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Characterization and Application of Activated Carbon from Palm Oil Fuel Ash (POFA) Activated with H_3PO_4 for Surfactant Adsorption in Household Laundry Waste: Review Article

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ABSTRACT. The rapid growth of laundry businesses has increased the generation of wastewater containing surfactants, particularly Linear Alkyl Benzene Sulfonate (LAS), which can negatively affect aquatic ecosystems if discharged without proper treatment. Adsorption is considered one of the most effective and economical methods for surfactant removal. Palm Oil Fuel Ash (POFA), a by-product of the palm oil industry with high silica content, has attracted attention as a potential precursor for activated carbon. However, studies discussing the characteristics and adsorption performance of H_3PO_4-activated POFA for surfactant removal from household laundry wastewater remain limited and scattered. This review was conducted by analyzing 30 national and international publications published between 2021 and 2025, collected from Google Scholar, ScienceDirect, and other scientific databases using keywords related to POFA, H_3PO_4 activation, surfactants, and adsorbents. The reviewed literature shows that H_3PO_4 activation significantly improves the physicochemical properties of POFA by increasing surface area and pore volume, introducing active functional groups, and enhancing its amorphous structure. Characterization through BET, FTIR, and XRD analyses confirms its suitability as an adsorbent. Previous studies also reported high removal efficiencies for surfactants, COD, BOD, phosphates, and heavy metals, indicating the effectiveness of activated carbon-based adsorption processes. In conclusion, H_3PO_4-activated POFA has strong potential as an environmentally friendly and value-added adsorbent for laundry wastewater treatment. Further experimental studies are required to optimize activation conditions and evaluate adsorption performance under practical operating conditions.

1. INTRODUCTION

Micro, small, and medium sized businesses (MSMEs) in the laundry industry have grown significantly in the last several years. This is in line with the growth rate and the increasingly practical and efficient lifestyle of the community. Laundry is an activity that begins with washing clothes, drying them, and ironing them. The increase in the number of laundry services is inversely proportional to the amount of liquid waste produced at the end of the activity. The rapid development of laundry businesses in various regions has not been accompanied by the implementation of adequate liquid waste management, especially that which comes from detergent chemicals [1].

Water bodies will be impacted by the untreated disposal of laundry waste, which will lower oxygen levels, cause eutrophication, and disturb aquatic biota. Effective solutions are needed to lower the content of surfactants and other chemicals before they are released into water bodies since the fast expansion of laundry services makes this problem worse [2]. Due to its biodegradability, LAS (Linear Alkyl Benzene Sulfonate) is currently the most popular surfactant in the anionic surfactant group. Detergent residues can harm aquatic life and degrade water quality to some extent. The foam produced by detergents blocks light and air from entering, which hinders microalgae from photosynthesizing [3].

To address this problem, techniques are needed to reduce surfactant levels in laundry wastewater. Various treatment methods have been developed, including membrane filtration, coagulation flocculation, and adsorption. The utilization of various membrane types, such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, is fundamentally a potential option in water treatment due to their high selectivity [4]. However, the mechanism of membranes, which retains particles based on pore size, becomes a major drawback when applied to remove surfactants like Linear Alkyl Benzene Sulfonate (LAS). The inherent nature of surfactant molecules to accumulate on the surface and within membrane pores leads to severe membrane fouling. Consequently, permeate flow is hindered, resulting in a decline in separation efficiency and increased operational costs due to frequent cleaning and membrane replacement.

In addition to membrane technology, coagulation flocculation methods also possess significant limitations in removing surfactant residues. The coagulation process relies on chemical particle destabilization, the success of which depends heavily on operational factors such as coagulant type, dosage, mixing intensity, and pH control. Furthermore, the flocculation stage requires the addition of chemical flocculants to aggregate small particles into larger flocs [5]. This high dependence on chemicals generates a considerable amount of sludge, which requires further treatment and disposal. Therefore, adsorption is considered one of the simplest and most efficient techniques for surfactant removal because it has minimal harmful side effects and is relatively economical. The type of adsorbent used significantly impacts adsorption effectiveness therefore, materials with high adsorption capacity, low cost, and easy availability continue to be widely researched [6].

POFA, a solid waste product from the palm oil industry that contains substantial levels of SiO_2, Al_2O_3, and Fe_2O_3, is one substance that exhibits remarkable potential. This composition makes POFA a potential raw material for activated carbon that not only absorbs pollutants but also increases the added value of palm oil industry waste [7]. Due to its high SiO_2 content, it is a promising candidate for development as activated carbon [8]. Furthermore, chemical activation using H_3PO_4 has been reported to improve the pore structure and surface properties of activated carbon, thereby enhancing its adsorption performance [9].

Although numerous studies have investigated the use of activated carbon and various adsorbents for wastewater treatment, information regarding the characteristics and adsorption performance of H_3PO_4 activated POFA for surfactant removal from household laundry wastewater is still scattered across different studies. Therefore, a comprehensive review is needed to summarize the characteristics of H_3PO_4 activated POFA and evaluate its potential application for surfactant adsorption.

This review article aims to discuss the characteristics of H_3PO_4 activated POFA and evaluate its potential application for surfactant adsorption in household laundry wastewater based on findings reported in previous studies.

Table 1. Chemical Elements (Palm Oil Fuel Ash) POFA

No.	Chemical Elements	Persentage (%)
1.	Silicon dioxide (SiO_2)	64,36
2.	Aluminium oxide (Al_2O_3)	4,36
3.	Iron oxide (Fe_2O_3)	3,41
4.	Calcium oxide (CaO)	7,92
5.	Magnesium oxide (MgO)	4,58
6.	SO_3	0,04
7.	K_2O	5,57

Due to its high SiO_2 content, POFA is considered a promising precursor for activated carbon production. The high silica content provides numerous active sites that can interact with adsorbate molecules [10]. However, to enhance its adsorption capacity, POFA requires an activation process. Important steps in the production of activated carbon to increase surface area and form pore structures in carbon materials can be carried out through activation. Activation can be done physically or chemically, but chemical activation is more commonly chosen because it significantly influences the surface area, pore volume, and functional groups of the adsorbent. Activating agents such as H_3PO_4, $ZnCl_2$, and NaOH work through different mechanisms to open the internal carbon structure, increase porosity, and generate active sites that play an important role in the adsorption process.

