, respectively. The kinetic test with xylene adsorption showed that the 0.1–0.5 M prepared concentration exhibited rapid initial uptake reaching equilibrium in ~40–50 min; percentage removal decreased from ~88–89% at 0.1–0.2 M to ~79–81% at 0.5 M due to site saturation. The selectivity shift observed for the swelling test showed that UMSD swelled most in water, whereas 0.5MSD exhibited increased swelling in hydrocarbons, especially under agitation. The treated biomass was improved by the successful replacement of surface hydroxyl groups via an esterification reaction. The reaction induces carbonyl and ester functionalities, which reduce hydrophilicity and promote organophilic wetting; mild microstructural changes aid film and capillary uptake of viscous oils.

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## INTRODUCTION

The sorption technique involves the clean-up of an oil spill using sorbents. Sorbents are mainly used for minor oil spills and final clean-up of oil spill leftovers at offshore [1]. Oil sorbents are made from natural and synthetic materials designed to recover oil rather than water. Sorbents collect oil via absorption, adsorption, or a combination of both mechanisms, without forming or breaking chemical bonds. Both processes are based on van der Waals forces, π-electron interactions, and water-repellent effects. Ideally, an adsorbent is naturally organic-loving and water repellent so that it attracts oil and repels water [2].

In adsorption, oil is ideally adsorbed onto the material's surface, whereas in absorption, it involves the assimilation of the liquid molecular species throughout the bulk of the sorbent. It is a bulk phenomenon [3]. In adsorption, we have the 'adsorbent' and the 'adsorbate' [4]. The adsorbent usually has a very high internal surface area that permits adsorption; it is usually a solid. The adsorbate is the substance that accumulates on the adsorbent surface. It is generally liquid. In this study, the adsorbent is the sawdust, while the adsorbate is the hydrocarbon solvents to be removed. Adsorption can be classified into two types: physical adsorption between the adsorbate and the adsorbent, and chemical adsorption.

In physical adsorption, a weak attractive force binds the adsorbate to the adsorbent; this force is called the Van der Waals force. There is no transfer or sharing of electrons between the adsorbate and adsorbent; a new equilibrium adjustment occurs without disrupting the original association of electrons with their respective interacting species. Chemical sorption, chemisorption, involves a chemical reaction between the adsorbent and the adsorbate. New chemical bonds are created at the adsorbent surface [5].

There are two modes of adsorption: Batch flow and Column flow. In a batch flow system, the adsorbent and adsorbate are placed in a vessel and continuously mixed until the desired level; then the mixture is separated by filtration [6]. In a column flow system, the adsorbent is packed in a vertically placed column, and the adsorbate is introduced slowly and allowed to flow through. The rate of flow is then calculated, and the filtrate is collected. The column system does not need shaking or disturbance, unlike the batch system [7, 8]. Adsorption processes are affected by factors such as contact time, nature of the adsorbate, Surface area of the adsorbent, pH, temperature, and adsorbent weight. Contact time significantly affects the adsorption process, influencing both economic efficiency and adsorption kinetics. The longer the time, the more complete the adsorption would be. Therefore, contact time is another performance-governing factor in the adsorption process [9, 10]. The degree of adsorption is dependent on the nature of the adsorbate. Normally, easily liquefiable gases, such as those with a critical temperature, are adsorbed more readily than gases adsorbed onto porous, finely powdered solid adsorbents, as compared to hard, non-porous materials [11]. The adsorption time depends significantly on the adsorbent's surface area. Larger surface area implies greater adsorption capacity [12, 13]. The adsorption capacity of the adsorbent is influenced by its functional groups and structural features [14]. The pH of the solution has a severe effect on the adsorption processes, as hydrogen and hydroxide ions compete with other species that may participate in adsorption. Most studies that discussed the impact of pH, such as Jorge *et al*. [15]; Nourmoradi *et al*. [16]; Mustapha *et al.* [17] and Oyekanmi *et al.,* [18], showed that adsorption is favoured at low pH. When adsorbate removal from the solution is to be enhanced, the adsorbent weight should be increased to increase the number of pores and adsorption sites [19, 20].

