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An Overview of the Applications of Periwinkle (*Tympanotonus fuscatus*) Shells

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Authors' contributions

This work was carried out in collaboration between both authors. Author VJA designed the study, wrote the protocol, and wrote the first and final draft of the manuscript. Author GBL managed the literature searches. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The waste generated by the periwinkle (*Tympanotonus fuscatus*) shell cannot be undermined. In coastal communities worldwide, periwinkle is a major source of proteins and other vital minerals in most delicacies. The shells of these aquatic species, notable for their nutrient provision, contribute to environmental degradation because of the indiscriminate disposal. The absence of a proper waste management program leads to the blockage of drainages, resulting in flooding. This study reviews the various avenues by which the *Tympanotonus fuscatus* shell can be processed and utilized. The review was conducted to synthesize the current body of knowledge in the research area to help present a proper perspective to periwinkle shell utilization. The study showed that periwinkle shell could effectively be utilized directly as a partial replacement for coarse aggregates and cement in concrete, and in the adsorption of heavy metals from wastewater. The shell was also a suitable replacement for asbestos in brakepad production. Perspectives for future research in periwinkle shell utilization as raw materials

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for the production of synthetic stones and ceramic mugs, calcium supplements, fluid loss control additive for drilling mud, adsorbents for poisonous and odorous gas capture were identified. Other areas of future research include the use of periwinkle shells as gravel pack and fluid proppants alternatives in oil and gas wells and as replacements for molecular sieves in natural gas conditioning and biogas upgrading.

Keywords: Periwinkle shell; waste management and conversion; pollution control; shell-derived products.

1. INTRODUCTION

The reuse and recycling of wastes have proven to be an efficient method of addressing the waste disposal problem in recent times [1]. Waste generation increases with climate change, population growth, and economic development [2,3]. Waste reuse help in reducing waste generation, lowers the rate of depletion of natural resources, and maintains ecological balance. Most of these wastes, primarily because of industrialization, become an environmental menace resulting in pollution if not properly disposed. Pollution prevention and control involve preventing or removing harmful materials from streams or effluents before disposal to the environment [4]. Pollution prevention amounts to reducing the quantity of waste required to be controlled, treated, or disposed. It is a process that helps protect the environment by conserving and protecting natural resources, which ultimately translates to a reduction in both financial costs associated with waste management and environmental cost related to public health and the environment.

The booming seafood industry has seen an increase in the number of waste shells generated globally annually. For instance, there are about ten million tonnes of waste shells generated in China [5], nearly two million tonnes in Japan [6], and two hundred and five thousand tonnes in France [7]. Converting these wastes into valuable products can help reduce the number of shell wastes disposed into the environment. Also, the public health risk associated with the indiscriminate disposal of the shells will be reduced considerably. The usability of these shells lies in their availability, low cost, and high amounts of calcium carbonate [8] and chitin [9-11], which can be extracted and used to produce various products. The reuse capacity of these shells can be expanded by utilizing them for the development of value-added products. In that sense, the utilization of shell waste is a valuable strategy for sustainable resource management, reduced waste storage [12], reduced material costs, and wealth creation.

Several authors have reported the various applications of waste shells (egg, oysters, snail, cockle, mussel, clam, and scallop shells). These shells have been suitable in engineering, medicine, pollution control, agriculture, and other applications of human endeavors. Fig. 1 shows examples of some typical waste seashells found in the Niger Delta region of Nigeria. In building and construction, studies have revealed that the similarities in the composition (especially calcium oxide- CaO) of the waste shells and limestone is one of the significant reasons they could be used as substitutes for limestone [13]. The over-dependence on naturally occurring limestone, granite, and other naturally occurring raw materials for building and construction activities, has led to an increase in the cost of these materials. In the coastal regions of the Niger Delta, for instance, a 50kg bag of cement and a tonne of granite chippings costs about ₦ 4,000 ($ 9.76) and ₦10, 500 ($ 25.61), respectively. The exploitation of these natural resources has often led to the degradation of the environment caused mainly by mining activities. Groundwater, air, and land pollution (which are health risks to humans) are some of the consequences of mining activities [14].

Recent studies have shown that using crushed waste shells as aggregates in concretes does not improve its performance significantly. The concrete's durability, compactness, and compressive strength have often declined with time [7,15]. Nonetheless, it is suggested that they can still be used as aggregates at a partial replacement extent of up to 20% in concrete for non-structural purposes [5, 16, 17]. However, when used as fillers or a partial cement replacement in cementitious material, the waste seashell powder can improve cement hydration and enhance the mechanical strength of the hardened cement mixture [15]. Using locally sourced waste shells as a partial or complete replacement for concrete aggregates can help reduce the production cost of concrete, mitigate environmental degradation, and improve waste management for sustainable development.

Waste shells have gained acceptance as effective materials for removing heavy metals, phosphates, and dyes from wastewater and treating odorized gaseous effluents. This is primarily due to its low cost and its ability to replace conventional wastewater bio-filters like photocatalysts, gravels, stones, and activated carbon. Waste shells have been applied in removing numerous heavy metal pollutants from wastewater and other effluents from various industries [18-21]. Onoda and Nakanishi [22] deployed calcium phosphate made from oyster shells to remove lanthanum metals from wastewater efficiently. In a similar study, Naik et al. [23] investigated the removal of heavy metals (Mercury, Cadmium, Arsenic, Lead, Nickel) using mainly bivalve, crab, and oyster shells powder. They concluded that a heavy metal removal efficiency of at least 85% was achievable. In another study, Dorris [24] investigated the use of treated crab shells through an ion exchange chelation mechanism to remove lead, cadmium, and nickel metals from wastewater. The results showed good uptake of the heavy metals. In the same vein, Park et al. [25] showed that both calcined and natural waste eggshells could be used for heavy metals removal in wastewater. Several other works utilizing waste shells like Mollusca shells [26] and Mussel shells [27] in removing heavy metals from wastewater have been reported. Waste shells have also been successfully used as bio-filters in water quality improvement. Zukri et al. [28] used calcinated mussel shells to solve eutrophication in lake water in their work. They established an uptake efficiency of 31.28% and 21.74% of ammonium and phosphorous oxide ions, respectively, when a 7.5g of mussel shell was used. Oyster shells have been used as aerated biological filters for municipal wastewater treatment. The oyster shells effectively treated the wastewater with a chemical oxygen demand removal of 85.1%, ammonia nitrogen removal of 98.1%, and total phosphorous removal of up to 90.6% [29]. A similar study has been conducted using oyster shells as a bio-filter for nitrogen uptake in domestic water purification [30].

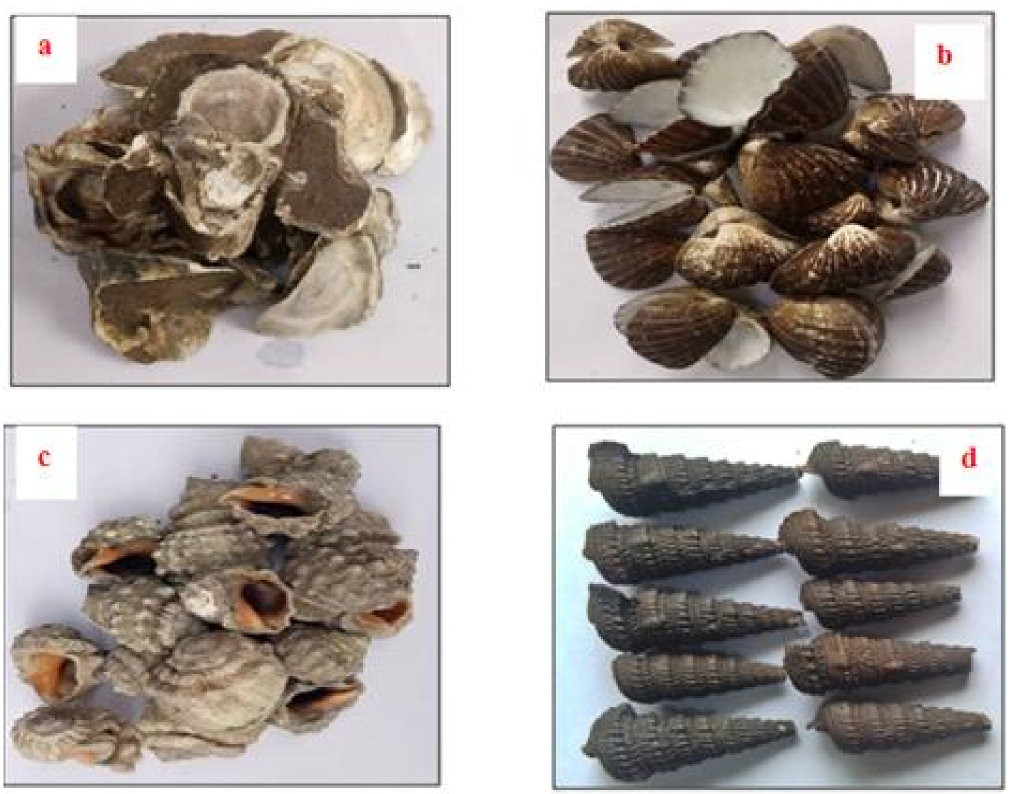

Fig. 1. Common waste shells (a) Oyster (b) Limpet (c) Whelk (d) Periwinkle shells

Low-cost and environmentally friendly waste shells have been reported to remove dyes from wastewater effectively. In the investigations conducted by El Haddad et al. [31,32], calcined mussel shells were found to efficiently remove textile dyes from aqueous solutions. The thermodynamics and kinetics of the bio-sorption of safranin dye from aqueous solutions were examined and found to be favorable. In another study, Suteu et al. [33,34] examined the use of powdered waste seashells as a bio-sorbent to remove reactive dye from textile wastewater. Their results showed that waste seashell powder could be used as a low-cost bio-sorbent alternative in large-scale applications to extract color and suspended solids.

The emission of odorous and toxic gases into the environment can result in severe environmental and health concerns [35]. These gases, which include COx, NH3, CH4, SOx, NOx, H2S, volatile organic compounds (VOCs), and volatile organic gases [36], are usually effluents from wastewater treatment plants, oil and gas processing facilities, paint manufacturing factories, petrochemical plants, and other industrial facilities. Among these gases, the common odorous gases are nitrogen and sulfur compounds [37]. Conventional adsorbents for scrubbing of these gases include activated carbon [38], metal-organic frameworks [39], porous organic polymers [40], and membranes [41]. A review of conventional adsorbents for the sequestration of odorous and harmful gases has been reported in the open literature [42]. In this regard, Jong-Hyeon et al. [43] used waste oyster shells to treat and remove acid gases in flue gas. They concluded that treated waste oyster shells could be used in industrial applications to remove sulfur and nitrogen oxides from effluents. The authors attributed the remarkable ability of waste shells to adsorb acid gases to the presence of alkaline materials (mainly oxides and hydroxides of potassium, sodium, and calcium) in the shells.

The suitability of waste shells (due to the high amounts of calcium oxide -CaO) for use as a heterogeneous catalyst has also been investigated by several researchers. The choice of waste shells is due to the rising interest in calcium oxide (CaO) catalysts [44-46], especially in biodiesel and hydrogen gas production. As a result, the low-cost and renewable waste shells represent a viable alternative to conventional CaO sources. In this regard, Laskar et al. [47] used waste snail shells to synthesize heterogeneous catalyst, which was then used to produce biodiesel from soybean with a 98% yield. Similarly, Buasri et al. [48,49] developed heterogeneous catalysts from waste shells of mussel, oyster, cockle, pyramidella, and scallop in biodiesel production through transesterification of jatropha and palm oil, using methanol. Likewise, Perea et al. [50] used mussel, clam, and oyster shells to produce heterogeneous catalysts for biodiesel synthesis through the transesterification of Camelina sativa oil. In another study, Taufiq-Yap et al. [51] showed that eggshell-derived catalysts could be used effectively to gasify wood to produce hydrogen gas. Similarly, Karoshi et al. [52] investigated the partial oxidation of methane gas to produce long-chain (C_2 – C_7) hydrocarbons using an eggshell-derived catalyst. A successful mean methane conversion rate of about 30% was achieved.