Previous studies have reported various applications of POFA. POFA has been utilized as a supplementary material to improve the compressive strength of concrete [11] and as an adsorbent for the removal of heavy metals and other pollutants from wastewater [12]. Several studies have also investigated the use of POFA based adsorbents for the removal of Remazol Brilliant Blue R dye from batik industrial wastewater [10]. However, studies specifically focusing on the characteristics and adsorption performance of H_3PO_4 activated POFA for surfactant removal from household laundry wastewater remain limited. Therefore, a comprehensive review is needed to summarize the characteristics and adsorption performance of H_3PO_4 activated POFA, with particular emphasis on its application for surfactant removal. This review article aims to discuss the characteristics of H_3PO_4

activated POFA and evaluate its potential application for surfactant adsorption in household laundry wastewater based on findings reported in previous studies.

2. METHODS

The literature review approach, which entails gathering and compiling primary data from numerous sources pertinent to the subject of study, was used to write this article. Data was collected from open access national and international literature through scientific websites and databases such as Google Scholar, ScienceDirect, and other scientific sources published between (2021-2025). The search process was conducted using the keywords Palm Oil Fuel Ash (pofa), H_3PO_4 activator, surfactant, and adsorbent. A total of 30 pieces of literature were analyzed in this study. Reference management and organization were carried out with the help of Mendeley software.

3. RESULTS AND DISCUSSION

Table 2 presents the findings from five selected journals. Each journal was obtained based on the results of screening titles, abstracts, publication years (2021-2025), and relevance to the topic. The comparison can be seen in the following table:

Table 2. Summary of Selected Literature

No.	Name	Method	Result
1.	Bouchelkia et al. 2023	Chemical activation using H_3PO_4 with variations in concentration and temperature; characterization using BET, FTIR, and SEM.	Highly porous activated carbon with high adsorption capacity for textile wastewater dyes.
2.	Amna et al. 2024.	Oil palm trunk carbonized and activated using H_3PO_4 (5–15%); analysis of moisture, ash, and fixed carbon.	Fixed carbon increased up to 99.5% and moisture reduced, indicating high-quality activated carbon for wastewater adsorption.
3.	Sylvia et al. 2021.	Characterization of palm oil bottom ash using SEM and FTIR; preliminary adsorption tests for organic pollutants.	Bottom ash shows adsorption potential; chemical activation recommended to enhance capacity.
4.	Simparmin Br Ginting et al. 2024.	Chemical activation of POFA using H_3PO_4 followed by Cu/Zn impregnation; BET, SEM, FTIR analysis.	Significant increase in porosity and higher β-carotene adsorption than non activated POFA.
5.	Sugito et al. 2025.	Coagulation using PAC combined with activated carbon adsorption; COD, phosphate, and surfactant analysis.	PAC and activated carbon combination reduced COD by >80% and significantly lowered surfactant levels.
6.	Yusoff et al. 2021.	Chemical activation of oil palm fronds using H_3PO_4 with varied carbonization temperatures and impregnation ratios.	Highly porous activated carbon effective for organic contaminant adsorption; applicable to laundry wastewater.
7.	Riyanto et al. 2022.	Carbonization at 400 °C (1 h); H_3PO_4 activation (1:3–1:7, 24 h); activation heating at 400–800 °C; FTIR, XRD, TEM.	Nano activated carbon (22–36 nm) from annatto seed peels with amorphous structure under optimal conditions (500 °C, 1:5 w/w).
8.	Novita et al. 2022.	The adsorption process using eggshells with COD, BOD, and LAS analysis and variations in adsorbent size, namely 50, 100, 150, 200 mesh, variations in time, namely 30, 60, 90, 120 minutes, and the LAS adsorption isotherm model.	The optimum adsorbent size for reducing BOD and LAS levels is 150 mesh, which can reduce BOD levels by 80% and LAS levels by 38.85%, and 200 mesh, which can reduce COD levels by 67.34%. The optimum time for reducing COD and BOD levels is 90 minutes, which can reduce BOD levels by 80% and COD levels by 74.5%, and 120 minutes, which can reduce LAS levels by 35.67%. The

			appropriate LAS adsorption isotherm is the Freundlich equation with R2 of 0.95023.
9.	Kharabsheh & Bdour. 2025.	The adsorption process was carried out using zeolite and activated carbon. The adsorbent dosage varied between 0.1, 0.5, 1.0, 1.5, and 2.0 grams, the contact time varied between 5, 10, 30, 50, 60, 80, 100, and 120 minutes, and the temperature varied between 25°C and 45°C at a pH of 6.8. This study also compared two types of adsorbents, namely natural zeolite from Jordan and activated carbon, to see their effectiveness in absorbing SDBS (Sodium Dodecyl Benzene Sulfonate) from car wash wastewater. The analysis was carried out using the Langmuir and Freundlich isotherm models, as well as the pseudo second order kinetic model to determine the most appropriate adsorption mechanism and capacity.	The research results show that activated carbon has the highest adsorption efficiency of 99.21% at a dose of 2.0 grams and a time of 50 minutes, while natural zeolite achieves a maximum efficiency of 95.79% at a dose of 2.0 grams and a time of 60 minutes. Based on the isotherm results, the Langmuir model provides the best fit for activated carbon (R^2 = 1.00), while zeolite shows a good fit with both the Langmuir and Freundlich models (R^2 = 0.99 and 0.98).
10.	Veli et al. 2021.	This study used PAn/SH (Polyaniline Sunflower Hulls) adsorbent composites. The variations used include pH (4, 8, and 12), reaction time (5, 77.5, and 150 minutes), adsorbent dose (0.3, 0.9, and 1.5 g/100 mL), and stirring speed (50, 125, and 200 rpm). The optimization process was carried out using the Response Surface Methodology (RSM) with the Box Behnken Design (BBD).	Research shows that PAn/SH (Polyaniline Sunflower Hulls) composite adsorbents have a high ability to remove pollutants from laundry wastewater. Surfactant removal efficiency reaches 99%, while COD reduction reaches 74% under optimal conditions, namely pH 6, reaction time of 150 minutes, adsorbent dose of 1.48 grams, and stirring speed of 50 rpm.
11.	Wulandari et al. 2023	This study used activated carbon from water hyacinth (Eichhornia crassipes). The adsorption process was carried out with variations in adsorbent mass of 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 mg and variations in contact time of 15, 30, 45, 60, 75, 90, 105, and 120 minutes.	DEG activated carbon has the ability to reduce phosphate levels in artificial waste by 78.35% and anionic surfactants in detergent waste by 52.99% at an optimum time of 90 minutes and an adsorbent mass of 25 mg.
12.	Kurnia & Nurul, 2021.	This study used the adsorption method with commercial activated carbon in an upflow stream with flow rate variations of 5 ml/minute, 10 ml/minute, and 15 ml/minute with height variations of 10 cm, 15 cm, and 20 cm and sampling times of 2 hours, 4 hours, 6 hours, 8 hours, 10 hours, and 12 hours.	The highest efficiency results were obtained from phosphate removal of 99.07% and anionic surfactant (detergent) of 95.35%. The optimum flow rate was 5 ml/minute with a height of 15 cm for phosphate and 20 cm for anionic surfactant (detergent). The appropriate model was Freunlidch, with an R2 value of 0.9418.
13.	Nordin et al. 2022.	The adsorption process in this study was conducted in batches, with the	Optimal adsorption conditions were obtained at a pH of two (2.0), an adsorbent dose of