Banerjee *et al.* [21] demonstrated the effectiveness of surface modification of sawdust by fatty acids and vegetable oils. Surface modification greatly favoured the removal of petroleum from contaminated seawater. The results showed that oleic acid-grafted sawdust has the highest sorption capacity for both crude and weathered oil. Sawdust, is friendly to the environment; it is biodegradable and will not cause pollution, contrary to polymers. The study also observed that as the light oil fraction of crude oil increases, sorption capacity increases. This was an added advantage of this material (sawdust) in contrast to other sorbents like straw, which cannot retain a large proportion of light oils. The outcome of the present study will show the uptake of hydrocarbon liquids on similar substrates; this is a more diverse set of liquids than fatty acids and vegetable oils, which supports a stronger selectivity claim than simple oil sorption alone.

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Bajpai *et al.* [22], did a work using cost-effective agricultural by-product of sawdust to remove the antibiotic drug ciprofloxacin hydrochloride (CH) from wastewater. The sawdust was characterized by FTIR and SEM analysis, sorbent particles were highly porous with an average pore diameter of about 10 μm, and optimum pH and solid/liquid ratio for the sorption of CH were found to be 5.8 and 2.0, respectively. The experimental equilibrium uptake values were in close agreement with those obtained from the pseudo-second-order equation for initial sorbate concentrations of 10 and 20 mg/L at 33° C. The mechanism is discussed based on the pH of sawdust and the zwitterionic nature of drug CH. Mass transfer analysis was performed using drug uptake data obtained at sorbate concentrations of 10 and 20 mg/L. The used sorbent could be regenerated using a 1.0 mol HCl solution with a regeneration efficiency of nearly 85%. The present study moves sawdust application away from dissolved pharmaceutical removal toward selective organic-liquid uptake and xylene kinetics relevant to oil and water remediation.

Nwufo *et al.,* [23], studied the adsorptive capacities of cost-effective raw hardwood and softwood sawdust, and the results were compared. The work found that softwood has better adsorptive capacity, with adsorption capacity dependent on the sawdust mesh size, oil concentration, sawdust quantity, and the contact time between the oil and sawdust. It was observed that the maximum oil uptake by both adsorbents occurred at 120 and 150 minutes, respectively, across all results. This work concludes that softwood sawdust is more effective in oil-water cleanup than hardwood sawdust; this was attributed to its lower density and higher porosity. This work will investigate the use of succinic acid to modify hardwood sawdust to improve its adsorption properties and demonstrate the effects of the 0.5 M succinic acid-modified hardwood adsorbent.

Although sawdust has been studied as a low-cost sorbent and surface modification has been shown to improve oil uptake, there remains limited comparative evidence on whether succinic-acid modification can transform hardwood sawdust from a water-favouring biomass into a hydrocarbon-selective sorbent across petroleum liquids, water, and a model aromatic adsorbate such as xylene, while also clarifying the roles of swelling behaviour and contact-time kinetics.

## 2.0 Materials and methods

### *2.1 Sample preparation*

The hardwood sawdust used for this work was collected from the wood sawmill industry; the hardwood was specifically African mahogany (*Khaya ivorensis).* The preparation and characterization of the wood sawdust were carried out following the method adopted by Nwufo *et al.* [23]. The sawdust was first washed with warm water to remove dirt, fungus, and other foreign materials, and then sun-dried for a full day. The sawdust was oven-dried at 110 °C for 4 hours until a constant drying weight was obtained. Afterwards, it was sieved to not more than 0.425 μm particle size and stored for modification and characterization.

### *2.2 Modification of the sawdust using succinic acid*

Following the method of Mutiara *et al.* [24], four sets of constant weight (10 g) of the dried sample of sawdust were put in a flat-bottomed flask, soaked, and mixed in 200 ml of succinic acid solution of varied concentrations (0.5 M, 0.3 M, 0.1 M, and 0.05 M). The mixture was stirred continuously under reflux for 4 hours at 75 ºC, then cooled to room temperature, filtered through Whatman 42 filter paper, washed with distilled water to obtain a pH of 6-7 and filter, and oven-dried at 120 °C for 12 hours until a constant drying weight was obtained. Then, samples were collected for characterisation and used for the investigation.

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### *2.3 Determination of the density of adsorbates*

Density analysis was carried out on the adsorbates: Xylene, DPK, gasoline PMS, AGO, and lube oil. This was done promptly upon receipt of the samples in the laboratory to minimise loss of light ends. Containers remained closed during temperature equilibration; samples were gently mixed to ensure homogeneity without entraining air. A clean hydrometer cylinder was used to fill the liquid to be measured, and surface bubbles were removed with lint-free tissue. A calibrated API gravity thermohydrometer was lowered carefully to float freely, without contacting the cylinder walls or bottom; a slight spin dislodged clinging bubbles. After thermal and buoyancy equilibrium, the hydrometer scale and the sample temperature were read at the correct meniscus (bottom for clear liquids; top for opaque/dark liquids). Observed readings of API gravity and temperature were recorded in duplicate, and the average value was taken. The API gravity values were corrected to the reference temperature of 60 °F (15.56 °C) using API MPMS Ch. 11.1 API/ASTM petroleum correction tables; results were reported as API gravity at 60 °F [25, 26].