Waste shells have been applied as calcium supplements in improving the bone health of livestock and poultry [53,54] and bioremediation and improvement of the micro and macro minerals availability in the soil [55–57]. Waste shells have also demonstrated an excellent ability to remove acidic soil contaminants in soil liming activities, thereby improving soil fertility [58]. In this regard, Shen et al. [59] demonstrated that using fine oysters' shells improved soil pH better than conventional biochar and lime. Oyster shells have been proven to be a good ingredient for the manufacture of β-tricalcium phosphate containing hydroxyapatite, one of the essential mineral components of artificial bones and teeth [60–62]. Although not fully exploited, waste shells can find applications in orthopedic [63] and dental medicine. Other areas of application of waste shells not fully exploited are in the production of synthetic stones for workbench and tabletop surfaces, as demonstrated by Silva et al. [64] using oyster shells, and in the manufacture of ceramics with oyster shells illustrated by Hao et al. [65].

Several review articles have been published on the use of waste shell-derived products and applications [5, 12, 66-69]. The emphasis of their works mainly relied on the use of eggs, oysters, mussels, snail, and clamshells, with little or no mention of the use of periwinkle (*tympanotonus fuscatus*) shells. This limited literature on the use of *tympanotonus fuscatus* shells is of great concern knowing that the source and composition of different shells could strongly influence the shell-derived product's performance [70]. The review works focused on the use of waste shells as aggregates or cement replacements in lightweight concrete production, the production of synthetic stones and ceramics, development of bio-filters for wastewater and odorous gas treatment, synthesis of heterogeneous catalysts for biodiesel, hydrogen, and long-chain hydrocarbon production, calcium supplements for livestock and poultry, and applications in orthopedic and dental medicine. However, these review articles did not consider the potential use of waste shells to improve the geotechnical properties of lateritic soil and as composite materials for particleboard production. Also, they did not consider using the shells as fluid loss control additives to formulate oil and gas well drilling fluids, manufacture asbestos-free brakepads, and manufacture abrasive materials.

The major areas of applying the *tympanotonus fuscatus* shells in building and construction, wastewater treatments, and catalysts synthesis are reported in this review. Applications in the formulation of oil and gas well drilling fluids, the improvement of the geotechnical properties of lateritic soil, as composite materials for particleboard production, in the manufacture of abrasive materials, and asbestos-free brakepads, are also presented. This review will provide a foundation and direction to researchers to develop new ideas of periwinkle shell utilization. Furthermore, perspectives for future research in the use of periwinkle shells highlighted in this study will guide researchers in creating a pathway for future research on periwinkle shell applications. For this work, periwinkle shells considered herein refer to the *tympanotonus fuscatus* species.

2. PERIWINKLE SHELLS

There are about twelve million tonnes of waste shells disposed of on land and the seashores in Nigeria annually [69]. A considerable amount of these waste shells are periwinkle shells. The periwinkle shells, discarded after the consumption of the edible part, generate massive sources of waste. Without a proper waste management system, these shells litter marketplaces, residential areas, and refuse dumpsites located within the locality, thus contributing to land and air pollution. The decomposition of the waste shells results in the production of offensive stench, leaching and weathering of heavy metals from the waste dump, and the contamination of public water systems. On decomposition, disease-carrying organisms and other animals in contact with the wastes can spread diseases, thereby causing environmental sanitation problems and threatening public health [5, 6, 71]. The rise in the consumption of shelly seafood, especially in coastal communities, as a healthy protein source, cannot be over-emphasized. In the coastal region of the Niger Delta, the *Tympanotonus fuscatus*, commonly known as periwinkle, are found in the large stretch of mangroves, swamps, and mudflats that characterize the region [72-74]. Its shell, which makes up about 70% of its weight [63, 75], is much harder and stronger than that of an ordinary snail. *Tympanotonus fuscatus* is a prosobranch gastropod common in many brackish water creeks and mangrove swamps within the Niger Delta province. The genus *Tympanotonus* comprises a single species with two varieties.. *Tympanotonus fuscatus var* fuscatus [76, 77] and *Tympanotonus fuscatus var radula* [78,79]. *T. fuscatusvar fuscatus* is characterized by turreted, granular, and spiny shells. On the other hand, *T. fuscatus var radula* is distinguished from the other variety by the absence of a spiny tubercle on the shell. Several varieties of these invertebrates are herbivores. Their sizes vary from small (about 2.5cm long) to large (about 5cm long). These periwinkles are often referred to as male and female periwinkle species by the locals in the region. Their structures can easily be used to identify them. Fig 2 shows the predominant periwinkle varieties and the calcined form of the shells at 800°C.

The people in these areas consume the edible part and dispose of the shells as waste. Few people utilize the shells. However, many of these shells are still disposed of as garbage, thereby constituting environmental sanitation problems in areas where they cannot find any use. Large deposits have accumulated in many places over the years [72]. Various authors have reported the characteristics of other periwinkle varieties in the literature [, 74, 80].

3. CHARACTERISTICS OF PERIWINKLE SHELLS

The major minerals in the natural periwinkle shell are calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$), with a typical composition of 88.22 ± 0.75% and 10.25 ± 0.42%, respectively [81]. On calcination of the shells, the $CaCO_3$ is converted to calcium oxide (CaO), and complete conversion of $CaCO_3$ to CaO is expected at calcination temperatures above 800 °C [82]. However, the optimum calcined temperature for periwinkle shell ash when used as a partial replacement for cement in concrete is 800°C [83]. The calcination temperature plays a significant role in determining the calcined shells' final composition and physical properties. For instance, the weight percent of CaO, specific surface area, and pore volumes, increase with the calcination temperature [47, 83, 84]. Table 1 shows that the composition of the calcined periwinkle shells at temperatures of 800°C to 1200 °C are relatively the same, with CaO and silicon oxides (SiO_2) the most predominant compounds. This relatively high percentage composition of CaO and SiO_2 could make the periwinkle shell a reliable alternative source of CaO and SiO_2 derived materials. Periwinkle shells also contain polar functional groups like hydroxyl, carboxylic, phenolic, and primary amines [85]. These functional groups could make the shells good candidates for sorption applications.

4. APPLICATIONS OF PERIWINKLE SHELLS

Studies on the uses of periwinkle shells for industrial applications have gained traction and have increased recently. This increase in the research of periwinkle shell utilization can be attributed to both the economic and environmental benefits associated with its use. The reuse of waste materials into valuable products has become one of the most efficient ways of solving waste disposal problems [1]. The various applications of the periwinkle shells are discussed in subsequent sections.

(a) Tympanotonus fuscatus var fuscatus

(b) Tympanotonus fuscatus var radullar

(c) Calcined periwinkle shell ash @ 800 °C

Fig. 2. Periwinkle varieties and the calcined form of the shells at 800°C

Table 1. Composition of periwinkle shells at various calcined temperatures

Compound	Concentration (wt. %)				
	[83] 1000 °C	[83] 800 °C	[86] 1200 °C	[87] 800 °C	[88] 800 °C
SiO_2	33.80	33.85	32.83	34.74	33.84
Al_2O_3	10.84	10.24	7.52	15.57	10.20
Fe_2O_3	5.58	6.25	9.84	0.12	6.02
CaO	46.39	40.63	41.36	37.54	40.84
MgO	0.73	0.83	-	-	0.48
P_2O_5	-	0.01	-	-	0.01
CuO	-	-	-	0.03	-
ZnO	-	-	0.03	-	-
TiO_2	0.23	0.05	0.04	0.01	0.03
Na_2O/K_2O	0.54	0.41	0.41	0.03	0.38
SO_3	0.18	0.25	0.08	0.04	0.26
MnO_2	-	-	0.22	0.02	-
LOI	6.28	7.08	6.30	-	7.60

4.1 Building Materials and Construction

Periwinkle shell utilization is primarily predominant in the building materials and construction industry. It is used either as a partial replacement for cement, fine aggregates, or coarse aggregates to construct mostly pavement slabs among the locals of the coastal regions where the shell waste is abundant. It is either used in whole or crushed to desired sizes as aggregates after treatment, usually including washing and drying. Fig. 3 shows some applications of periwinkle shells in concrete production. Investigations have shown that heating the waste shells at high temperatures and crushing to achieve appropriate fineness enables the shells to be effective for use as a partial replacement for cement [14, 89-92].

To determine the suitability of periwinkle shells as a partial replacement for cement in concrete for building and construction, Offiong and Akpan [83] assessed the physico-chemical properties of the shells. The properties of the periwinkle shell investigated were fineness, bulk density, moisture content, and specific gravity. Compressive strength tests using 0, 10, 20, 30, and 40 % of periwinkle shell ash (calcined at 800 and 1000 °C) as a partial replacement for cement were also studied. Comparison with the specification given by the American society of testing and material showed satisfactory results for fineness, composition, and 28 days compressive strength activity index. This result indicated that the periwinkle shell is suitable for use as a partial replacement for cement. Olushola and Umoh [88] carried out compressive and tensile test analysis to determine the strength characteristics of periwinkle shell ash (PSA) blended with cement in concrete in a similar work. Using a design strength of 25 N/mm^2 and PSA replacement from 0 to 40%, the results obtained were similar to conventional concrete. The compressive strength increased with the curing age of 7 to 180 days, decreasing as the PSA percentage composition increased. Another study evaluating the effectiveness of PSA as a partial replacement for cement in concrete production can be found in the literature [87]. From the results, it can be inferred that when using PSA as a partial replacement for cement in concrete production, the proportion of PSA in the mix should not exceed 10%.

Waste periwinkle shells have been used as aggregates for the full or partial replacement of granitic chippings, sand, and other forms of aggregates to produce lightweight or low-strength concrete [13, 93-99]. In the light of this, Olugbenga [100] evaluated the strength characteristics of concrete with varying percentages of periwinkle shell aggregate by measuring the aggregate impact value (AIV), aggregate crushing value (ACV), and compressive strength properties. Using the standard mix of 1:2:4, a water-cement ratio of 0.55, and varying the percentage replacement of the shells from 0% to 100%, optimum compressive strength values of 16.79 N/mm^2 and 16.71 N/mm^2 for 20% and 30% replacements, respectively in 28 days, were obtained. The ACV and AIV results were 31.59% and 22.61%, respectively. These results were found to be within acceptable limits, thereby confirming the suitability of periwinkle shells for use as coarse aggregates in lightweight concrete.

(a) Drainage Concrete Slab **(b) Concrete Pavement**

Fig. 3. Some applications of periwinkle shells as aggregates in concrete

Similarly, Adewuyi and Adegoke [101] reported sufficient compressive strengths for the concrete mix with periwinkle shells replacing granite chippings up to 35.4% and 42.5%, using concrete mix ratios 1:2:4 and 1:3:6, respectively. Also, Ettu et al. [102] conducted experiments on the prospects of using periwinkle shells as a partial replacement for granite. In doing this, saturated surface dry bulk density and compressive cube strength tests were performed at 7 and 28 days for different percentage replacements of granite chippings with periwinkle shells, using a constant water-cement ratio of 0.65 and three sets of cement/sand/coarse aggregate mix ratios of 1/1.5/3; 1/2/3 and 1/2.5/3. The results showed that the density of the concrete decreased with increasing percentage periwinkle shells, from 2466.67 Kg/m^3 for 25% periwinkle shell replacement at a mix ratio of 1/1.5/3 to 2103.33 Kg/m^3 for 75% periwinkle shell replacement at a mix ratio of 1/2.5/3. Also, values of 28-day compressive strength ranged from 24.15 N/mm^2 for 75% periwinkle shell replacement to 33.63 N/mm^2 at 25% replacement. These compressive strength results meet the BS 8110 requirement, which stipulated a minimum compressive strength standard of 25 N/mm^2. Conclusively, 25% periwinkle shells on the basis of compressive strength can be used as a partial replacement for granite chippings in lightweight concrete.