		optimum parameters studied including pH, adsorbent dose, and contact time. (pH variations: 2.0, 2.5, 3.5, 4.0, 4.5, and 5.0) (Variations in POFA adsorbent mass dose to obtain adsorbent concentrations of 5, 10, 20, 40, 60, 80, 100, and 150 g/L) (Variations in contact time of 2, 4, 6, 10, 15, 20, and 30 minutes) and a constant stirring speed of 200 rpm.	eighty (80) grams per liter, and a contact time of six (6) minutes, with Cr (VI) removal efficiency reaching ninety-two percent (92%).
14.	Dasar & Patah, 2024.	This study used Portland Composite Cement (PCC) in accordance with SNI 15-7064-2004, with partial replacement of cement by Palm Oil Fuel Ash (POFA) at 0%, 10%, 20%, and 30% by cement weight. POFA was obtained from palm oil mill waste and sieved through No.100 sieve to improve its reactivity. Fine aggregate was river sand and coarse aggregate was gravel, both used in saturated surface dry (SSD) condition after washing. Cylindrical specimens (100×200 mm) were cast using three-layer compaction (25 tamping per layer) and then water cured. Compressive strength tests were conducted at 28 and 91 days using a compression testing machine in accordance with ASTM C39, with three specimens for each mixture variation.	At 28 days, the compressive strength values for 0%, 10%, 20%, and 30% POFA were 18.54 MPa, 13.46 MPa, 15.81 MPa, and 11.01 MPa, respectively. The reductions compared to the control mix were 27.40%, 14.75%, and 40.64%, where the 20% POFA mix showed the highest strength among POFA-modified concretes. At 91 days, the compressive strength values were 31.74 MPa, 14.62 MPa, 19.58 MPa, and 13.35 MPa, with reductions of 53.93%, 38.32%, and 57.93%. The decrease in compressive strength was attributed to the relatively coarse particle size of POFA and its high porosity, which increased water absorption and reduced concrete strength.
15.	Assegaf, et al. 2023.	This study employed a batch adsorption method using activated Palm Oil Fuel Ash (POFA) as an adsorbent to reduce iron (Fe) concentration in acid mine drainage (AMD). The adsorbent masses used were 0 g (control), 2.5 g, 5 g, and 10 g, with pH variations of 5, 7, and 9. The mixtures were stirred at 300 rpm for 30 minutes and then allowed to settle for 3 hours to enable adsorbent sedimentation. The solutions were subsequently filtered using filter paper, and the Fe concentration and removal efficiency were analyzed.	The results demonstrated that POFA effectively reduced Fe concentration in AMD. Boiler ash exhibited better adsorption performance than incinerator ash, achieving average Fe removal efficiencies of 98.26% (pH 5), 98.20% (pH 7), and 94.50% (pH 9). In comparison, incinerator ash achieved removal efficiencies of 68.84% (pH 5), 97.30% (pH 7), and 92.56% (pH 9). The superior adsorption performance of boiler ash was attributed to its high silica content (89.91%). Furthermore, increasing the adsorbent dosage enhanced the adsorption performance, with the highest adsorption capacity obtained at an adsorbent mass of 10 g.
16.	Ginting et al. 2024.	This study utilized modified Palm Oil Fuel Ash (POFA) as an adsorbent for the batch adsorption of β-carotene from crude palm oil (CPO) using the soaking method. POFA was physically	The results demonstrated that POFA can be effectively used as an adsorbent for β-carotene removal from CPO. All modified POFA samples exhibited mesoporous structures. XRD analysis identified the presence of CuO,