The API gravity at 60/60 °F, and density (ρ) at 60 °F (kg·m$^{-3}$) of the substances were obtained as shown in Equations 1 and 2, respectively:

$$API\ gravity\ @\ 60\,^{o}F = \frac{141.3}{S.G\ @60\ °\text{F}} - 131.3 \qquad (1)$$

$$\rho\ of\ substance = S.G\ of\ substance\ x\ \rho\ of\ equal\ volume\ of\ water \qquad (2)$$

### *2.4 Determination of adsorption capacity in a static regime*

The adsorption capacity of the unmodified and acid-modified sawdust was determined using the following hydrocarbon solvents: Diesel /AGO, gasoline/PMS, dual-purpose kerosene (DPK), lube oil, and xylene. It was carried out following the method of Cadigena *et al.* [27]. In this method, a small glass mesh bucket with tiny holes at the bottom was first weighed empty, and its weight was recorded. 0.2 grams of the adsorbent (sawdust), carefully wrapped in a net, was placed in a small glass mesh bucket; the weight of the adsorbent in the mesh bucket was recorded. Then, a beaker was filled with 50 ml of hydrocarbon solvent, and the glass mesh bucket with the wrapped sample was placed into the beaker containing the hydrocarbon solvent for 30 minutes (Plate 1). Afterwards, the mesh bucket with the sample was lifted vertically from the beaker, and excess solvent was allowed to drip for a period of 15 seconds. The final weight was recorded by weighing the mesh bucket and the sample after the dripping. The test was carried out with the various solvents, PMS, DPK, lube oil, xylene, AGO, and water.

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Plate 1: Adsorption capacity experiment in static regime

### *2.5 Determination of the foster swelling*

Foster swelling test was carried out using the methods of Burgentzle *et al.* [28], Paiva & Morales [29], and Ewuzie *et al*. [30]. The unmodified sawdust and the 0.5 M succinic acid-modified sawdust were both used for the test. A measured amount of 0.5 g of the adsorbent was added to a 50 ml calibrated glass tube (Plate 1), and the volume occupied by the sawdust was noted. Exactly 50 ml of each hydrocarbon solvent was then added to the glass tube containing the sawdust, and the mixture was undisturbed and allowed to stand for a period of 24 hours (Plate 2). The new volume of the adsorbent was recorded. The tube was agitated, allowed to stand for another 24 hours unperturbed, and the final volume was recorded after 24 hours. The test was repeated using each solvent (PMS, DPK, lube oil, AGO, xylene, and water).