Laterites are a special type of reddish sands used as construction material for soil consolidation in many roads, pavement, and foundations. However, not all lateritic soils can be used for this purpose. This is because some of these soils are made up of heaving clays which contain minerals like illite and montmorillonite. The presence of heaving clays in lateritic soils can decrease the shear strength of the soils and increase the pore pressure and swelling potential. Consequently, such lateritic soils are unsuitable for sub-base or base materials for construction purposes [103]. A review on the use of lateritic soils for construction purposes has been published in the literature [104]. Periwinkle shell ash's potential for geotechnical applications and the improvement of soil properties have also been published in the literature [105-107].In this regard, Etim et al. [86] investigated the compaction behavior of lateritic soil treated with periwinkle shell ash calcined at 1200^{o}C. Their objective was to determine the suitability of the treated lateritic soil as road sub-base construction material. In doing this, the peak unconfined compression strength (UCS) and the California bearing ratio (CBR) of the selected samples were measured by varying the periwinkle shell ash component up to 12%. Using three compaction energy standards, including the British standard light (BSL), West African Standard (WAS), and the British Standard Heavy (BSH), they found out that the peak UCS and CBR were obtained at a 6% periwinkle shell ash content threshold. The scanning electron microscope (SEM) morphology of the natural lateritic soil and the optimal 6% periwinkle shell ash content showed significant microstructure and grain size distribution changes. The formation of cementitious products, which were easily identified on the

SEM micrograph of the treated soil, acted as cementing agents resulting in a denser structure than the untreated soil. This denser structure depicts fewer voids and high compaction. The difference in the soil fabrics and pore surface area of the treated and untreated soil samples was studied using a fibermetric interactive software integrated into the SEM micrograph. The fiber histogram revealed the changes in micro-fabric orientation as a result of the soil treatment. The reduction in the micro fabric orientation from 565.94 nm to 13.01 μm for the untreated soil and from 562.60 nm to 4.66 μm for the treated lateritic soil after both 7 and 28 curing periods indicates an improvement in the geotechnical properties of the soil [108]. Likewise, the pore histogram results were obtained from the fibermetric interactive software embedded in the SEM micrograph. The untreated soil's pore surface area ranged from 0.18 μm^2 to 973.39 μm^2, while that of the treated soil ranged from 0.18 μm^2 to 7.36 μm^2, for the seven-day curing period. This result is indicative of a reduction in pore spaces attributed to the periwinkle shell filling up the void spaces, leading to a reduction in the surface area [109, 110].

Although the results showed that lateritic soil treated with 6% periwinkle shell ash improved the soil's compaction and strength, it did not meet the UCS and CBR strength criteria. It, therefore, cannot be used as a standalone stabilizer [86]. Nonetheless, the improvement in the soil strength and compaction properties suggests that periwinkle shells could be used as admixtures to improve the geotechnical properties of lateritic soils and should be further investigated.

4.2 Wastewater Treatment and Bio-filters

As with other waste shells, periwinkle shells have been used for wastewater treatment and bio-filters to remove mostly poisonous and harmful heavy metals [110-112]. In one study, Badmus et al. [113] investigated the use of periwinkle shell ash to remove copper in polluted water. In the study, periwinkle shells were heated to 300 ^oC for 2 hours, crushed, and sieved with a 180 μm Standard Tyler Sieve No 80. The sieved sample was then activated with hydrochloric acid, washed, oven-dried at 110^{o}C, and further crushed to obtain fine particle sizes of the adsorbent. 100 ml of wastewater samples were treated with varying mass of adsorbents. The effect of contact time, adsorbent dose, pH, agitation speed, and adsorbent particle size on the rate of adsorption were investigated. The authors found out that the periwinkle shell adsorbent removed up to 84.19% of the copper metals at a pH of 8. The equilibrium adsorption data had a good fit with both the Langmuir and Freundlich adsorption models. The results were consistent with those obtained when a standard commercial activated carbon was used for the adsorption process.

Similarly, Odoemelam and Eddy [114] studied the suitability of oyster, snail, and periwinkle shells for lead ($Pb^{2+)}$ adsorption from aqueous solutions. The shells were furnace dried up to 400^{o}C, crushed, and ground to powder form to increase the surface areas in the study. 100 ml of different concentrations of Pb $(NO_3)_2$ were added to 100g of each adsorbent at different contact times. The Pb^{2+} concentration was determined using the PyeUnicam model of atomic absorption spectrophotometer. Although the species of the periwinkle shells used in the experiment were not indicated, their adsorption of Pb^{2+} was less effective than oyster and snail shells. Nonetheless, the removal of Pb^{2+} from aqueous solutions using periwinkle shells was efficient and adequate. The adsorption equilibrium data also fitted adequately with the Temkin, Freundlich, and Langmuir adsorption isotherms. A similar study on the effectiveness of periwinkle shells for removing lead ions from wastewater has also been reported [115]. Other similar works have shown that periwinkle shells can be blended with coconut husk and palm kernel shell, thiolated, and used to remove Co^{2+}, Ni^{2+}, and Cd^{2+} metallic ions in an aqueous solution [85]. In the study, the adsorbent materials were each oven-dried at 400^{o}C, milled separately, and the optimum blend (blend with the highest surface area) ratio of 1:1:1 was chosen. One gram of the blended mix was used as the adsorbent to remove the selected heavy metals after ten minutes. It was found that the composite samples were more effective and absorbed the metals more by a factor of twenty-six compared to using periwinkle shell alone. The optimum time for the metal uptake was 70, 80, and 90 minutes for Co^{2+}, $Cd^{2+,}$ and Ni^{2+}, respectively. As such, it can be inferred that periwinkle shells can be blended with coconut husk and palm kernel shell for the removal of Co^{2+}, Ni^{2+}, and Cd^{2+} with reasonable efficiency in aqueous solutions. Fig 4 shows a typical industrial wastewater channel for treated wastewater into a river body.

Fig. 4. A wastewater channel in an industrial facility

Works on the use of periwinkle shells as bio-filters for wastewater treatment are scarce and almost non-existent in the open literature. However, Uzukwu et al. [116] investigated the economics of using periwinkle shell bio-filters against commercial bio-filters. In their work, two separate $3m^3$ tanks were set up for catfish reticulating aquaculture systems. The tanks consisted of a vertical flow trickling periwinkle shell bio-filters and commercial bio-filters, respectively. Each tank was stocked with 400 juveniles / m^3. Fish growth was monitored at a four-week interval, while water quality was monitored daily. Based on net present value, profitability index, and pay-out time, it was found that using periwinkle shell bio-filters was cheaper compared to using commercial bio-filters. However, the efficiency of the periwinkle shell bio-filter was not reported. Consequently, periwinkle shells utilization as bio-filters in wastewater treatment, town water purification, and aquaculture should be further investigated.

4.3 Fluid Loss Additive in Drilling Fluids

Drilling mud often referred to as drilling fluid, refers to a viscous fluid mixture used in the oil and gas well construction to help lift drilled formation cuttings from the hole section to the surface. It also assists in the cooling and lubrication of the drilling bits. Other significant functions of the drilling mud are helping to control formation pressures, stabilize the well, prevent it from collapsing, and prevent formation materials from entering the well [117]. The drilling mud comprises various additives which help in the efficient construction of the oil and gas well. Among these additives is the fluid loss additives or loss circulation materials. Fluid loss additives are materials in the drilling fluid which helps in minimizing the rate of fluid loss into the formation, thereby enhancing filtration control [118]. To improve the filtration control efficiency of the drilling mud, fibrous, flaky, or granular materials have been proposed as fluid loss additives in plugging the pores, thereby minimizing fluid loss. Consequently, various materials like starch, guar gum, polysaccharides, acrylic polymers are common fluid loss additives used in the oil and gas industry. Recent research has investigated the use of materials like the amphoteric polymer [119], silicon nanoparticles from sugar cane bagasse [120], and environmentally friendly corn cobs and coconut shells [121] as suitable fluid loss additives in drilling mud. However, reports on the use of waste shells as fluid loss additives are limited in the literature.

In the light of this, Igwe and Kinate [122] investigated the use of a different species of periwinkle shells (*Littorina littorea*) as fluid loss control additive in water-based drilling mud. The washed and dried shells were calcined at 995°C in an electric muffle furnace and then re-dried and ground into fine particles to form the periwinkle shell ash. Varying mass of the periwinkle ash (2g, 2.5g, and 3g) was used in preparing three mud samples, with a control mud sample without the periwinkle shell ash as the benchmark. According to API RP 13B-1 standard [123], a static filtration test was performed with the mud samples for 30 minutes. Filtration control properties like the filtrate volume and filtrate cake thickness were investigated. It was found that the mud formulated with 2g of periwinkle shell ash had a minimum filtrate volume of 6.7ml and a minimum filter cake thickness of 0.75mm. These results indicate that periwinkle shell ash could be used as fluid loss additives in drilling fluid formulation. However, the application needs further investigation and scale-up. Other waste shell materials should be investigated as fluid loss control additives in the formation of drilling fluids for oil and gas wells.

4.4 Polymer Composites

Composites have gained wider acceptance in almost all human endeavors, including engineering, aerospace, medical equipment, sporting goods, marine applications, wind energy, electronics, and chemical protection equipment [124,125] due to their numerous advantages. They synergize the properties of constituent materials to form a single reinforced material more useful structurally or functionally than any of the constituents alone. A composite is any material made up of at least two or more distinct phases, namely, matrix and dispersed. The matrix phase is the primary continuous phase, while the dispersed phase is the reinforcing phase.

Polymer matrix composites are very popular; hence they are the most used commercial composites. This is due to their relatively low cost and simple fabrication methods, among other advantages [126]. Consequently, they have increasingly been used as an alternative to conventional materials like metals in many industrial applications. The matrix phase is usually a polymer or resin made up of polyester, vinyl ester, epoxy, phenolic, polyimide, polyamide, or polypropylene. The reinforcement phase can include carbon fibers, glass, silica fillers, or other suitable materials. The suitability of low-cost waste shells as a reinforcement phase in polymer composites has been investigated and reported in the open literature [63, 127-129]. Studies on the effects of CaO on the properties of polymer composites have been conducted and reported in the literature [130, 131]. Hence, cheap, biodegradable, and lightweight waste shells are becoming better alternative sources of CaO than their inorganic counterparts [132 –135]. In this regard, some studies, though limited, have been conducted to ascertain the suitability of periwinkle shells as a reinforcement phase in the production of various composite materials.

In one study, Onuoha [136] investigated the tribologicalbehavior of periwinkle shell ash and recycled polypropylene composites. The composites were made with the injection molding technique. They contained 100g of virgin polypropylene, 100g of recycled polypropylene, and 5, 10, 15, 20, and 25 wt% respectively of periwinkle shell ash as fillers. The wear resistance, impact strength, and fatigue strength properties of the composites were investigated using the standard test methods of ASTM D4060, ASTM D256, and ASTM D671, respectively. The study revealed that while the composites' wear resistance and fatigue strength improved consistently with an increasing percentage of periwinkle shell powder filler, there was a decrease in the impact strength.

Furthermore, Onuoha et al. [75] investigated the physical and morphological properties of the periwinkle shell-filled recycled polypropylene composites. The study examined the specific gravity, water absorption tendency, flame retardant property, and solvent sorption properties of the developed composites. It was found that the specific gravity of the composite increased with the filler loading due to the higher density of the periwinkle shells and the enhanced dispersion of finer particle sizes. Also, the water and solvent sorption abilities of the composites increased with the filler loading. The flame retarding characteristics of the composites decreased with an increase in the filler loadings. According to the authors, these results give credence that the periwinkle shell can be used as fillers to produce good quality recycled polypropylene composites. However, these studies are limited and require further investigations.

Particleboard, a viable alternative to plywood, is primarily used in buildings, furniture, and speakers (for sound deadening. Environmental concerns, wood shortages, and the low cost of non-wood materials have led to natural fibers and other non-wood materials for particleboard production in recent times [137]. Hence particleboards have been developed from composites of polystyrene and bamboo waste [138], sunflower stalks using urea-formaldehyde resin [139], corn husks and citric acids [140], stems of the cotton plant, and bone adhesives [141], kenaf (*Hibiscus cannabinus* L.) stalks

[142], wheat straw and corn pith [143] and lignocellulosic particles of (*Prosopis cineraria* L.) Druce [144]. However, studies on the use of periwinkle shells for particleboard production are limited.

In their work Abdullahi and Sara, [145] investigated the suitability of a periwinkle shell polymer composite for particleboard manufacture. The composites were developed with periwinkle shell ash as the reinforcement, and recycled polyethylene from *pure water* sachets, as the matrix using the compression molding method. In the study, periwinkle shell ash weights of 5 to 25 wt%, was investigated. To determine the composite composition with the best quality, composite properties like water absorption, density, modulus of rupture (MOR), thickness swelling, modulus of elasticity (MOE), ultimate tensile strength (UTS), percentage elongation (EI), and tensile modulus (E), were determined. It was found that the mechanical properties of the produced polyethylene composites were enhanced up to 10 wt% of periwinkle shell ash filler loading. Also, the developed polyethylene composites were suitable for use in particleboard production as their MOR satisfied the EN 312-2 minimum MOR requirements for general-purpose boards. However, more studies are required to establish the suitability of periwinkle shells and other waste shells for particleboard production.