		activated through particle size reduction and heating at different durations of 90, 150, and 210 minutes, followed by chemical activation using a 9% H_3PO_4 solution. Three adsorbent variants were produced, namely POFA modified 1, POFA modified 2, and POFA modified 3, which were subsequently used for β-carotene adsorption from CPO.	ZnO, quartz, and SiO_2 phases, while FTIR analysis revealed O–H groups, Si–H stretching vibrations, Al–O vibrations, Si–O asymmetric stretching vibrations, and Si–O–Si bending vibrations. UV–Vis spectrophotometric analysis showed that the best adsorption performance was achieved by POFA modified 2, activated at a heating time of 150 minutes, resulting in a β-carotene concentration reduction of 116.98 ppm and an adsorption efficiency of 86%. These findings indicate that activation conditions significantly influence the adsorption performance of POFA.
17.	Darmayanti & Indriani, 2024.	Cadmium (Cd) adsorption was carried out using zeolite at a dosage of 2 g/L in 100 mL of Cd solution with an initial concentration of 10 mg/L. The pH was varied from 3 to 7, and the mixtures were stirred at 120 rpm for 60 minutes. After adsorption, the solutions were filtered, and the residual Cd concentrations were determined using ICP-OES.	The optimum adsorption conditions were achieved at pH 6, an adsorbent dosage of 2 g/L, and a contact time of 120 minutes, resulting in a Cd removal efficiency exceeding 95%. The adsorption data were well described by both the Langmuir and Freundlich isotherm models, with a maximum adsorption capacity (Qm) of 64.58 mg/g.
18.	Nordin et al. 2021.	POFA collected from a local palm oil mill was washed with distilled water, dried at 105°C for 24 h, ground into powder, and sieved to obtain particle sizes below 250 μm. The adsorbent was characterized using X-ray diffraction (XRD, Bruker D8 Advance) to determine its crystalline phases.	POFA effectively removed Cr(VI) from aqueous solution, achieving a maximum removal efficiency of 92% and an adsorption capacity of 0.464 mg/g. The optimum conditions were pH 2, adsorbent dosage of 80 g/L, and contact time of 6 min. Adsorption behavior followed the Freundlich isotherm and pseudo second order kinetic models, indicating multilayer adsorption on a heterogeneous surface through chemisorption or ion-exchange mechanisms. In column studies, the maximum removal efficiency reached 90% with an adsorption capacity of 0.412 mg/g.
19.	Amir et al. 2025.	Adsorption experiments were conducted in 100 mL Schott bottles containing 30 mL of Reactive Orange 16 (RO16) or Crystal Violet (CV) solution. The effects of POFA/LDH ratio, hydrothermal temperature, pH (2–12), dye concentration (20–1000 mg/L), adsorbent dosage (0.25–2 g/L), and contact time (0–1440 min) were evaluated. Residual dye concentrations were measured using a UV–Vis spectrophotometer at 493 nm (RO16) and 608 nm (CV).	The Mg/Fe LDH–POFA composite (P-LDH, 1:1 ratio) showed excellent adsorption performance due to its abundant functional groups and favorable surface properties. Maximum adsorption capacities reached 484.65 mg/g for RO16 and 1045.44 mg/g for CV at pH 7. Adsorption followed the pseudo-second-order kinetic model and the Langmuir isotherm model. The adsorption mechanisms were predominantly chemisorption for RO16 and physisorption for CV. The adsorbent maintained good performance after five regeneration cycles.

20.	Darmayanti & Indriani, 2024	Adsorption of Cd was performed using 2 g/L POFA-based zeolite in 100 mL of 10 mg/L Cd solution. The effect of pH (3–7) was evaluated by adjusting the solution with 1 M HCl or NaOH, followed by shaking at 120 rpm and analysis of the filtrate using ICP OES.	The optimum adsorption conditions were pH 6, adsorbent dosage of 2 g/L, and contact time of 120 min, achieving over 95% Cd removal. The adsorption data fitted both Langmuir (Qm = 64.58 mg/g; KL = 0.77 L/mg) and Freundlich (KF = 38.46) isotherms, while the kinetics followed the pseudo second order model (Qe = 5.167 mg/g; K2 = 0.449 g/mg·min), indicating the potential of POFA-based zeolite as an effective adsorbent.
21.	Anggriani et al. 2021.	Adsorption of Cu(II) and Pb(II) was conducted using activated carbon with adsorbent masses of 1.0 and 1.5 g. A 50 mL metal solution (100 ppm) was treated at contact times of 10 - 40 min. Residual metal concentrations were analyzed using AAS (GBC 932 Plus).	The optimum adsorption condition was achieved at 40 min contact time and 1.5 g adsorbent dosage. Maximum removal efficiencies were 34.18% for Cu(II) and 85.61% for Pb(II). The adsorption of Cu(II) followed the Freundlich isotherm, while Pb(II) followed the Langmuir isotherm. Adsorption kinetics for both metals were best described by the pseudo second order model.
22.	Oktavianty, 2022.	Fly ash was purified and activated using H_2SO_4 solutions (5, 7.5, and 10 N), followed by mixing with sodium aluminate. The material was then calcined at 500 - 700°C for 2 - 4 h. The resulting adsorbent (2% w/w) was applied for crude biodiesel purification using the dry-washing method.	The synthesized adsorbent improved biodiesel purity by increasing the methyl ester content. The optimum methyl ester content (67.58%) was obtained using 7.5 N H_2SO_4 activation, a calcination temperature of 600°C, and a calcination time of 3 h. The adsorbent exhibited zeolite X characteristics, enhanced surface basicity, and increased surface area from 72 to 98 m^2/g.
23.	Ambaa et al. 2025.	Adsorption kinetics were evaluated by adding 2 g of H_3PO_4 HNO_3 activated candlenut shell charcoal to 25 mL of 1 N CH_3COOH solution. The mixtures were shaken for 1 min and allowed to stand for 30, 60, and 90 min. After filtration, 10 mL of filtrate was titrated with 0.5 N NaOH using phenolphthalein as an indicator.	EDS analysis showed that the activated charcoal contained the highest carbon content (86.7%). The adsorption kinetics of CH_3COOH on the activated charcoal followed a third order reaction model with an R^2 value of 0.8284.
24.	Fahmijal et al. 2023.	Peat water (100 mL) was mixed with 2 g of H_3PO_4 activated coconut coir activated carbon, stirred for 1 h using a magnetic stirrer, and then filtered. The filtrate was analyzed for its physical and chemical properties.	Increasing H_3PO_4 concentration improved the quality of the activated carbon by reducing moisture (6.92%), volatile matter (16.11%), and ash content (7.47%), while increasing fixed carbon content (76.42%). The best performance was obtained with 12% H_3PO_4 activation, which produced abundant pores, a cubic crystalline structure, and a strong C=C functional group. Application of the adsorbent successfully improved peat water quality, meeting the Indonesian clean water standards for color and iron (Fe) content.
25.	Fernianti & Suryati, 2022.	Detergent solutions were prepared by dissolving detergent in 2.5 L of water at different concentrations. The initial	The activated carbon met the Indonesian activated carbon standard (SII No. 0258-79), with moisture content of 9.15%, ash content of