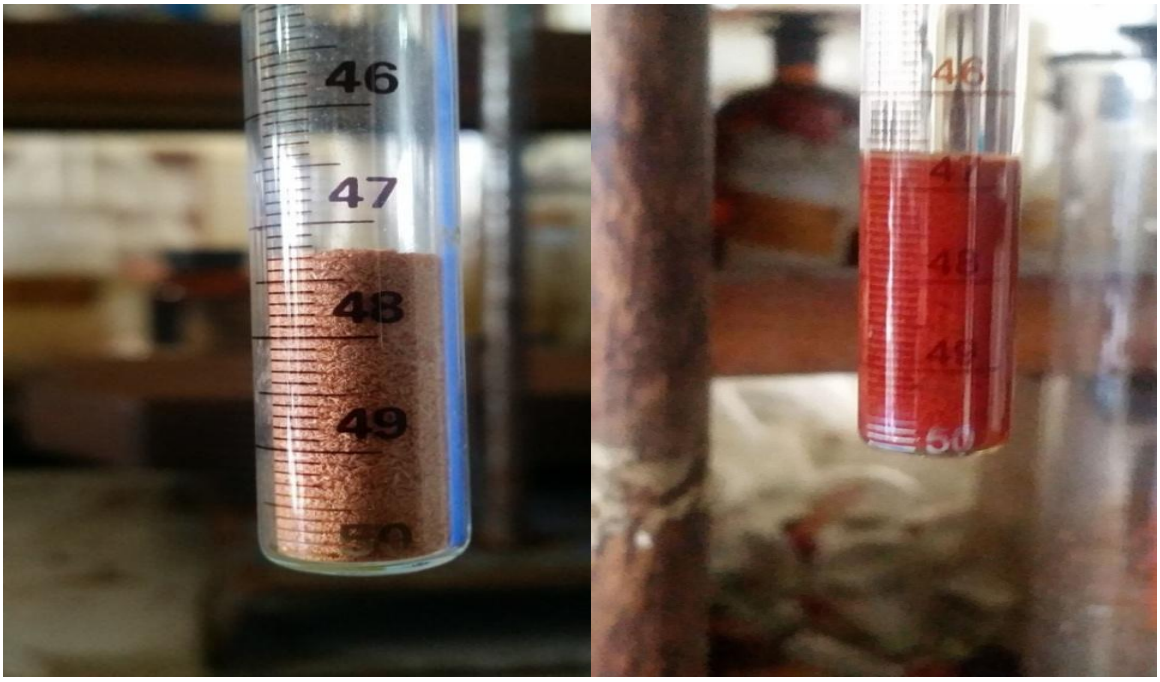


Plate 2: Initial volume of sawdust (A) and Final volume with solvent after 24 hours (B)

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### *2.6 Batch adsorption of xylene*

The experiment was carried out following the method of Nordine *et al.* [31]. The batch adsorption experiments were conducted at a controlled temperature by adding a known weight (0.2 g) of sawdust into some 250 ml glass stoppered conical flasks attached to a mechanical shaker. The experiment was carried out by shaking 0.2 g of the adsorbent (sawdust) mixed with 100 ml of different concentrations of xylene at 300 rpm (revolutions per minute). Five (5) concentrations (0.5, 0.4, 0.3, 0.2, and 0.1 M) of xylene were used, and the shaking also varied (15, 30, 60, 90, 120 mins).

### *2.7 Determination of the amount of xylene adsorbed by the modified sawdust*

UV/Vis Spectrophotometric analysis was carried out to determine the concentration of xylene remaining after batch adsorption at 15, 30, 60, 90, and 120 min. During the study, the filtrates after batch adsorption were collected in cuvettes and placed in a UV/Vis Spectrophotometer (Drawell DU-8200) at wavelengths of 267–307 nm. The xylene sample in the cuvette absorbs UV or visible radiation, and the xylene concentration in solution was determined. The amount of light that was absorbed by the xylene solution depended on the concentration of xylene in the solution, the path length of the cuvette, and how well the xylene absorbed the light at a specific wavelength. Transmittance indicates the concentration of the analyte in the sample [32].

## 3.0 Results and discussions

The API gravity of the substances was obtained as explained in the previous section, and the S.G of the substances was evaluated using Equation 1. Figure 1 shows the S.G of the organic solvents that are considered in the study.

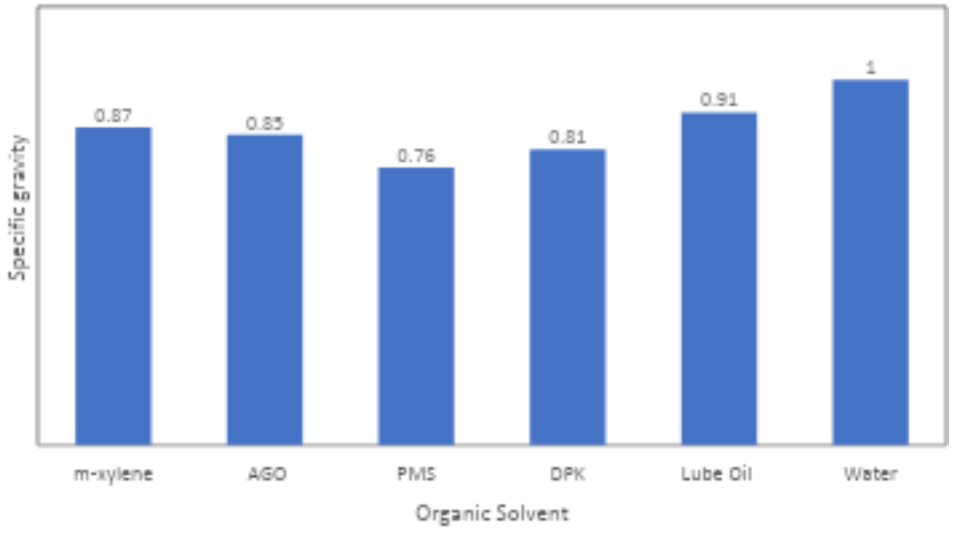


Fig. 1. Specific Gravities of Adsorbates

### *3.1 Specific density of solvents*

Figure 1 shows the specific gravity or density (SG) relative to the adsorbates. Their values, presented in decreasing order, are Water > Lube oil > m-Xylene >Diesel (AGO) > Kerosene (DPK) > Gasoline (PMS). Specific gravity (density relative to water) depends on how tightly molecules pack and on molecular mass and structure. The causes of the observed spread in the specific gravity of the adsorbates may be because:

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higher average chain length or more complex molecules give higher density (lube oil contains large, high molecular weight hydrocarbons and gives higher specific gravity); aromatic rings (xylene) are relatively dense and highly polarizable; straight-chain alkanes (parts of kerosene) pack differently. Branched hydrocarbon isomers reduce packing efficiency, thereby decreasing the liquid density; this explains gasoline's low density. The hydrocarbon commercial fuels used in this study are mixtures of hydrocarbons as follows: gasoline contains many light, branched low-molecular-weight components; diesel and kerosene contain heavier fractions, and lubricant base stocks are much heavier [33]. Among the organic compounds or substances analysed here, xylene is selected for further investigation because of its pure state among the other compounds that are said to be mixtures of different hydrocarbon compounds.

### *3.2 Effect of contact time on the removal of xylene*

Figure 2 shows the adsorption performance of the modified sawdust for the removal of xylene from aqueous solution at different initial concentrations (0.1 – 0.5 M). The results indicated a clear dependence of the percentage removal on both contact time and the initial concentration of the adsorbate in the solvent. From Figure 2, the earliest contact time tested is 10 min, and it gave the lowest % removal for all xylene concentrations, with a rapid uptake phase at 20 min. The 40-50 min is the equilibrium time, and only a very small percentage removal is observed afterward. The adsorption occurred optimally at 60 min; removal is about **94%** for 0.4–0.5 M, about **93%** for 0.3 M, about **91%** for 0.2 M, and about **77%** for 0.1 M. This shows that adsorption increased with contact time, then approached a near-plateau at longer times.

At lower concentrations, the adsorbent surface provided sufficient active sites to bind nearly all xylene molecules in solution, resulting in high removal efficiency. However, as concentration increased, the relative efficiency declined due to progressive site saturation and possible multilayer interactions that were less energetically favourable; these may serve as the reason for the inverse relationship between initial concentration and percentage removal of the adsorbates; these findings are consistent with the outcome of the works of Bethrand *et al.* [34] and Ekwere [35]. The observed equilibrium time of approximately 40 min further underscores the potential of succinic acid-modified sawdust as a low-cost, efficient adsorbent for xylene removal from aqueous solutions.

It was observed that the percentage removal increased gradually with an increase in time. The xylene uptake was rapid at time 15 min within the period of this investigation. As time progresses, and as concentration of xylene is increased, the surface area diminished because sites became used up and the adsorption started in pores, which signifies the possible monolayer coverage on the surface of the sawdust by xylene molecules in connection with the work reported by Mane *et al.* [36]. Consequently, the xylene adsorption became slow and weak. From the graph in Figure 2, the reaction shows the potential to continue after the highest observed contact time in this study, 120 min. Also, subsequent studies have shown that as contact time is further increased, adsorption percentage removal tends to level off and eventually decrease because of adsorption-desorption equilibrium [37, 38]. The concentration of xylene adsorbed within the study period was measured with the use of a UV/Vis Spectrophotometric analysis, and the results of the analysis are shown in Figure 2.

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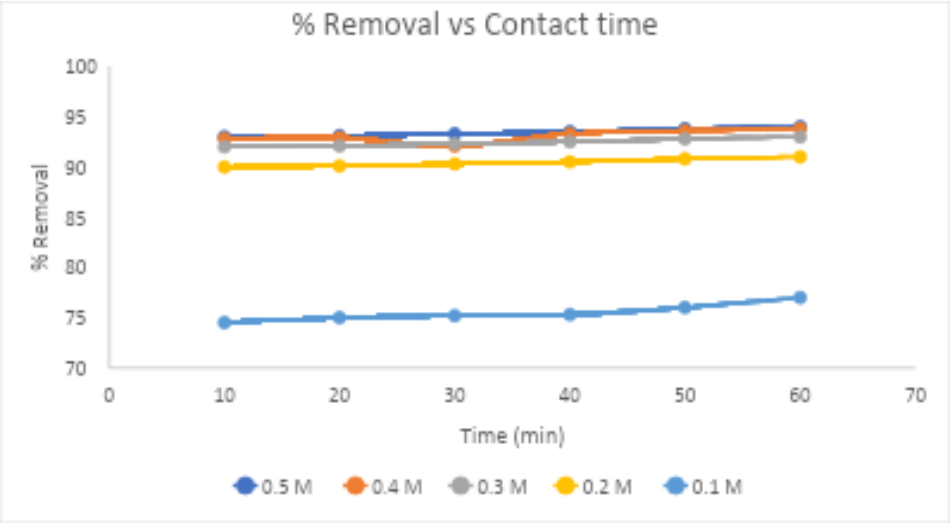