Polymer matrix composites developed with the periwinkle shell have been reported to be effective abrasives. Abrasives are materials used for processing other materials to finished or polished shapes by rubbing or grinding on them to gain a smooth surface. They are used to wear away the surfaces of other less resistant materials. They are cutting tools characterized by high hardness, sharp edges, and good cutting ability [146]. The use of abrasive materials has aided the manufacturing industry to produce components with exact geometry and ultra-smooth surfaces required in automobiles, furniture, domestic appliances, industrial equipment, aerodynamic and hydrodynamic vehicles, mechanical and electrical appliances, and machine tools. The use of low-cost yet efficient abrasive materials made from locally sourced materials has been investigated and reported in the open literature. In one such study, Wai and Lily [147] developed sandpaper abrasive using silicon sand (quartz) as the abrasive grit and epoxy resins as binders. The efficiency of the abrasive sandpaper was consistent with the properties of commercial sandpapers, and the manufacturing of the developed abrasive sandpaper was recommended.

In a similar study, Obot et al. [148] developed sandpaper using periwinkle shell grains as the abrasive grits and polyester resin as the binder. The sandpaper abrasive was made up of periwinkle shell grain, polyester resin, cobalt naphthalene accelerator, and methyl ethyl ketone peroxide catalyst in different percentage compositions. The periwinkle shells were ball milled using the FEPA grits standards and the ASTM E11 sieving techniques into P40, P60, and P140 grit sizes and then developed into polymer matrix composites. To ascertain the effectiveness of the developed sandpaper, abrasive properties like hardness, compressive strength, and wear resistance, were investigated. It was found that while hardness and compressive strength increased, wear resistance decreased with an increase in the polyester resin content. The optimum composition for the most improved abrasive properties was found to be 87 wt. % periwinkle shell grains, 12 wt. % polyester resin, 0.5 wt. % cobalt naphthalene accelerator, and 0.5 wt. % methyl ethyl ketone peroxide catalyst. Furthermore, the scanning electron microscope (SEM) images showed good interfacial bonding between the periwinkle shell grains and the polyester resin, with less distortion from compressive stresses and less grain pull-out from wear, for the optimum composition. These results show that periwinkle shells could be effective when used to produce polyester matrix composite abrasives.

4.5 Bio-medical Applications

In orthopedic medicine, biomaterials are often used to make prosthetic devices to replace bones and bone fillers in the human body. However, these biomaterials must be compatible with the environment in which it is to be placed and must possess good physicomechanical properties and thermal stability [149]. Some researchers [60, 150, 151] have reported that $CaCO_3$ chitin materials from waste shells can be used to produce the compound calcium phosphate (hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$), which is the primary mineral constituent of human bones. They also found that calcium phosphate (hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$) was compatible with the human body, and as such, can be used to make artificial bones or used as bone fillers in bone engineering.

Periwinkle shells and other waste shells contain chitin [10, 11, 152]. Chitin is a polymer consisting of *N*-acetylglucosamine subunits joined by covalent β-(1→4)-linkages. It is structurally like cellulose and functionally similar to the protein keratin. It exists naturally in the exoskeletons of arthropods, mollusk shells, and fish scales. Chitin is the second most abundant biopolymer, after cellulose, and can be used in food preservation, medicine, paper manufacturing, and fillers in numerous bio-polymer composite materials [153, 154].

In their study to extract good quality chitin from periwinkle shells, as bio-fillers in bone fixation materials, Gbenebor et al. [155] demineralized the shells at 32°C by soaking 100 g of the samples in 1.5, 1.7, and 1.9M HCl, respectively. The demineralized samples were washed with distilled water to a pH of 7, filtered, and oven-dried at 70 °C for 4 hours to constant weights. The samples were then deproteinized by heating in 0.4, 0.8, and 1.2M NaOH solutions at 100°C for 1 hour and subsequently soaked in new sets of the same NaOH concentrations for another 18 hours for effective protein removal. The deproteinizedsamples were depigmented and bleached by soaking them in a 1M H_2O_2 solution at 32°C for 24 hours. Successful extraction of $CaCO_3$ from the periwinkle shells was achieved, and the resulting chitin extracted was found to be of good quality. The successful removal of $CaCO_3$ and the subsequent extraction of high-grade chitin was confirmed from the images of the scanning electron microscope (SEM) with energy dispersive X-ray (EDS). The absence of $CaCO_3$ and the predominance of carbon and hydrogen contents indicated in the EDS image of the demineralized (acid-treated) sample showed the presence of a chitin structure. Furthermore, the fibrillar structure in the extracted chitin was attributed to the presence of a high OH bond, which is a fundamental characteristic indicative of high-grade chitin [155]. These results, therefore, indicate the possibility of extracting high-grade chitin from periwinkle shells for numerous industrial applications. However, the amount of chitin extracted from a specific mass of periwinkle shells was not reported and hence, should be further investigated.

4.6 Development of Asbestos-free Brakepads

The importance of brakepads in industrial machines, especially automobiles, cannot be overemphasized. It is responsible for slowing down and ultimately bringing a moving object to a stop by converting kinetic energy to heat energy through the pads and disc friction. Brakepads are made up of steel plates with an attached binding friction material [156], usually made up of varying compositions of abrasives, lubricants, binders, fillers, and performance modifiers. During the early brakepads development era, asbestos, a hydrated magnesium silicate [157], was primarily used as fillers due to its numerous advantages. These advantages resulted in the continuous use of asbestos in the development of brakepads. However, asbestos dust emanating from the grinding of the brakepads on the disc drums is carcinogenic [156, 158, 159], making the continuous use of asbestos brakepads a public health concern. Consequently, various studies and investigations on developing asbestos-free brakepads using other cost-effective and environmentally friendly materials are becoming more rampant. Alternative materials such as sugar cane bagasse [156], palm kernel shell [158], rice straw and rice husk dust [160], waste coconut shells [161], and coconut fiber [162], have been successfully used as a viable replacement for asbestos in brakepad development.

Using periwinkle shells to replace asbestos is effective compared to commercial asbestos brakepads [163]. In one such study, Aku et al. [164] investigated the suitability of periwinkle shells for brakepad development. The X-ray diffractometer and thermogravimetric analysis were used for the characterization of the shells. The tribological properties of the shells, like density, hardness, and wear rates, were measured. It was found that periwinkle shells can be used as replacements for asbestos in brakepad development. Furthermore, Amaren et al. [165] investigated the effect of periwinkle shell particle sizes on the wear behavior of the asbestos-free brakepad using phenolic resin as the binder. The pin on disk machine method was used to determine the wear rate by varying the sliding speed, temperature, and applied load while varying the periwinkle shell sizes from 125 to 710 µm. It was found that while the optimum periwinkle particle size for best wear resistance was 125 µm, the wear rate increased with increasing sliding speed, applied load, temperature, and periwinkle shell particle size. The coefficient of friction was found to be within acceptable recommended standards for automobile brakepads, indicating that periwinkle shell particles could effectively be used as a replacement for asbestos in brakepad development.

In a similar study, Yawas et al. [166] investigated the morphology and properties of brakepads made from periwinkle shells and 35% resin. The study was done to ascertain the suitability of the periwinkle shell particles as a replacement for asbestos in brakepads manufacture. Periwinkle particle sizes varied from 710 to 125 µm, and the physical, mechanical, and tribological properties of the different particle size brakepad were measured. It was found that the compressive strength, density, and hardness of the brakepads, increased with decreasing periwinkle particle sizes from 710 to 125 µm, while the oil soak, wear rate, and water soak decreased with decreasing particle sizes. The brakepads developed with 125 µm particle size compared to commercial asbestos brakepads. This indicates that a 125 µm periwinkle shell particle size is a suitable replacement for asbestos in brakepad manufacture.

5. PERSPECTIVES FOR FUTURE STUDIES

Reported investigations on using periwinkle shells to improve the geotechnical properties of waterlogged and lateritic soils, to develop composites (particleboard, abrasives, bio-fillers in orthopedic medicine), and to formulate fluid loss control additives in drilling mud, are very limited in the published literature. These limited studies call for further investigation. These investigations are imperative because the source and content of $CaCO_3$ from different shells could strongly influence the performance and properties of the shell-derived products [70]. Other potential areas of application of the periwinkle shell that require further investigation are presented.

5.1 Concrete, Ceramics and Synthetic Stones

One central area of application of periwinkle shells that has shown some success is the building material and construction industry. To some extent, periwinkle shells have been used as aggregates and partial replacements for cement in lightweight concrete. However, limited research exists on using periwinkle shells to replace cement mortar for masonry and plastering.

Recently, studies have shown that waste shells can be deployed to manufacture ceramics such as tiles and mugs. The fine powder form of the shells is bio-ceramic [167]. In one study, Silva et al. [64] developed synthetic stones from waste oyster shell powder and polymeric resins for tabletop and workbench surfaces. The mechanical and physical properties of the manufactured synthetic stones were relatively similar to those of commercial marble and granite stones. The development of ceramic and synthetic stones was studied using only oyster shells. Also, Hao et al. [65] successfully developed ceramic-like materials using oyster shells and concluded that waste shells have great potential as materials for ceramic production. Studies on periwinkle shells and other waste shells for producing synthetic stones and ceramic mugs and tiles are rare. Using waste shells as a complete or partial replacement for conventional ceramic and artificial stone raw materials could be a viable strategy for proper waste management, environmental sustainability, and wealth creation. Consequently, further studies should be conducted using periwinkle shells to produce synthetic stones, ceramic tiles, and mugs for various applications.

5.2 Wastewater Treatment and Noxious Gas Capture

Waste shells have been used for the removal of heavy metals from wastewater effluents. In some of the studies, waste shells were shown to be more efficient in removing lanthanum [22], phosphorous [168], and boron [169] from wastewater compared to broken bricks, gravel, and zeolite. They are also effective in dye treatment and color removal [33, 34, 170] and for domestic and municipal wastewater treatment [29, 30, 171]. In many of these studies, only oyster and clam shells were used as the bio-filter medium. Waste shells have also been used as a liming agent in acidic soil treatment due to their high amount of $CaCO_3$ [172]. In this regard, mussel and oyster shells have shown significant efficiency in the bioremediation of contaminated soils [58, 173]. The use of periwinkle shellsto treat wastewater effluents is limited. Only metals like lead, copper, cadmium, nickel, and cobalt removal from wastewater have been investigated in very limited studies. Its use in removing phosphates and phosphorous, boron, and other numerous heavy and poisonous metals found in wastewater is minimal and nearly non –existent in the open literature. Also, studies on periwinkle shells as bio-filters for wastewater treatment, liming, and bioremediation agents in contaminated soils are scarce. Consequently, further investigation of periwinkle shells for wastewater treatment and bioremediation of contaminated soils is imperative.

Poisonous gaseous emissions resulting from industrialization and other economic activities usually result in severe air pollution, which constitutes environmental hazards detrimental to humans, plants, and animals [174]. Some of these emissions dissolve in rainwater in the atmosphere to form acid rain, which in turn falls back to the earth, contaminating the soil, plants, water bodies [175], and corroding roofing sheets and other materials. For instance, in the Niger Delta region of Nigeria, one of the major sources of air pollution is the continuous gas flaring and gaseous emissions emanating from artisanal oil refining. The release of these hydrocarbon effluents into the environment cause severe damage to both land and marine ecosystem [176-178]. Figs 5 to 7 show the impact of air pollution due to artisanal oil refining and gas flaring in parts of Port Harcourt metropolis, Nigeria. Fig 5 shows some parts of Port Harcourt city's poor visibility due to the gaseous emissions and soot. Fig 6 shows the effect of pollution over two months on mosquito-treated nets used indoors in Port Harcourt city compared to a treated net used in a location in Jos town, Nigeria, where pollution is less severe. Fig 7 compares clean water and wastewater from indoor domestic cleaning in Port Harcourt metropolis.

Fig. 5. Poor visibility due to severe air pollution in parts of Port Harcourt metropolis

Fig. 6. Effect of pollution on indoor mosquito treated nets in Jos town (a) and parts of Port Harcourt metropolis (b).