		pH and surfactant concentration were measured before adsorption. A 300 mL solution was passed through a column containing 5 cm of activated carbon derived from tea waste, and effluent samples were collected at 5 - 30 min intervals for surfactant analysis. The procedure was repeated for both powder and liquid detergents at different dilution ratios.	2.09%, pure carbon content of 69.60%, and yield of 90.16%. The optimum surfactant removal for powder detergent was achieved at a concentration of 46 g/2.5 L after 10 min, reducing the surfactant concentration to 0.958 mg/L. For liquid detergent, the optimum condition was 10.5 g/2.5 L after 15 min, reducing the surfactant concentration to 0.949 mg/L. Both values were below the applicable wastewater discharge standard.
26.	Munira et al. 2022.	A total of 1 g of modified bioadsorbent was mixed with 25 mL of 0.1 N iodine solution and stirred for 15 min. After filtration, 10 mL of filtrate was titrated with 0.1 N sodium thiosulfate using 1% starch as an indicator to determine the iodine adsorption capacity. The bioadsorbent was prepared from pineapple leaf waste and modified using H_3PO_4, DBS surfactant, and NaOH at concentrations of 2 - 6%.	The adsorption performance was evaluated using the iodine adsorption number (iodine uptake, mg/g), which reflects the adsorbent's ability to adsorb small molecules and indicates its micropore content. The study examined the effect of H_3PO_4, DBS, and NaOH concentrations (2–6%) on the iodine adsorption capacity of the modified pineapple leaf bioadsorbent.
27.	Fitrianingsih et al. 2025.	Adsorption experiments were conducted using 400 mL of laundry wastewater and coconut shell activated carbon at a dosage of 9 g/L. The mixture was stirred at 400 rpm with contact times of 60, 75, 90, 105, and 120 min. COD and phosphate concentrations were analyzed using spectrophotometric methods according to SNI 6989-73:2019 and SNI 06-6989-31:2021, respectively.	Coconut shell activated carbon effectively reduced COD and phosphate concentrations in laundry wastewater. The optimum performance was achieved at 120 min, reducing COD from 353.6 to 64.4 mg/L (82% removal) and phosphate from 22.04 to 0.62 mg/L (97.2% removal). These results demonstrate the potential of coconut shell activated carbon as an effective and environmentally friendly adsorbent for laundry wastewater treatment.
28.	Purnama & Santoso, 2024.	Laundry wastewater (250 mL) was treated using 2 g of activated carbon and 3% alum as a coagulant. The mixture was subjected to rapid mixing at 150 - 240 rpm for 5 min, followed by slow mixing at 40 rpm for 20 min and settling for 30 min. The filtrate was analyzed for COD and TSS using titration and gravimetric methods, respectively.	Increasing the mixing speed enhanced pollutant removal by promoting floc formation and settling. The lowest TSS concentration was obtained at 240 rpm, with the best performance achieved using activated carbon prepared with a 3 N activator concentration. Under these conditions, TSS removal efficiency reached 87.10%, indicating effective treatment of laundry wastewater through the combined coagulation adsorption process.
29.	Safitri et al. 2025.	Adsorption experiments were carried out by mixing activated carbon derived from oil palm shell and empty fruit bunches with methylene blue solution. Contact times of 5, 10, and 15 min were evaluated while the solution was gently stirred using a magnetic stirrer.	Adsorption efficiency increased with increasing contact time, reaching optimum performance at 15 min. Activated carbon from empty fruit bunches achieved the highest methylene blue removal efficiency (79.91%), followed by oil palm shell activated carbon (77.50%). The superior performance of empty fruit bunch carbon was attributed to its higher

			porosity, while shell derived carbon exhibited greater structural durability.
30.	Utami, et al. 2024.	Adsorption of methylene blue was conducted using 0.25 g of nitric acid activated perlite in 250 mL dye solution. Contact time experiments were performed for up to 4 h at the optimum pH, while adsorption isotherms were evaluated using methylene blue concentrations of 10 - 80 ppm. Residual dye concentrations were determined using UV - Vis spectrophotometry at 664.8 nm.	The optimum adsorption conditions were obtained at pH 9 and a contact time of 180 min, with a maximum adsorption capacity of 3.873 mg/g. The adsorption process followed the pseudo-second-order kinetic model and the Langmuir isotherm model.

This article presents a literature review on the characteristics of activated carbon derived from Palm Oil Fuel Ash (POFA) through chemical activation using phosphoric acid (H_3PO_4). The material characteristics are evaluated through BET, FTIR, and XRD analyses to understand the changes in the physical and chemical properties of POFA after the activation process. All discussions are based on previously published studies; therefore, the analysis is theoretical and comparative in nature without involving direct experimental investigation.

POFA generally has a high percentage of silica and metal oxides, but in its unprocessed state, it has a poorly formed pore structure and a comparatively small specific surface area. In order to increase POFA potential as a precursor for activated carbon, chemical activation with H_3PO_4 is essential for opening the pore structure, minimizing volatile components, and changing surface functional groups.

BET analysis is commonly employed to evaluate the specific surface area, pore volume, and pore size distribution of activated POFA based carbon. Based on numerous previous studies, chemical activation using H_3PO_4 has been shown to significantly increase the surface area of activated carbon compared to non-activated materials [21]. Researchers observed that the development of well developed micro and mesoporous structures resulted in a significant increase in surface area in H_3PO_4 activated carbon.

H_3PO_4 can serve as a dehydrating agent for biomass based materials and industrial ashes like POFA, encouraging condensation and aromatization processes during thermal treatment. A more stable network of porous carbon is created as a result of these activities. Additionally [8] observed that POFA activation with H_3PO_4 increased pore volume and surface area, both of which directly improved adsorption capacity.

BET values are predicted to be significantly impacted by the POFA to H_3PO_4 impregnation ratio. Up to an ideal setting, higher impregnation ratios typically result in greater surface areas. On the reverse hand, pore blockage or structural deterioration of the carbon matrix could result from overuse of the activating agent. According to [21] an impregnation ratio of 1:5 (w/w) at an activation temperature of 500°C is therefore commonly considered as the ideal setting for generating activated carbon with an ideal surface area and balanced pore distribution.

Functional groups on the surface of POFA based activated carbon are identified both before and after activation using FTIR analysis. FTIR spectra offer important insights into surface chemical alterations brought about by H_3PO_4 treatment. Based of its intrinsic silica concentration, unactivated POFA usually displays few functional groups, such as hydroxyl (–OH) and silicate (Si–O–Si) groups. It is anticipated that new absorption peaks linked to phosphate and phosphoryl groups will begin to appear following activation with H_3PO_4. Adsorption bands in the 1000–1200 cm^{-1} range have been identified in a number of investigations and are related to P–O and P=O vibrational modes. According to [8], POFA H_3PO_4 activation boosted the intensity of phosphate and hydroxyl functional groups, which use as active sites for adsorption processes.