Fig. 2. Effect of contact time on adsorption for various concentrations of Xylene using 0.5 M succinic acid modified sawdust.

### *3.3 The Swelling capacity of unmodified and modified sawdust*

The swelling capacities of unmodified sawdust (UMSD) and 0.5 M succinic acid-modified sawdust (0.5MSD) were evaluated before and after agitation in the different adsorbates, namely water, lube oil, AGO (diesel), xylene, PMS (gasoline), and DPK (kerosene). The results presented in Figure 3 reveal marked differences in swelling behaviour depending on solvent polarity, surface modification, and agitation.

Before agitation, UMSD exhibited preferential swelling in polar media, with water and DPK (having intermediate polarity) showing the highest capacities (0.296 mL and 0.59 mL, respectively). At the same time, nonpolar hydrocarbons such as lube oil, AGO, xylene, and PMS all recorded lower but nearly identical capacities in the range of 0.11–0.15 mL. In contrast, 0.5 M sawdust (SD) displayed a shift in behaviour. Although DPK still exhibited the highest swelling (0.63 mL), water swelling was reduced (0.259 mL), while slight but uniform improvements were observed in AGO, xylene, PMS, and lube oil (0.17–0.19 mL). This suggests that succinic acid modification altered the surface chemistry of the sawdust, making it less hydrophilic but more organophilic [21].

The set-ups were agitated, and there was an observable increase in the swelling of both UMSD and 0.5 M modified substrate. 0.296 and 0.480 mL were determined for the adsorptions before and after agitation, respectively; this shows that agitation is significant in the process. The observable change in PMS was 0.15 to 0.315 mL, and AGO, xylene, and lube oil were moderate at 0.19-0.22 mL. DPK remained nearly unchanged, with values stable around 0.63 mL, indicating that its interaction with UMSD was already near saturation before agitation [39]. For 0.5 M SD, the effect of agitation was more pronounced in hydrocarbons. PMS, AGO, xylene, and lube oil have volumes increased to 0.48, 0.35, 0.41 and 0.296 mL, respectively, showing greater compatibility with the modified surface. The DPK again recorded the highest swelling capacity (0.67 mL), while water showed a comparatively lower (0.296 mL) value. This behaviour confirms that modification enhanced the affinity of sawdust for organic adsorbates, particularly nonpolar hydrocarbons, while slightly reducing its swelling in water.

Overall, these findings demonstrate that succinic acid treatment shifted the interaction profile of sawdust from strongly hydrophilic and increased its relative affinity for hydrocarbon liquids. Adsorption of polar

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solvents such as water was favoured with UMSD, while the acid-modified sawdust exhibited enhanced compatibility with hydrocarbons, especially during agitation. The intermediate polarity and efficient penetration of DPK into the adsorbent structure was indicated in its consistent high swelling ability in both adsorbents. These results highlight the dual role of chemical modification and agitation in tailoring the adsorption potential of sawdust for specific classes of pollutants.

Figure 4 compares the equilibrium uptake of six liquid adsorbates by unmodified sawdust (UMSD) and 0.5 M succinic acid–modified sawdust (0.5MSD). The adsorption capacity for UMSD followed the decreasing order: DPK ≈ PMS (0.23 and 0.227) > xylene (0.15) > water (0.14) > AGO ≈ lube oil (0.09 and 0.089) [40]

Investigation with the modified adsorbent showed that adsorbate uptake decreased in the order: DPK > PMS > xylene > AGO > lube, and water was net-repelled (-0.07). This gave a relative gain in adsorption value from UMSD treatment to treatment with 0.5MSD of DPK (+39%), PMS (+28%), xylene (+87%), AGO (+200%), and lube oil (+192%); water decreased by ~0.21 mg $g^{-1}$ (from +0.14 to −0.07). These changes may have been due to an intentional switch in surface preference from hydrophilic to hydrophobic interaction [41] [42].