Fig. 7. Comparison between clean water and waste water from indoor domestic cleaning in Port Harcourt

Green adsorbents for capturing poisonous gases are beginning to gain wider acceptance [179 – 181] due mainly to their environmental compatibility. In this regard, waste shells have been deployed as adsorbents for odorous and acid gas conditioning [43, 182]. Waste shell materials as alternative materials for gas conditioning are economical and vital for waste management and reuse. In this regard, Jong-Hyeon et al. [43] showed that waste shells, particularly oyster shells, can be used for acid gas treatment in gaseous effluents. In similar studies, quail eggs and oyster shells [183], chicken eggshells [184], and oyster shells [185], have been used to adsorb carbon IV oxide from flue gases successfully. The successful removal of CO_2 can be attributed to the presence of CaO in the shells, which tends to adsorb acid gases. However, there are limited studies on waste shell utilization as acid and odorous gas treatment agents in the literature. Studies using periwinkle shells as adsorbents for capturing acid and odorous gases from gaseous effluents are scarce, if not non-existent, in the available literature. Consequently, studies on the use of periwinkle shells as adsorbents for sequestering odorous and acid gases should be further investigated.

5.3 Heterogeneous Catalysts

Calcium oxide (CaO) derived catalyst has become a leading area of catalyst research for bio-diesel production through the trans-esterification process [44 - 46]. Biodiesel production has gained considerable attention due to the negative environmental consequences of using conventional diesel from fossil fuels. As a result, researchers are exploring the use of waste shells that contain a high percentage of $CaCO_3$, from which CaO can be obtained by calcination of the $CaCO_3$ at high temperatures of between 700 – 1000 ^oC [186 – 188]. Snail [47, 189] mussel, scallop, cockle, oyster, and pyramidella [48, 49] shells, have mainly been investigated as CaO derived catalyst materials for biodiesel production, with adequate biodiesel yields of more than 90% at considerable operating conditions. CaO has also been found to be an effective catalyst in the production of hydrogen gas. In one study, Assabumrungart et al. [190] investigated the thermodynamics of the production of hydrogen gas from biogas using CaO catalyst. The thermodynamics of hydrogen production was found to be favorable.

Consequently, CaO has been used successfully in the catalytic gasification of biomass and coal to produce hydrogen gas [191]. Also, Taufiq – Yap et al. [51] used eggshells in the catalytic gasification of wood to produce hydrogen gas. Reported investigations on the use of periwinkle shells as a heterogeneous catalyst for biodiesel and hydrogen production in the open literature rarely exist. The utilization of these waste shells as a catalyst will aid waste recycling and management. Hence further investigations on its use as a catalyst for hydrogen gas and biodiesel production are required.

5.4 Calcium Supplements

Calcium supplements are an integral part of livestock and poultry bone and eggshell development [192]. In most cases, $CaCO_3$ from finite non-renewable limestone resources is used as a calcium supplement. Studies have validated the use of potentially cheap $CaCO_3$ from waste shells as a calcium supplement. Consequently, oyster shells are a valuable source of more affordable calcium supplements [53]. Accordingly, Oso et al. [54] found that using oyster and mussel shells as a calcium supplement in poultry was effective. However, studies on the use of periwinkle shells as calcium supplements for poultry and livestock egg and bone development rarely exist in the literature, and as such, needs further investigation.

5.5 Gravel Packs, Fluid Proppants and Molecular Sieves

The compositional analysis of periwinkle shells shows that they contain mainly CaO and SiO_2, followed by Fe_2O_3 and Al_2O_3,in significant quantities when calcined at 800 ^oC and above. Silicon, iron, and aluminum can provide some mechanical strength and resilience to the periwinkle shell. The strength and resilience of the shells can make them suitable replacements for gravel packs in oil and gas wells and fluid proppants for hydraulic fracking in low permeability reservoirs. Gravel packs are granular media made up of clean, round natural sand, gravel, or synthetic material held in place by screens inside the well [193]. Periwinkle shells can be investigated for use as a partial or complete replacement of gravel packs (made from finite non-renewable materials) for sand prevention and exclusion in oil and gas wells. Furthermore, the application of the shells as replacements for conventional fluid proppants, mostly made of sand and ceramic materials [194] for the hydraulic fracking of low permeability formations, can be further investigated.

Also, molecular sieves used for gas conditioning (dehydration and sweetening) are made of zeolites mainly consisting of alumino-silicate compounds [195]. Periwinkle shells contain good proportions of silicon and aluminum compounds. Therefore, they should be investigated for use as a partial or complete replacement for zeolite in packed bed columns for natural gas conditioning and biogas upgrading.

6. CONCLUSION

The waste generated by periwinkle shells can result in a substantial environmental problem resulting in severe sanitation and public concern if not properly disposed. This review has highlighted the environmental concerns associated with the indiscriminate disposal of the periwinkle shells and the various reuse options for the shells. These varieties of periwinkle shell applications will contribute to wealth creation and reduce the negative environmental consequences associated with its indiscriminate disposal. The conclusions from this study are highlighted as follows.

1. A periwinkle shell ash replacement of not more than 10% is effective as a partial replacement for cement in lightweight concrete.
2. When used as aggregates in lightweight concrete, periwinkle shells of up to 25% is adequate based on compressive strength.
3. Further studies on the efficiency of an optimum 6% periwinkle shell to improve the geotechnical properties of lateritic soils should be further investigated.
4. Periwinkle shell ash is effective for the removal of heavy metals from wastewater. Composites of periwinkle shell ash, rice, and coconut husks, are more effective than periwinkle shell ash alone.
5. An optimum periwinkle grain size of 125μm is an adequate replacement for asbestos in brakepads production.
6. Good quality chitin can be extracted from periwinkle shells.
7. Periwinkle shell grains of up to 87% can be adequate for producing sandpaper abrasives.
8. Particleboards can be developed from periwinkle shells. However, further investigation is required.
9. The development of synthetic stones and ceramic mugs, and tiles using periwinkle shells should be investigated.
10. The use of periwinkle shells as heterogeneous catalysts for biodiesel and hydrogen gas production should be investigated.
11. Studies on using periwinkle shells as a fluid loss additive in the formulation of drilling mud should be further investigated.
12. The adequacy of periwinkle shells as replacements for gravel packs and fluid proppants in oil and gas wells should be investigated.
13. Studies on the development of low-cost adsorbents for the adsorption of harmful gases using periwinkle shells should be carried out.
14. Using periwinkle shells as replacement for molecular sieves for gas conditioning and biogas upgrading should be investigated.
15. The effectiveness of calcium supplements derived from periwinkle shells for livestock and poultry should be investigated.

16. Periwinkle shells should be investigated as biofilters for wastewater treatment, soil liming, and bioremediation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ahmed YA, Ayman MO, Afaf, AM. Effect of using waste cement dust as mineral filler on the mechanical properties of hot mix asphalt. Assuit University Bulletin for Environmental Researches. 2006;9:55-59.
2. Gichamo T, Gökçekuş H. Interrelation between climate change and solid waste. Journal of Environmental Pollution and Control. 2019;2 :1 -7.
3. Bogner J, Pipatti R, Hashimoto S, Diaz C, Mareckova K, Diaz L, . Kjeldsen P, Monni S, Faaij A, Gao Q, Zhang T, Ahmed MA, Sutamihardja RT, Gregory R. Intergovernmental Panel on Climate Change (IPCC) Working Group III (Mitigation). Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report.), Waste Management Resource. 2008;26:11-32.
4. USEPA, 2006: Accessed on March 2021. Available: https://www.epa.gov/p2/learn-about-pollution-prevention.
5. Mo KH, Alengaram UJ, Jumaat MZ, Lee SC, Goh WI, Yuen CW. Recycling of seashell waste in concrete: A review, Construction and Building Materials. 2018;162:751–764. DOI.org/10.1016/J.CONBUILDMAT.2017.12.009
6. Sawai J. Antimicrobial characteristics of heated scallop shell powder and its application. Biocontrol Science. 2011;16 (3): 95–102.
7. Nguyen DH, Boutouil M, Sebaibi N, Baraud F, Leleyter L. Durability of pervious concrete using crushed seashells, Construction and Building Materials. 2017;135:137–150. DOI.org/10.1016/j.conbuildmat.2016.12.219 0950-0618/Ó 2017
8. Barros MC, Bello PM, Bao M, Torrado JJ. From waste to commodity: transforming shells into high purity calcium carbonate. Journal of Cleaner Production. 2009;17 (3):400–407. DOI: 10.1016/j.jclepro.2008.08.013
9. Maruthiah T, Palavesam A. Characterization of haloalka-lophilic organic solvent tolerant protease for chitin extraction from shrimp shell waste, International Journal of Biological Macromolecules. 2017; 97:552–560. DOI:10.1016/j.ijbiomac.2017.01.021
10. Rasti H, Parivar K, Baharara J, Iranshahi M, Namvar F. Chitin from the mollusk Chiton: extraction, characterization, and chitosan preparation, Iranian Journal of Pharmaceutical Research. 2017;16(1) :366–379.
11. Hamdi M, Hammami A, Hajji S, Jridi M, Nasri M, Nasri R. Chitin extraction from blue crab (Portunussegnis) and shrimp (Penaeuskerathurus) shells using digestive alkaline proteases from P. segnis viscera, International Journal of Biological Macromolecules. 2017;101:455 – 463. DOI:10.1016/j.ijbiomac.2017.02.103
12. Jovic M, Mandic M, Šljivic-Ivanovic M, Smiciklas I. Recent trends in application of shell waste from mariculture, Studia Marina. 2019;32 (1):47-62.
13. Safi B, Saidi M, Daoui A, Bellal A, Mechekak A, Toumi K. The use of seashells as a fine aggregate (by sand substitution) in self-compacting mortar (SCM), Construction and Building Materials. 2015;78:430–438.
14. Soltanzadeh F, Emam-Jomeh M, Edalat-Behbahani A, Soltan-Zadeh Z Development and characterization of blended cements containing seashell powder, Construction and Building Materials. 2018;161: 292–304. DOI.org/10.1016/j.conbuildmat.2017.11.111
15. Wang J, Liu E, Li L. Characterization on the recycling of waste seashells with Portland cement towards sustainable cementitious materials. Journal of Cleaner Production. 2019;220:235–252. DOI.org/10.1016/j.jclepro.2019.02.122.
16. Yang EI, Yi ST, Leem YM.. Effect of oyster shell substituted for fine aggregate on concrete characteristics: Part I. Fundamental properties, Cement and Concrete Research. 2005;35(11): 2175–2182. DOI.org/10.1016%2Fj.cemconres.2005.03.016