Because they facilitate hydrogen bonding and electrostatic interactions, polar functional groups like –OH, C=O, and P–O are crucial to the adsorption of anionic surfactants. Therefore, FTIR data are important markers of how well chemical activation advances the surface reactivity of activated carbon based on POFA. The structure of crystals and level of amorphousness of POFA based activated carbon are ascertained by XRD examination. Materials constructed from activated carbon often have little graphitic organization and are amorphous. Broad diffraction peaks at 20 values of roughly 20–25° and 42–45° are characteristic of activated carbon XRD patterns, implying a disordered carbon structure.

As indicated by [9], activated carbon with a mostly amorphous structure and small crystallite sizes was created by chemical activation using H_3PO_4 and thermal treatment at 500°C. Because it is linked to increased surface areas and more adsorption sites, this amorphous form is preferred. The structural changes that take place during activation and carbonization may also result in a decrease in the intensity of crystalline silica peaks in activated POFA. The broadening of XRD diffraction peaks indicates that a higher degree of structural disorder is expected with increasing H_3PO_4 impregnation ratios. This response indicates that POFA's initial crystalline structure is successfully disrupted by chemical activation, causing a more amorphous and reactive activated carbon structure.

H_3PO_4 activated POFA shows great promise as an adsorbent for surfactants in domestic laundry wastewater based on the examined BET, FTIR, and XRD properties. The key elements for adsorption potency include high surface area, the presence of active functional groups, and a mostly amorphous structure. These results are in line with research by [17] and [16] which proved that extremely porous activated carbon can considerably lower pollutant parameters in water waste from laundry.

In The literature review concludes that there is a good chance of producing highquality activated carbon by varying the H_3PO_4 impregnation ratio applied to POFA at an activation temperature of 500°C. This review supports the use of POFA as a value added and ecologically friendly alternative adsorbent material and offers a strong scientific foundation for upcoming experimental investigations.

The adsorption approach is an efficient and reliable way to reduce different pollutant parameters in wastewater, especially anionic surfactants (LAS/SDBS), COD, BOD, phosphate, and heavy metals, according to the conclusions of a review of multiple research. The kind of adsorbent, particle size, adsorbent dosage, contact time, pH, and system operation variables all have a significant impact on the adsorption process efficacy.

Based to research by [1] adsorption performance is significantly influenced by the adsorbent's particle size. A bigger surface area from a smaller adsorbent size (150–200 mesh) enhances the interaction between the adsorbent and the adsorbate. The reductions in LAS by 38.85%, COD by 67.34%, and BOD by up to 80% demonstrate this. The adsorption process takes place on an amorphous surface with multilayer formation, according to the correctness of the Freundlich isotherm model (R2 = 0.95023).

The findings are supported by a study by [19] which demonstrates that the kind of adsorbent significantly affects the surfactant absorption efficiency. With an efficiency of up to 99.21%, activated carbon outperformed natural zeolite. While zeolite reveals mixed adsorption properties (Langmuir and Freundlich), the Langmuir isotherm model fit for activated carbon ($R^2 = 1.00$) shows that adsorption is occurring in a monolayer on a homogenous surface. This demonstrates activated carbon's value as an adsorbent.

[20] combined the RSM statistical optimization method with PAn/SH adsorbent composites. The results obtained demonstrated that a COD of 74% and a surfactant removal efficiency of up to 99% could be achieved under the correct operating circumstances. Because of the synergy between the functions of conductive polymers and biomaterials, the consumption of composite materials has been shown to boost adsorption capacity, making them a viable substitute for efficient and durable adsorbents.

In while studies by [37] and [22] indicate the efficacy of biomass based adsorbents such commercial activated carbon and water hyacinth in eliminating phosphate and anionic surfactants. The high efficiency attained suggests that hydrodynamic circumstances and reactor configuration also have an impact on adsorption performance, particularly in continuous flow (upflow) systems. The adsorbent surface's heterogeneity is confirmed by the Freundlich model, which predominates in this investigation.

In reference to research by [38] the adsorption technique has been demonstrated to be successful in eliminating heavy metals in addition to organic chemicals. The removal of Cr (VI) up to 92% at a very acidic pH (pH 2.0) reveals how important pH levels are in managing adsorbent surface charge and metal ion speciation. Additionally, the little contact period (6 minutes) suggests quick and effective adsorption kinetics.

4. CONCLUSION

Due to this finding, palm oil fuel ash (POFA) has a lot of scope for application as an activated carbon raw material, particularly when phosphoric acid (H_3PO_4) is used to chemically activate it. This activation process has been proven to improve the quality of POFA by increasing its surface area, forming micro and meso pores, adding active functional groups to the surface, and changing the structure of the material to become more amorphous. All these changes directly improve adsorption capacity.

The results of various studies show that POFA activation with H_3PO_4 under optimal conditions (the right impregnation ratio and a temperature of around 500°C) produces activated carbon with high absorption capacity.

BET analysis shows an increase in surface area and pore volume, FTIR shows the emergence of active functional groups such as hydroxyl and phosphate that aid the adsorption process, while XRD shows an amorphous structure that supports high adsorption.

Comparison with other studies also shows that activated carbon performs better than other adsorbents (such as zeolite or unactivated biomass) in removing anionic surfactants from laundry wastewater. High removal efficiency of surfactants, COD, BOD, phosphate, and heavy metals is greatly influenced by the properties of the adsorbent, particle size, contact time, pH, and operating conditions of the system. This confirms that adsorption is an effective and reliable wastewater treatment method.

However, this study also highlights a research gap, namely the limited number of studies specifically discussing the use of H_3PO_4 activated POFA to absorb surfactants in household laundry wastewater. Most POFA studies still focus on heavy metals or applications in the construction sector. Thus, this conclusion confirms that H_3PO_4 activated POFA has great potential as an environmentally friendly and value added adsorbent for laundry wastewater treatment, and is worthy of being used as a scientific basis for further experimental research.