### *3.4 Chemical origin of the selectivity switch*

The observed reduction in hydrogen-bond density and surface polarity weakens water affinity and improves dispersion interactions with non-polar liquids. This is a significant effect of succinic acid's reaction with the lignocellulose components, which masks a fraction of surface hydroxyls and introduces –COO– groups, forming esters. Prior work on succinic anhydride modification of cellulose reports the same chemical changes and an ensuing rise in oil sorption, consistent with the observations [43].

Foster swelling test was carried out, and the results are as shown in Figure 3, for the adsorbates and adsorbent considered in this study. The adsorption capacity of the adsorbents were measured and the results are as shown in Figure 4.

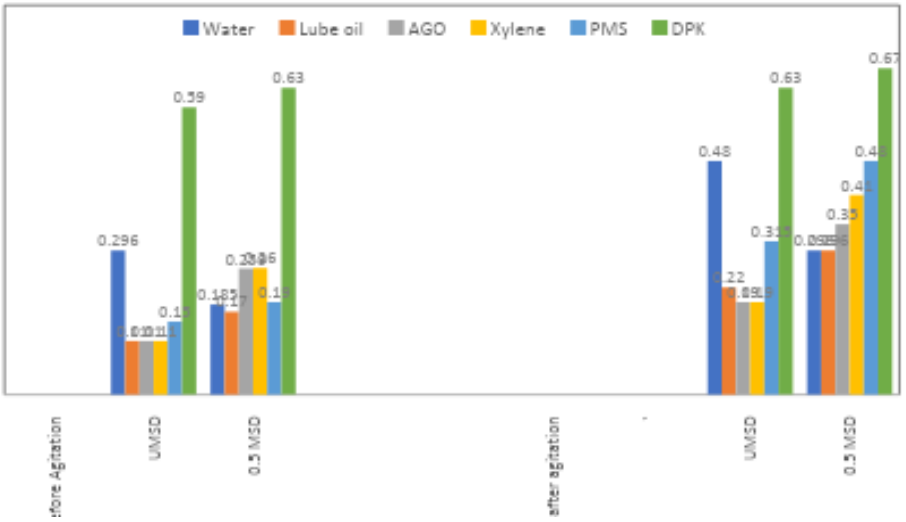


Fig. 3. Total swelling capacity of unmodified sawdust and 0.5 M acid-treated sawdust before and after agitation

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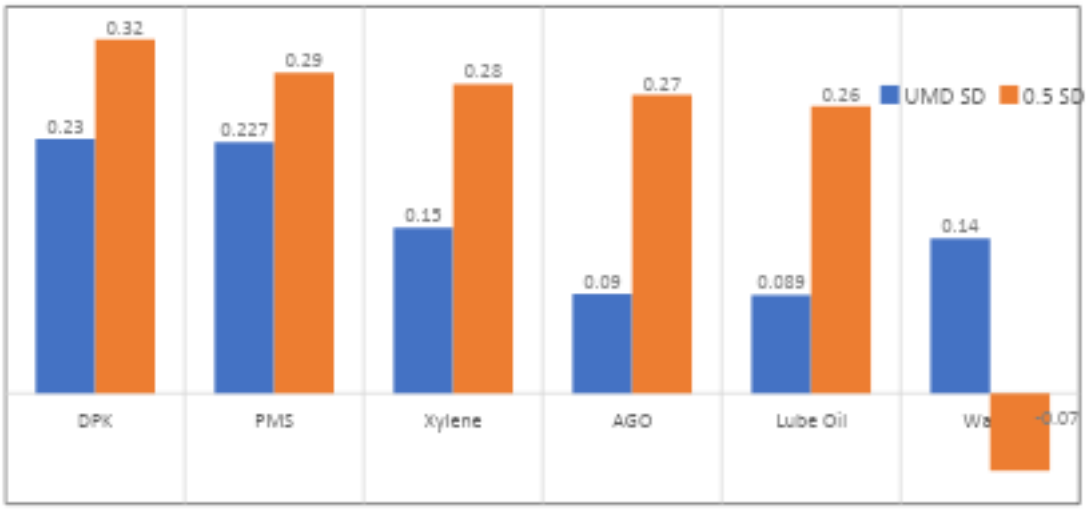


Fig.4. Total adsorption capacity with various adsorbates using UMSD and 0.5 MSD

### *3.5 Wettability and water suppression*

The negative gravimetric change for water on 0.5MSD reflects strong hydrophobization: the modified surface no longer stabilizes a water film. It may shed loosely held moisture during handling; the findings are in accordance with the work of Jing *et al.* [44] *as* acylated and relatedly modified cellulosic show substantial increases in water contact angle, corresponding to decreases in water amount.