17. Yang EI, Kim MY, Park HG, Yi ST. Effect of partial replacement of sand with dry oyster shell on the long-term performance of concrete. Construction and Building Materials. 2010;24 (5):758–765.
18. Egerić M, Smičiklas I, Mraković A, Jović M, Šljivić-Ivanović M, Sokolović J, Ristić M. Separation of Cu (II) ions from synthetic solutions and wastewater by raw and calcined seashell waste, Desalination and Water Treatment. 2018;132:205–214. DOI: 10.5004/dwt.2018.23131.
19. Papadimitriou CA, Krey G, Stamatis N, Kallianiotis A. The use of waste mussel shells for the adsorption of dyes and heavy metals, Journal of Chemical Technology and Biotechnology. 2017;92:1943– 1947.
20. Peña-Rodríguez S, Fernández-Calviño D, Nóvoa-Muñoz JC, Arias-Estévez M, Núñez-Delgado A, Fernández-Sanjurjo MJ, Álvarez-Rodríguez E. Kinetics of Hg (II) adsorption and desorption in calcined mussel shells,Journal of Hazardous Materials. 2010;180: 622–627.
21. Wu Q, Chen J, Clark M, Yu Y. Adsorption of copper to different biogenic oyster shell structures. Applied Surface Science. 2014;311:264–272. DOI.org/10.1016/j.apsusc.2014.05.054.
22. Onoda H, Nakanishi H. Preparation of calcium phosphate with oyster shells, Natural Resources. 2012;3 (2):71–74.
23. Naik S, Megha BS, Aishwarya J, Shwetha, Wastewater treatment using shells of marine source. Research Journal of Chemical and Environmental Sciences. 2016;4 [4S] :123-128.
24. Dorris K, Removal of Heavy Metals from Wastewater Using Crab shells. 2021. Accessed on the 4th of March 2021. Available: https://www.lamar.edu/arts-sciences/_files/documents/chemistrybiochemistry/dorris/removal-of-heavy-metals.pdf.
25. Park HJ, Jeong SW, Yang JK, Kin BG, Lee, SM. Removal of heavy metals using waste eggshell, Journal of Environmental Sciences. 2007;19(12):1436 – 1441.
26. Weerasooriyagedra MS, Kumar SA. A review of utilization of Mollusca shell for the removal of contaminants in industrial wastewater, International Journal of Scientific and Research Publications. 2018;8 (1):282 – 287.
27. Jones MI, Wang LY, Abeynaike A, Patterson DA. Utilization of waste material for environmental applications: calcination of mussel shells for wastewater treatment, Advances in Applied Ceramics. 2011;110 (5):280 – 286.
28. Zukri NI, Khamidun MH, Sapiren MS, Abdullah S, Rahman MA. Lake water quality improvement by using waste mussel shell powder as an adsorbent, IOP Conference. Series: Earth and Environmental Science. 2018;140. 012057.
29. Liu Y, Yang TO, Yuan D, Wu X. Study of municipal wastewater treatment with oyster shell as biological aerated filter medium, Desalination. 2010;254:149–153. DOI.org/10.1016/j.desal.2009.12.003.
30. Shih PK, Chang WL. The effect of water purification by oyster shell contact bed, Ecological Engineering. 2015;77: 382–390.
31. El Haddad M, Regti A, Laamari MR, Slimani R, Mamouni R, El Antri S, Lazar S. Calcined mussel shells as a new and eco-friendly biosorbent to remove textile dyes from aqueous solutions, Journal of the Taiwan Institute of Chemical Engineers. 2014a;45:533–540.
32. El Haddad M, Regti A, Slimani R, Lazar S. Assessment of the biosorption kinetic and thermodynamic for the removal of safranin dye from aqueous solutions using calcined mussel shells, Journal of Industrial and Engineering Chemistry. 2014b;20: 717–724.
33. Suteu D, Bilba D, Doroftei F, Malutan T Sorption of brilliant red HE-3B reactive dye from aqueous solution onto seashells waste: Equilibrium and kinetic studies, Separation Science and Technology. 2011;46 (9):1462–1471. DOI.org/10.1080/01496395.2011.561514.
34. Suteu D, Bilba D, Aflori M, Doroftei F, Lisa G, Badeanu M, Malutan T. The seashell wastes as biosorbent for reactive dye removal from textile effluents. Clean – Soil, Air, Water. 2012;40 (2):198–205. DOI.org/10.1002/clen.201100138.
35. Balali-Mood M, Riahi-Zanjani B, Ghorani-Azam A. Effects of air pollution on human health and practical measures for prevention in Iran, Journal of Research in Medical Sciences. 2016; 21(65) .
36. Kumar P, Kim KH, Kwon EE, Szulejko JE, Metal-organic frameworks for the control and management of air quality: Advances and future direction, Journal of Material Chemistry A. 2016;4(2):345 – 361. doi: 10.1039/C5TA07068F.
37. Barbusinski K, Kalemba K, Kasperczyk D, Urbaniec K, Kozik V. Biological

methods for odor treatment: a review, Journal of Cleaner Production. 2017;152:223–241.
DOI: 10.1016/j.jclepro.2017.03.093.

38. Le Cloirec P, Pré P, Delage F, Giraudet S. Visualization of the exothermal VOC adsorption in a fixed bed activated carbon adsorber, Environmental Technology. 2011;33(3):285-290.
DOI.org/10.1080/09593330.2011.571713
39. Han X, Yang S, Schroder M. Porous metal-organic frameworks as emerging sorbents for clean air. Nature Reviews Chemistry;2019 .
DOI.org/10.1038/s41570-019-0073-7.
40. Das N, Alam A, Ansari M, Bera R. Triptycene, Phenolic-OH, and Azo-Functionalized Porous Organic Polymers: Efficient and Selective CO_2 capture, ACS Applied Polymer Materials. 2019;1(5): 959-968.
41. Mittal G, Dhand V, Yop K, Par S, Ro W. A review of carbon nanotubes and graphene as fillers in reinforced polymer nanocomposites, Journal of Industrial and Engineering Chemistry. 2015; 21:11–25.
DOI.org/10.1016/j.jiec.2014.03.022.
42. Aimikhe VJ, Eyankware OE, Adsorbents for Noxious Gas Sequestration: State of the Art, Journal of Scientific Research and Reports. 2019; 25(1&2):1-21.
43. Jong-Hyeon J, Kyung-Seun Y, Hyun-Gyu K, Hyung-Keun L, Byung-Hyun S. Reuse of waste oyster shells as a SO2/NOx removal absorbent, Journal of Industrial and Engineering Chemistry. 2007;13:512–517.
44. Kawashima A, Matsubara K, Honda K. Acceleration of catalytic activity of calcium oxide for biodiesel production, Bioresource Technology. 2009;100: 696–700.
45. Kouzu M, Umemoto M,Kasuno T, Tajika M, Aihara Y, Sugimoto Y, Hidaka J. Biodiesel production from soybean oil using calcium oxide as a heterogeneous catalyst, Journal of the Japan Institute of Energy. 2006;85: 135–141.
46. Liu X, He H, Wang Y, Zhu S, Piao X. Transesterification of soybean oil to biodiesel using CaO as a solid base catalyst. Fuel. 2008;87: 216–221.
47. Laskar IB, Rajkumari K, Gupta R, Chatterjee S, Paul B, Rokhum L. Waste snail shell derived heterogeneous catalyst for biodiesel production by the transesterification of soybean oil, RSC Advances. 2018;8: 20131–20142.
48. Buasri A, Chaiyut N, Loryuenyong V, Worawanitchaphong P, Trongyong S. Calcium oxide derived from waste shells of mussel, cockle, and scallop as the heterogeneous catalyst for biodiesel production, The Scientific World Journal. 2013;1 – 7.
DOI.org/10.1155/2013/460923.
49. Buasri A, Rattanapan T, Boonrin C, Wechayan C, Loryuenyong V. Oyster and Pyramidella shells as heterogeneous catalysts for the microwave-assisted biodiesel production from Jatrophacurcas oil, Journal of Chemistry. 2015;1 – 7.
doi.org/10.1155/2015/578625.
50. Perea A, Kelly T, Hangun-Balkir Y. Utilization of waste seashells and camelina sativa oil for biodiesel synthesis, Green Chemistry Letters & Reviews. 2016;9:27–32.
51. Taufiq-Yap YH, Wong P, Marliza ST, NurulSuziana NM, Tang LH, Sivasangar S. Hydrogen production from wood gasification promoted by waste eggshell catalyst, International Journal of Energy Research. 2013;37(14):1866–1871.
DOI.org/10.1002/er.3003.
52. Karoshi G, Kolar P, Shah SB, Gilleskie G, Das L. Calcined eggshell as an inexpensive catalyst for partial oxidation of methane. Journal of the Taiwan Institute Chemical Engineers. 2015;57:123–128.
53. Morris JP, Backeljau T, Chapelle G. Shells from aquaculture: a valuable biomaterial, not a nuisance waste product, Reviews in Aquaculture. 2019;11:42–57.
DOI.org/10.1111/raq.12225.
54. Oso AO, Idowu AA, Niameh OT. Growth response, nutrient and mineral retention, bone mineralization, and walking ability of broiler chickens fed with dietary inclusion of various unconventional mineral sources, Journal of Animal Physiology and Animal Nutrition. 2011;95: 461– 467.
55. Ok YS, Lim JE, Moon DE. Stabilization of Pb and Cd contaminated soils and soil quality improvements using waste oyster shells, Environmental Geochemistry and Health. 2011;33: 83–91.
56. Fernández-Calviño D, Cutillas-Barreiro L, Núñez-Delgado A, Fernández-Sanjurjo MJ, Álvarez-Rodriguez E, Nóvoa-Muñoz JC, Arias-Estévez M. Cu Immobilization and Loliumperenne Development in an Acid Vineyard Soil Amended with Crushed Mussel Shell, Land Degradation and Development. 2017;28 (2017) :762– 772.

57. Ahmad M, Lee SS, Lim JE, Lee SE, Cho JS, Moon DH, Hashimoto Y, Ok YS. Speciation and phytoavailability of lead and antimony in a small arms range soil amended with mussel shell, cow bone, and biochar: EXAFS spectroscopy and chemical extractions, Chemosphere. 2014; 95: 433–441.
58. Álvarez E, Fernández-Sanjurjo MJ, Seco N, Núñez A. Use of mussel shells as a soil amendment: Effects on bulk and rhizosphere soil and pasture production, Pedosphere. 2012; 22: 152–164.
59. Shen G, Zhang S, Liu X, Jiang Q, Ding W. Soil acidification amendments change the rhizosphere bacterial community of tobacco in a bacterial wilt-affected field, Applied Microbiology and Biotechnology. 2018;102: 9781–9791.
60. Wu SC, Hsu HC, Hsu SK, Tseng CP, Ho WF. Preparation and characterization of hydroxyapatite synthesized from oyster shell powders, Advanced Powder Technology. 2017;28 (4): 1154–1158. DOI.org/10.1016%2Fj.apt.2017.02.001
61. Morris JP, Report synthesizing the existing and potential uses of shells as by-products of the aquaculture industry. WP6: Mollusc shell production as a model for sustainable biominerals. Brussels, Belgium;2017.
62. Zhang G, Brion A, Willemin AS, Piet MH, Moby V, Bianchi A, Mainard D, Galois L, Gillet P, Rousseau M. Nacre, a natural, multi-use, and timely biomaterial for bone graft substitution, Journal of Biomedical Materials Research. Part A. 2017a;105(2):662–671. DOI: 10.1002/jbm.a.35939.
63. Yao Z, Xia M, Li H, Chen T, Ye Y, Zheng H. Bivalve shell: not an abundant useless waste but a functional and versatile biomaterial, Critical Reviews in Environmental Science and Technology. 2014;44 (22):2502–2530. DOI.org/10.1080/10643389.2013.829763.
64. Silva HT, Mesquita-Guimarae J, Henriques B, Silver FS, Fredel MC. The potential use of oyster shell waste in new value-added by-product, Resources. 2019;8(1):13. DOI.org/10.3390/resources8010013.
65. Hao L, Gao W, Yan S, Niu M, Liu G, Hao H. Preparation and characterization of porous ceramics with low-grade diatomite and oyster shell, Materials Chemistry and Physics. 2019; 235:121741. DOI:10.1016/j.matchemphys.2019.121741.
66. Tan YH, Abdullah MO, Nolasco-Hipolito C. The potential of waste cooking oil-based biodiesel using heterogeneous catalyst derived from various calcined eggshells coupled with an emulsification technique: A review on the emission reduction and engine performance, Renewable and Sustainable Energy Reviews. 2015;47:589–603. DOI.org/10.1016/j.rser.2015.03.048.
67. Tan YH, Abdullah MO, Nolasco-Hipolito C, Taufiq-Yap HY. Waste ostrich and chicken-eggshells as heterogeneous base catalyst for biodiesel production from used cooking oil: Catalyst characterization and biodiesel yield performance, Applied Energy. 2015b;160:58–70. DOI.org/10.1016/j.apenergy.2015.09.023.
68. Eziefula UG, Ezeh JC, Eziefula BI. Properties of seashell aggregate concrete: A review, Construction and Building Materials. 2018;192:287–300.
69. Hart A, Mini-review of waste shell-derived materials' applications, Waste Management and Research. 2020;38 (5):514 – 527.
70. Olivia M, Oktaviani R, Ismeddiyanto WG. Properties of concrete containing ground waste cockle and clam seashells, Procedia Engineering. 2017;171:658–663.
71. Hou Y, Shavandi A, Carne A, Bekhit AA, Ng TB, Cheung RF, Bekhit AE. Marine shells: Potential opportunities for extraction of functional and health-promoting materials, Critical Reviews in Environmental Science and Technology. 2016;46:1047–1116.
72. Olutoge FA, Okeyinka OM, Olaniyan OS. Assessment of the suitability of periwinkle shell ash (PSA) as partial replacement for ordinary Portland cement (OPC) in concrete, International Journal of Research and Reviews in Applied Sciences. 2012;10(3):428-434.
73. Bob-Manuel FG, A preliminary study on the population estimation of the periwinkles Tympanotonusfuscatus and Pachymelaniaaurita at the Rumuolumeni mangrove swamp creek, Niger Delta, Nigeria, Agriculture and Biology Journal of North America. 2012;3(6):265-270. DOI:10.5251/abjna.2012.3.6.265.270.
74. Fayeofori GB, A preliminary study on the population estimation of the periwinkles Tympanotonusfuscatus (Linnaeus, 1758) and Pachymelaniaaurita (Muller) at the Rumuolumeni mangrove swamp creek,