REFERENCES

[1] H. H. Fasihah Novita Sari, Yeyen Maryani, “Pengolahan Air Limbah Laundry Menggunakan Adsorbsi Cangkang Telur Ayam Novita,” *J. Ilm. Wahana Pendidik.*, Vol. 8, No. 20, Pp. 129–139, 2022.

[2] S. Salamah, I. Mufandi, A. A. Krismawati, And S. Humairrah, “Kemampuan Cangkang Telur Sebagai Adsorben Untuk Meningkatkan Baku Mutu Air Limbah Laundry (Air Deterjen),” *J. Tek. Kim.*, Vol. 29, No. 1, Pp. 47–53, 2023.

[3] A. H. Dhani Putri Rizki Rahma, Hendrayana, Nuning Vita Hidayati, “Konsentrasi Limbah Pencemar Mbas (Methylen Blue Active Substance) Pada Perairan Muara Kali Ijo, Kabupaten Kebumen,” *J. Maiyah*, Vol. 2, No. 3, Pp. 181–190, 2023.

[4] T. & Manurung, “Studi Literatur: Aplikasi Teknologi Membran Dalam Pengolahan Limbah Cair Untuk Keberlanjutan Lingkungan,” *Pros. Semin. Nas. Dan Teknol.*, Vol. 1, No. 2, Pp. 561–574, 2024.

[5] S. F. Ekoputri, A. Rahmatunnissa, F. Nulfaidah, Y. Ratnasari, M. Djaeni, And D. A. Sari, “Pengolahan Air Limbah Dengan Metode Koagulasi Flokulasi Pada Industri Kimia,” *J. Serambi Eng.*, Vol. 9, No. 1, Pp. 7781–7787, 2023.

[6] V. Amalia, A. R. Nisa, And E. P. Hadisantoso, “Tinjauan Nanokomposit Hidroksiapatit/Fe3o4 Sebagai Adsorben Logam Berat Pada Air,” *Gunung Djati Conf. Ser.*, Vol. 7, Pp. 8–24, 2022.

[7] S. Amna *Et Al.*, “Sintesis Karbon Aktif Dari Batang Kelapa Sawit Menggunakan Aktivator Asam Fosfat (H3po4) Active Carbon Syntetic From Palm Oil Trunk Using Activotor Phosphoric Acid (H 3 Po 4),” *Abdi Geomedisains*, Vol. 15, No. 01, Pp. 96–105, 2024.

[8] S. B. Ginting, S. Erlangga, H. Rustamaji, Darmansyah, M. N. Wijaya, And H. Wardono, “Effect Of Heating Time Variation On The Activation Of Modified Palm Oil Fly Ash As B-Carotene Adsorbent On Crude Palm Oil,” *J. Bahan Alam Terbarukan*, Vol. 13, No. 2, Pp. 117–129, 2024.

[9] C. A. Riyanto, E. Kurniawan, And N. R. Aminu, “Pengaruh Naoh Dan Suhu Aktivasi Terhadap Karakteristik Karbon Aktif Sekam Padi Teraktivasi H3po4,” *Rafflesia J. Nat. Appl. Sci.*, Vol. 1, No. 2, Pp. 59–68, 2021.

[10] Y. Siswanti, Putri And A. H. Oktaviana, “Adsorpsi Zat Warna Remazol Brilliant Blue R Pada Limbah Industri Batik Menggunakan Adsorben Dari Mahkota Buah Nanas Adsorption Of Remazol Brilliant Blue R Dye On Batik Industry Waste Using Pineapple Crown Adsorbent,” *J. Ilm. Tek. Kim.*, Vol. 21, No. 1, Pp. 9–16, 2024.

[11] A. Dasar And D. Patah, “Kekuatan Dan Durabilitas Beton Menggunakan Palm Oil Fuel Ash (Pofa) Dan Pasir Pantai,” *Borneo Eng. J. Tek. Sipil*, Vol. 8, No. 1, Pp. 83–94, 2024, Doi: 10.35334/Be.V8i1.5090.

[12] M. H. Assegaf, Rosyani, And Z. Alamsyah, “Studi Isotherm Langmuir Dan Freundlich Pada Adsorpsi Logam Berat Fe (Ii) Menggunakan Abu Pofa Teraktivasi,” *J. Pembang. Berkelanjutan*, Vol. 6, No. 2, Pp. 69–79, 2023.

[13] N. Bouchelkia *Et Al.*, “Study And Characterization Of H3po4 Activated Carbons Textile Effluents,” *Processes*, Vol. 11, P. 2694, 2023.

[14] N. Sylvia *Et Al.*, “Characterization Of Bottom Ash Waste Adsorbent From Palm Oil Plant Boiler Burning Process To Adsorb Carbon Dioxide In A Fixed Bed Column,” Vol. 21, No. 6, Pp. 1454–1462, 2021.

[15] S. B. Ginting, S. Erlangga, H. Rustamaji, And M. Niki, “Jurnal Bahan Alam Terbarukan Effect Of Heating Time Variation On The Activation Of Modified Palm Oil Fly Ash As B -Carotene Adsorbent On Crude Palm Oil,” Vol. 13, No. 200, Pp. 117–129, 2024.

[16] F. L. F. Sugito, Aliffia Rica Ambima, Muhammad Al Kholif, “Optimizing Laundry Wastewater Treatment : A Hybrid Approach Using Poly-Aluminum Chloride Coagulation And Activated Carbon Adsorption,” Vol. 10, No. 37, Pp. 146–154, 2025.