### *3.6 Textural contributions*

In addition to the chemical changes that occurred during succinic acid modification of lignocellulose, mild organic-acid modification can break down fibers into fibrils, thereby increasing surface roughness or accessible porosity. Even when Brunauer–Emmett–Teller (BET) area changes are modest, roughness promotes film adsorption and capillary wicking of viscous oils once the surface energy is lowered. Previous work has shown that citric-acid-modified cellulose surfaces increase wetting and oleophilic morphologies, providing a mutually consistent mechanism for the high amounts of AGO and lube oil adsorbed [45].

### *3.7 Adsorbate-specific trends*

Among the adsorbates tested on the 0.5 M modified sawdust, DPK was identified with the highest adsorption capacity, followed by PMS, xylene, AGO, and lube oil (Figure 4). The slightly higher uptake of kerosene relative to gasoline may be due to the lower volatility losses and a better cohesive-energy match to the organophilic surface. Xylene's substantial rise is due to π–π–type interactions between aromatic adsorbates and lignin aromatic domains exposed within the sawdust matrix. These interactions are well documented for lignin-containing materials and aromatic solutes [46].

### *3.8 Comparison with related studies*

The magnitude and direction of the changes in Figure 4 agree with prior reports on hydrophobized lignocellulosics used as oil sorbents. Succinic anhydride-modified celluloses exhibit markedly improved oil absorbency compared with their native forms, mirroring our shifts for all petroleum fractions (light and

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heavy). Studies [47, 48] have shown that acetylated fibers and peels convey significantly higher sorption of organophobic components than their untreated biomass, indicating that conversion of surface –OH groups to esters is a reliable route to hydrocarbon selectivity. So, our reports on mild acid-treated sawdust also showed upward shifts in the adsorption capacity of oil or organic adsorbates, even though typically smaller than those achieved by full esterification; our 2–3× increases for AGO and lube oil sit at the high end of this spectrum, suggesting that 0.5 M succinylation provides both chemical and microstructural benefits [49].

In practical terms, 0.5MSD delivers two desirable outcomes for oil-in-water remediation: Near-uniform capacity for chemically diverse organic compounds, from aromatics to heavy hydrocarbon distillates, and decisive rejection of water, which translates into high oil and water selectivity under mixed-phase conditions. These results, supported by the known chemistry of lignocellulose reactions with succinic acid to form half-esters, position 0.5MSD as a promising, low-cost adsorbent for selective oil capture and polishing applications [50].

## CONCLUSION

In this study, hardwood sawdust was modified with succinic acid. This produced a transition from hydrophilic to hydrophobic behaviour and improved the removal of organic adsorbates. Analysis of the adsorbate densities showed in decreasing order: water > lube oil > m-xylene > AGO > DPK > PMS. Kinetic tests with 0.5 M succinic acid modified sawdust showed that a rapid uptake phase characterised the first 20 minutes, and within 40-50 minutes, an approach to equilibrium. Such that, at higher initial concentrations, the percentage removal decreased (≈88–89% at 0.1–0.2 M down to ~79–81% at 0.5 M). The changes in the physical behaviour of the adsorbents were also investigated using Foster swelling experiments; unmodified sawdust preferentially uptakes polar media, while the modified sawdust showed suppressed water swelling but enhanced uptake of organic and nonpolar components. The effect was intensified by agitation. At equilibrium, succinic acid reactions with lignocellulosic biomass delivered broad, near-uniform capacities for diverse organics (≈0.26–0.32 mg $g^{-1}$) alongside net water rejection. This study demonstrates that sawdust modified with 0.5 M succinic acid is a low-cost, optimizable sorbent that is characterized by fast kinetics, high percentage removals at practical concentrations, and strong oil-in-water selectivity.

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## CONFLICT OF INTEREST STATEMENT

The authors declare that there is no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

## AUTHOR'S CONTRIBUTIONS

Idongesit Ekpo and Nwamaka carried out the research, Ifiok Ekwere and Idongesit Ekpo managed the literature search and prepared the manuscript; All authors proofread the manuscript before publication.

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