Niger Delta, Nigeria, Agriculture and Biology Journal of North America. 2012;3(6):265-270.
75. Onuoha C, Onyemaobi OO, Anyakwo CN, Onuegbu GC. Physical and morphological properties of periwinkle shell-filled recycled polypropylene composites, International Journal of Innovative Science, Engineering and Technology. 2017;4(5):186 – 196.
76. Jamabo N, Chinda A. Aspects of the ecology of tympanotonusfuscatusVarFuscatuis (Linnaeus, 1758) in the mangrove swamps of the upper bonny River, Niger Delta, Nigeria, Current Research Journal of Biological Sciences. 2010;2(1):42-47.
77. Jamabo NA, Alfred-Ockiya JF, Chindah AC. Growth, mortality, and recruitment studies of Periwinkle Tympanotonusfuscatusvar radula (Linnaeus, 1758) in the Bonny River, Niger Delta, Nigeria, Environment and Ecology. 2009;27(4):160-167.
78. Moruf RO, Some aspect of the biology of periwinkle (Tympanotonusfuscatus) var, radula in the mangrove swamp of Lagos Lagoon Front. Lagos, Nigeria. MSc Thesis, University of Lagos, Nigeria; 2015.
79. Moruf RO, Lawal AO. Growth pattern, whorl, and girth relationship of the periwinkle tympanotonusfuscatusvar radula (Linnaeus, 1758) from a tropical estuarine Lagoon Lagos, Nigeria. International Journal of Fisheries and Aquatic Studies. 2015;3(1): 111-115.
80. Ogamba EN, Izah SC, Omonibo E. Bioaccumulation of hydrocarbon, heavy metals, and minerals in tympanotonusfuscatus from coastal region of Bayelsa State, Nigeria, International Journal of Hydrology Research. 2016;1(1):1 – 7.
81. Orji BO, Igbokwe GE, Anagonye CO, Modo EU. Chemical content of the periwinkle shell and its suitability in thin layer chromatography, International Journal of Chemistry Studies. 2017;1(2): 9 – 11.
82. Cho YB, Seo G. High activity of acid-treated quail eggshell catalysts in the transesterification of palm oil with methanol, Bioresource Technology. 2010;101(22):8515 – 8519. DOI.org/10.1016/j.biortech.2010.06.082.
83. Offiong UD, Akpan GE. Assessment of physico-chemical properties of periwinkle shell ash as partial replacement for cement in concrete, International Journal of Scientific Engineering and Science. 2017;1(7):33 – 36.
84. Boro J, Thakur AJ, Deka D. Solid oxide derived from waste shells of Turbonillastriatula as a renewable catalyst for biodiesel production, Fuel Processing Technology. 2011;92:2061–2067.
85. James MO, Okolo PO. Removal of Heavy Metal Ions by Blended Periwinkle Shells, Journal of Applied Sciences. 2006;6(3):567 – 571.
86. Etim RK, Attah IC, Eberemu AO, Yohanna P. Compaction behavior of periwinkle shell ash treated lateritic soil for use as road sub-base construction material, Journal of GeoEngineering. 2019;14(3):179 – 190.
87. Olorunmeye FJ, Barambu YU, Ishaya AA. Effects of periwinkle shell ash on water permeability and sorptivity characteristics of concrete under different curing conditions. International Journal of Modern Trends in Engineering and Research. 2017; 4(11):101 – 108.
88. Olusola KO, Umoh AA. Strength characteristics of periwinkle shell ash blended cement concrete, International Journal of Architecture, Engineering, and Construction. 2012;1(4):213 – 220.
89. Olufemi IA, Joel M. Suitability of periwinkle shell as partial replacement for river gravel in concrete, Leonardo Electronic Journal of Practices and Technologies. 2009;15:59-66.
90. Dahunsi BIO, Bamisaye JA. Use of periwinkle shell ash (PSA) as partial replacement for cement in concrete. Proceedings Nigerian Materials Congress and Meeting of Nigerian Materials Research Society, Akure, Nigeria, 2002;184–186.
91. Lertwattanaruk P, Makul N, Siripattarapravat C. Utilization of ground waste seashells in cement mortars for masonry and plastering, Journal of Environmental Management. 2012;111: 133–14.
92. Othman NH, Abu Bakar BH, Don MMJohari MA. Cockleshell ash replacement for cement and filler in concrete, Malaysian Journal of Civil Engineering. 2013: 25 (2): 201–211.
93. Dahunsi BI. Properties of Periwinkle-Granite Concrete, Journal of Civil Engineering, JKUAT. 2002;8(1): 27-35.

94. Umoh AA, Femi OO. Comparative evaluation of concrete properties with varying proportions of periwinkle shell and bamboo leaf ashes replacing cement, Ethiopian Journal of Environmental Studies and Management. 2013;6(5):570-580.
95. Oyedepo OJ. Evaluation of the properties of lightweight concrete using periwinkle shells as a partial replacement for coarse aggregate, Journal of Applied Sciences and Environmental Management. 2016;20(3):498 – 505.
96. Ibearugbulem OM. Characterization of periwinkle shell as aggregate material for concrete production, The Heartland Engineer. 2009;4 (1):1 – 9.
97. Falade F, Ikponmwosa EE, Ojediran NI, Behavior of lightweight concrete containing periwinkle shells at elevated temperature, Journal of Engineering Science and Technology. 2010;5(4): 379-390.
98. Osarenmwinda JO, Awaro AO, The potential use of periwinkle shell as coarse aggregate for concrete, Advanced Materials Research. 2009;62-64:39-43.
99. Agbede OI, Manasseh J. Suitability of periwinkle shell as partial replacement for river gravel in concrete, Leonardo Electronic Journal of Practices and Technologies. 2009;15:59-66.
100. Olugbenga JO. Evaluation of the properties of lightweight concrete using periwinkle shells as a partial replacement for coarse aggregate, Journal of Applied Science and Environmental Management. 2016;20 (3):498 – 505.
101. Adewuyi AP, Adegoke T. Exploratory study of periwinkle shells as coarse aggregates in concrete works, ARPN Journal of Engineering and Applied Sciences. 2008;3(6):1 – 5.
102. Ettu LO, Ibearugbulem OM, Ezeh JC, Anya UC. A reinvestigation of the prospects of using periwinkle shell as partial replacement for granite in concrete, International Journal of Engineering Science Invention. .2013;2(3):54 – 59.
103. Francis IA, Venantus A. Models and optimization of rice husk ash-clay soil stabilization, Journal of Civil Engineering and Architecture. 2013;7(10):1260-1266. Available: http://dx.doi.org/10.17265/1934-7359/2013.10.009.
104. Oyelami CA, Van Rooy JL. A review of the use of lateritic soils in the construction/development of sustainable housing in Africa: A geological perspective, Journal of African Earth Sciences. 2016;119: 226-237.
105. Quadri HA, Adeyemi OA, Olafusi OS. Investigation of the geotechnical engineering properties of lateritic as a subgrade and base material for road constructions in Nigeria, Civil Environmental Research. 2012;2 (8):23–31
106. Nnochiri ES, Aderinlewo OO. Geotechnical properties of lateritic soil stabilized with periwinkle shell ash in road construction, International Journal of Advanced Engineering, Management, and Science. 2016;2(5):484-487.
107. Dauda AM, Akinmusuru JO, Dauda OA, Durotoye TO, Ogundipe KE, Oyesomi, K. Geotechnical properties of lateritic soil stabilized with periwinkle shell powder, International Journal of Civil Engineering and Technology. 2019;10(1): 2014 – 2025.
108. Osinubi KJ, Yohanna P, Eberemu AO. Cement modification of tropical black clay using iron ore tailing as admixture, Transportation Geotechnics. 2015;5: 35-49. DOI.org/10.1016/j.trgeo.2015.10.001.
109. Morales A, Romero E, Jommi C, Garzón E, Giaménez A. Feasibility of a soft biological improvement of natural soils used in compacted linear earth construction, ActaGeotechnica. 2015;10 :157-171. DOI.org/10.1007/s11440-014-0344-x
110. Okwo JM, Ozioko AC. Adsorption of lead and mercury ions on chemically treated periwinkle shell, Journal of Chemical Society of Nigeria. 2011;26:60-65.
111. Awokoya KN, Sanusi RO, Oninla VO, Ajibade OM. Activated periwinkle shells for the binding and recognition of heavy metal ions from aqueous media, International research journal of pure and applied chemistry. 2016;13(4):1-10. DOI: 10.9734/IRJPAC/2016/31440.
112. Akanbi O, Babayemi AK. Comparative Analysis of heavy metal removing using activated bamboo and periwinkle shell, a case study of Cr (III) ion, Global Journal of Researches in Engineering: (C) Chemical Engineering. 2019;19(6).
113. Badmus M, Audu T, Anyata B. Removal of copper from industrial wastewaters by activated carbon prepared from periwinkle shells, Korean Journal of Chemical Engineering. 2007a;24: 246–252. DOI.org/10.1007/s11814-007-5049-5.

114. Odoemelam SA, Eddy NO. Studies on the use of oyster, snail, and periwinkle shells as adsorbents for the removal of Pb2+ from aqueous solution, E-Journal of Chemistry. 2009;6(1): 213-222.
115. Badmus M, Audu T, Anyata B. Removal of lead ion from industrial wastewaters by activated carbon prepared from periwinkle shells, Turkish Journal of Engineering and Environmental Sciences. 2007b;31:251-263.
116. Uzukwu PU, Ogbonna DN, Leton TG, Obinna FC. The economics of trickling biological periwinkle shell filter for closed reticulating catfish system. Paper presented at the 25th Annual International Conference and Exhibition in Administrative Staff College of Nigeria (ASCON). Topo-Badagry, Lagos, Nigeria;2020.
117. Fink J. Petroleum Engineers' Guide to Oil Field Chemicals and Fluids. 2nd edition. Gulf Professional Publishing, USA;2015.
118. Jarrett M, Clapper D. High-temperature filtration control using water-based drilling fluid systems comprising water-soluble polymers, US Patent 7 651 980. 2010.
119. Hamad BA, He M, Xu M, Liu W, Mpelwa M, Tang S, Jin L, Song J. A novel amphoteric polymer as a rheology enhancer and fluid-loss control agent for water-based drilling muds at elevated temperatures, ACS Omega. 2020;5(15): 8483-8495.
DOI: 10.1021/acsomega.9b03774
120. Hamad BA, Xu M, Liu W. Performance of environmentally friendly silica nanoparticles-enhanced drilling mud from sugarcane bagasse, Particulate science and technology, An international journal. 2019;39(2):1 – 12.
doi.org/10.1080/02726351.2019.1675835
121. Onuh CY, Igwilo KC, Anawe PAL Olakunle D, Omotoke O. Environmentally friendly fluid loss control agent in water-based mud for oil and gas drilling operations, International Journal of Applied Engineering Research. 2017:12(8):1520-1523.
122. Igwe I, Kinate B. The use of periwinkle shell ash as filtration loss control agent in water-based drilling mud, International Journal of Engineering Research and General Science. 2015:3(6): 375 – 381.
123. Fann, LPLT Filter Press Instruction Manual, 2014. Accessed on 3rd June 2021.
Available: http://hamdon.net/products/filter-press-api-lplt/
124. Shaw A, Sriramula S, Gosling PD, Chryssanthopoulo MK, Composites Part B. 2010;41:446–453.
125. Petre R, Petrea N, Epure G, Zecheru T. Polymer composite materials and applications for chemical protection equipment. International Conference Knowledge-Based Organization. 2015;21 (3):873 – 877.
126. Jose JP, Malhotra SK, Thomas S, Joseph K, Goda K, Sreekala MS. Advances in Polymer Composites: Macro- and Micro composites – State of the Art, New Challenges, and Opportunities. Polymer Composites. Vol 1, 1st edition. Wiley VCH, Hoboken, New Jersey, USA; 2012.
127. Funabashi M, Ninomiya F, Flores ED, Kunioka M. Biomass carbon ratio of polymer composites measured by accelerator mass spectrometry, Journal of Polymers and the Environment. 2010;18:85–93.
128. Usman A, Zia KM, Zuber M, Tabasum S, Rehman S, Zia F. Chitin and chitosan-based polyurethanes: a review of recent advances and prospective biomedical applications, International Journal of Biological Macromolecules. 2016;86:630–645.
DOI:10.1016/j.ijbiomac.2016.02.004
129. Petrenko I, Bazhenov VV, Galli R, Wysokowski M, Fromont J, Schupp PJ, Stelling AL, Niederschlag E, Stoker E, Kutsova VZ, Jesionowski T, Ehrlich H. Chitin of poriferan origin and the bioelectrometallurgy of copper/copper oxide, International Journal of Biological Micromolecules; 2017.
DOI:10.1016/j.ijbiomac.2017.01.084.
130. Mohamed WS, Nasr HE, Gutmann R, Sobh RA. Effect of CaO nanoparticles on the properties of polyamide 6, Egyptian Journal of Chemistry. 2015;58 (3):365–375.
131. Sönmez M, Alexandrescu L, Georgescu M, Gurau FD, Ficai D, Ficai A, Trusca R, Ovidiu O, Ioana LA, Constantinescu D. Influence of calcium oxide on thermal and mechanical properties of recycled polyethylene terephthalate/polyethylene mixture. In: Proceedings of the 4th world congress on new technologies (NewTech'18), Madrid, Spain; 2018.