[17] M. S. Yusoff, N. H. Adam, And K. Watalinggam, “Effectiveness Of Oil Palm Frond Activated Carbon For

Removing Cod , Color And Fe From Landfill Leachate," *J. Eng Technol*, Vol. 53, No. 1, 2021.
[18] C. A. Riyanto, M. S. Ampri, Y. Martono, And U. K. Satya, "Synthesis And Characterization Of Nano Activated Carbon From Annatto Peels (Bixa Orellana L .) Viewed From Temperature Activation And Impregnation Ratio Of," *Eksakta J. Sci. Data Anal.*, Vol. 1, No. 1, Pp. 44–50, 2021.
[19] R. M. Kharabsheh And A. Bdour, "Adsorption Of Sdbs-Mbas From Aqueous Solutions Using Natural Zeolite And Activated Carbon: A Comparative Study," *J. Ecol. Eng.*, Vol. 26, No. 5, Pp. 102–113, 2025.
[20] S. Veli *Et Al.*, "Deep Purification Of Pretreated Laundry Wastewater Through The Adsorption By Polymeric Composites And Optimisation Of The Process," *Int. J. Environ. Anal. Chem.*, Vol. 2, No. 1, Pp. 1–19, 2021.
[21] R. Wulandari, C. A. Riyanto, And Y. Martono, "Alchemy Jurnal Penelitian Kimia Kinerja Karbon Aktif Daun Eceng Gondok Pada Penurunan Kadar Fosfat Artifisial," *Alchemy J. Penelit. Kim.*, Vol. 19, No. 2, Pp. 149–161, 2023.
[22] L. Kurnia And E. Nurul, "Penurunan Fosfat Dan Surfaktan Anionik (Detergen) Pada Air Limbah Laundry," *Envirous Tek. Lingkung.*, Vol. 2, No. 1, Pp. 18–26, 2021.
[23] N. Nordin *Et Al.*, "Removal Of Hexavalent Chromium From Aqueous Solution By Adsorption On Palm Oil Fuel Ash (Pofa)," *J. Geosci. Environ. Prot.*, Vol. 8, No. 2, Pp. 112–127, 2022.
[24] L. Darmayanti And L. Indriani, "Adsorption Of Cadmium (Cd) Metal In Solution Using Pofa-Based Zeolite (Palm Oil Fly Ash)," *J. Kim. Dan Pendidik.*, Vol. 9, No. 2, Pp. 176–187, 2024.
[25] N. Nordin *Et Al.*, "Removal Of Hexavalent Chromium From Aqueous Solution By Adsorption On Palm Oil Fuel Ash (Pofa)," *J. Geosci. Environ. Prot.*, Vol. 8, No. 1, Pp. 112–127, 2021.
[26] M. Amir, A. Mohd, H. Norhaniza, Y. Juhana, J. Ahmad, And F. Ismail, "Transforming Palm Oil Fuel Ash Into High - Performance Biosorbents : One - Pot Synthesis Of Layered Double Hydroxide Composites For Efficient Removal Of Hazardous Dyes From Textile Wastewater," *Water, Air, Soil Pollut.*, 2025.
[27] Anggriani Ulfa Meila, A. Hasan, And I. Purnamasari, "Kinetika Adsorpsi Karbon Aktif Dalam Penurunan Konsentrasi Logam Tembaga (Cu) Dan Timbal (Pb) Kinetic Adsorption Of Activated Carbon In Decreasing Concentrations Of Copper (Cu) And Lead (Pb) Metals," *J. Kinet.*, Vol. 12, No. 02, Pp. 29–37, 2021.
[28] Oktavianty, "Sang Pencerah," *J. Ilm. Univ. Muhammadiyah But.*, Vol. 8, No. 2, Pp. 430–443, 2022.
[29] S. L. Ambaa, Meytij Jeane Rampe, "Karakterisasi Arang Tempurung Kemiri Hasil Aktivasi Dengan," *J. Fista Fis. Dan Ter.*, Vol. 6, No. 1, Pp. 43–49, 2025.
[30] S. Fahmijal, Lubis, "Pembuatan Karbon Aktif Dari Sabut Kelapa Dengan Aktivasi Menggunakan H 3 Po 4 Untuk Adsorpsi Air Gambut Prosedur Penelitian," *Jop*, Vol. 8, No. 2, Pp. 23–28, 2023.
[31] D. Fernianti And L. Suryati, "Terhadap Proses Penyerapan Surfaktan Dalam Ampas Teh," *J. Distilasi*, Vol. 2, No. 2, Pp. 10–14, 2022.
[32] M. Munira, M. Arman, T. Syarif, And D. Darnengsih, "Journal Of Chemical Process Karakterisasi Dan Modifikasi Karbon Aktif Dari Mahkota Nanas Sebagai (Characterization And Modification Of Activated Carbon From Pineapple Crown Waste As Bioadsorbant)," *J. Chem. Process Eng.*, Vol. 7, No. 2, Pp. 2655–2967, 2022.
[33] R. Fitrianingsih, Adzillah, "Jurnal Ilmu Alam Dan Lingkungan Evaluasi Efisiensi Adsorpsi Chemical Oxygen Demand Dan Fosfat Pada," *J. Ilmu Alam Dan Lingkung.*, Vol. 16, No. 2, Pp. 16–22, 2025.
[34] H. Purnama And C. A. Santoso, "Konsentrasi Aktivator Arang Tempurung Kelapa Pada Proses Koagulasi-Adsorpsi Limbah Laundry," *J. Chem. Eng.*, Vol. 5, No. 3, Pp. 25–33, 2024.
[35] M. Safitri, N. H. Haryanti, R. Oktafiansyah, M. I. Najmi, And N. Asyiah, "Adsorpsi Karbon Aktif Berbasis Limbah Sawit Terhadap Metilen Biru Dengan Spektrofotometri Uv-Vis : Perbandingan Sumber Bahan," *J. Pendidikan, Sains, Geol. Dan Geofis. (Geoscienceed Journal)*, Vol. 6, No. 3, Pp. 1361–1368, 2025.
[36] M. R. Utami, K. Riyani, And T. Setyaningtyas, "Chimica Et Natura Acta," *J. Chim. Nat. Acta*, Vol. 12, No. 2, Pp. 91–97, 2024.
[37] W. S. Wulandari And W. Winarsih, "Pengaruh Ekoenzim Berbagai Limbah Kulit Buah Terhadap Penurunan Konsentrasi Surfaktan Pada Air Limbah Laundry," *Lenterabio Berk. Ilm. Biol.*, Vol. 13, No. 1, Pp. 93–104, 2023, Doi: 10.26740/Lenterabio.V13n1.P93-104.
[38] D. O. Dwina, N. Nazarudin, O. Alfernando, D. Kumalasari, And T. Nofrina, "Pengolahan Pofa (Palm Oil Fuel Ash) Dan Semen Sebagai Material Alternatif Timbunan Pilihan Jalan Untuk Perbaikan Infrastruktur Jalan," *Fondasi J. Tek. Sipil*, Vol. 11, No. 1, P. 78, 2022.