132. Nwanonenyi SC, Obidiegwu MU, Onuchukwu TS. Studies on the properties of linear low-density polyethylene-filled oyster shell powder, International Journal of Engineering and Science (IJES). 2013;2(7):42-48.
133. Onuegbu GC, Madufor IC. Effect of filler loadings on the end-use properties of maize tassel filled high-density polyethylene, International Research Journal in Engineering, Science and Technology. 2012;9(1):2-9.
134. Onuegbu GC, Obasi H, Onuoha FN. Tensile behavior of cocoa pod-filled polyethylene composites, Asian Journal of Basic and Applied Sciences. 2014;1(2):1-2.
135. Atuanya CH, Edokpia RO, Aigbodion VS. The physio-mechanical properties of recycled low-density polyethylene/bean pod ash particulate composites, Results in Physics. 2014;4:88- 95.
136. Onuoha C. Tribological behavior of periwinkle shell powder-filled recycled polypropylene composites, International Journal of Engineering and Technologies. 2019;17: 11 – 20.
137. Jones D, Brischke C. Performance of bio-based building materials. 1stedition. Wood head Publishing, Cambridge, England;2017.
138. Abdulkareem SA, Adeniyi AG, Production of particleboards using polystyrene and bamboo wastes, Nigerian Journal of Technology. 2017;36(3):788 – 793.
DOI: 10.4314/njt.v36i3.18
139. Bektas I, Guler C, Kalaycioglu H. Manufacturing of particleboard from sunflower stalks (*Helianthus annuus* L.) using urea-formaldehyde resin, Journal of Science and Engineering of KSU, Turkey. 2002;5(2):49-56.
140. Prasetiyo KW, Gopar M, Kurniawati L, Syamani F, Kusumah SParticleboards from corn husks and citric acid. International Symposium on Bioeconomics of Natural Resources Utilization (ISBINARU). Center for Plant Conservation Botanic Gardens-LIPI, Bogor, Indonesia, 2017;453 – 458.
141. Kadja K, Banna M, Atcholi K, Sanda K. Utilization of bone adhesive to produce particleboards from stems of cotton plant at the pressing temperature of 140°C, American Journal of Applied Sciences. 2011;8(4):318-322.
142. Kalaycıoglu H, Nemli G. Producing composite particleboard from kenaf (Hibiscus cannabinus L.) stalks, Industrial Crops and Products. 2006;24:177–180.
143. Wang D, Sun XS. Low-density particleboard from wheat straw and corn pith, Industrial Crops and Products. 2002;15 (1):43-50.
144. Kumar A, Ganguly S, Dutt H, Poonia PK, Rajawat BS, Khali DP. Suitability of lignocellulosic particles of *Prosopis cineraria* (L.) druce for fabrication of particle boards, Indian Journal of Agroforestry. 2020;22(1):38 – 42.
145. Abdullahi I, Sara S. Assessment of periwinkle shells ash as composite materials for particleboard production. International Conference on African Development Issues (CU-ICADI): Materials Technology Track. 2015;158 – 163.
146. Marinescu ID, Dimitrov B, Rowe WB, Inaski I. Abrasives and Abrasive Tools, Tribology of Abrasive Machining Processes. Second edition, William Andrew Incorporated, Norwich, USA; 2004.
147. Wai JJ, Lily MT. Manufacturing of emery cloth (Sandpaper) from local raw materials, Global Journal of Engineering Research. 2012;1(1): 31–37.
DOI.org/10.4314/gjer.v1i1.18901.
148. Obot MU, Yawas DS, Aku SY. Development of an abrasive material using periwinkle shells, Journal of King Saud University – Engineering Science. 2017;29:284 – 288.
149. Saji GS, Shamnadh M, Varma S, Amanulla S, Bharath RS, Oommen C. Experimental evaluation of compressive strength of PMMA-seashell based biocomposites for orthopedic applications. Materials Today: Proceedings. 2018;5:16509-16515.
DOI.org/10.1016/j.matpr.2018.06.005
150. Rujitanapanich S, Kumpapan P, Wanjanoi P. Synthesis of hydroxyapatite from oyster shell via precipitation, Energy Procedia. 2014;56:112–117.
151. Karunakarana G, Choa E, Kumarb GS, Kolesnikovc E, Karpenkovd DU, Gopinathane J, Pillaie MM, Selvakumare R, Boobalang S, Gorshenkov MV. Sodium dodecyl sulfate mediated microwave synthesis of biocompatible superparamagneticmesoporous hydroxyapatite nanoparticles using black Chlamysvaria seashell as a calcium source for biomedical applications, Ceramics International. 2019;45:15143–15155

152. Ehrlich H, Bazhenov VV, Debitus C, de Voogd N, Galli R, Tsurkan MV, Wysokowski M, Meissner H, Bulut E, Kaya M, Jesionowski T. Isolation and identification of chitin from heavy mineralized skeleton of Subereaclavata (Verongida: Demospongiae: Porifera) marine demosponge. International Journal of Biological Macromolecules. 2017;104:1706–1712. DOI:10.1016/j.ijbiomac.2017.01.141
153. Helmenstine AM, What is Chitin? Definition and Uses. 2019: Accessed 14 the May, 2021. Availaible.:https://www.thoughtco.com/chitin-definition-4774350. 2019.
154. Tang WJ, Fernandez JG, Sohn JJ, Amemiya CT, Chitin is endogenously produced in vertebrate. Current Biology. 2015;25(7): 897–900. DOI:10.1016/j.cub.2015.01.058.
155. Gbenebor OP, Akpan EI, Adeosun SO. Thermal, structural, and acetylation behavior of snail and periwinkle shells chitin, Progress in Biomaterials. 2017;6:97 – 111.
156. Aigbodion V, Akadike U, Hasssn SB, Asuke F, Agunsoye JO. Development of asbestos-free brake pad using bagasse. Tribology in Industry. 2010;32(1):12 – 18.
157. Blau, Compositions, Functions, and Testing of Friction Brake Materials and Their Additives. Metals and Ceramics Division. Oak Ridge National Laboratory;2001. Accessed :7th June 2021, Available:https://info.ornl.gov/sites/publications/Files/Pub57043.pdf
158. Dagwa IM, Ibhadode AOA. Design and manufacture of experimental brake pad test rig, Nigerian journal of engineering research and development. Basade publishing press, Ondo, Nigeria. 2005;4(3):15 – 24.
159. Dagwa IM, Ibhadode AOA. Determination of optimum manufacturing conditions for asbestos-free brake pad using the Taguchi method, Nigerian journal of engineering research and development. 2006;5(4):1 – 8.
160. Mutlu I, Investigation of tribological properties of brake pads by using rice straw and rice husk dust, Journal of Applied Sciences. 2009;9(2): 377-381.
161. Ossia CV,Big-Alabo A, Ekpruke EO. Effect of particulate grain size on the physicomechanical properties of green automotive brake pads from waste coconut (CocosNucifera) shells, Advances in Manufacturing Science and Technology - The Journal of the Committee of Mechanical Engineering, Polish Academy of Sciences. 2020;44(4):135-144.
162. Craciun AL, Pinca-Bretotean C, Utu D, Josan A. Tribological properties of non-asbestos brake pad material by using coconut fiber. IOP Conference Series: Materials Science and Engineering. 2017;163: 012014. DOI:10.1088/1757-899X/163/1/012014.
163. Elakhame ZU, Olotu OO, Abiodun YO, Akubueze EU, Akinsanya OO, Kaffo PO, Oladele OE. Production of Asbestos Free Brake Pad Using Periwinkle Shell as Filler Material, International Journal of Scientific & Engineering Research. 2017;8(6):1728 – 1735.
164. Aku SY, Yawas DS, Madakson PB, Amaren SG, Characterization of periwinkle shells as asbestos-free brakepad materials. Pacific Journal of Science and Technology. 2012;13(2):57 – 63.
165. Amaren SG, Yawas DS, Aku SY. Effect of periwinkles shell particle size on the wear behavior of asbestos-free brake pad, Results in Physics. 2013;3:109 –114. DOI: 10.1016/j.rinp.2013.06.004.
166. Yawas DS, Aku SY, Ammaren SG, Morphology and properties of periwinkle shell asbestos-free brakepad. Journal of King Saud University – Engineering Sciences. 2016;28(1):103-109. DOI.org/10.1016/j.jksues.2013.11.002
167. Singamneni S, Behera MP, Le Guen M, Zeidler H. Mechanism of bonding in seashell powder-based ceramic composites used for binder-jet 3D printing, Bioceramics Development Applications. 2018; 8 (01). DOI.org/10.4172/2090-5025.1000108
168. Wang Z, Dong J, Liu L, Zhu G, Liu C. Screening of phosphate-removing substrates for use in constructed wetlands treating swine wastewater, Ecological Engineering. 2013;54:57–65. DOI.org/10.1016/J.ECOLENG.2013.01.017
169. Tsai HC, Lo SL, Kuo J. Using pre-treated waste oyster and clam shells and microwave hydrothermal treatment to recover boron from concentrated wastewater, Bioresource Technology. 2011;102 (17):7802–7806.

DOI.org/10.1016/j.biortech.2011.06.036.
170. Jung S, Heo NS, Kim EJ, Oh SY, Lee HU, Kim IT, Hur J, Lee G, Lee Y, Huh YS. Feasibility test of waste oyster shell powder for water treatment, Process Safety and Environmental Protection. 2016;102:129–139.
171. Luo H, Huang G, Fu X, Liu X, Zheng D, Peng J, Zhang K, Huang B, Fan L, Chen F, Sun X. Waste oyster shell as a kind of active filler to treat the combined wastewater at an estuary, Journal of Environmental Sciences. 2013;25:2047–2055.
DOI: 10.1016/S1001-0742(12)60262-9
172. Lee CH, Lee DK, Ali MA, Kim PJ. Effects of oyster shell on soil chemical and biological properties and cabbage productivity as a liming materials, Waste Management. 2008;28:2702–2708.
173. Ramirez-Pérez AM, Paradelo M, Nóvoa-Muñoz JC, Arias-Estévez M, Fernández-Sanjurjo MJ, Álvarez-Rodríguez E, Núñez-Delgado A. Heavy metal retention in copper mine soil treated with mussel shells: Batch and column experiments, Journal of Hazardous Materials. 2013;248–249: 122–130.
174. Ragothman A, Anderson WA. Air quality impacts of petroleum refining and petrochemical industries, Environments. 2017;4 (3):66.
DOI.org/10.3390/environments4030066.
175. Zhang Z, Wang H, Chen D, Li Q, Thai P, Gong D, Li Y,Zhang C, Gu Y, Zhou L, Morawska L, Wang B. Emission characteristics of volatile organic compounds and their secondary organic aerosol formation potentials from a petroleum refinery in Pearl River Delta, China, Science of the Total Environment. 2017b;584-585:1162-1174.
DOI.org/10.1016/j.scitotenv.2017.01.179.
176. Ojewumi ME, Okeniyi JO, Okeniyi ET, Ikotun JO, Ejemen VA, Akinlabi ET. Bioremediation: Data on biologically-mediated remediation of crude oil (Escravos Light) polluted soil using aspergillusniger, Chemical Data Collections. 2018;17 – 18:196 – 204.
177. Bebeteidoh OL, Kometa S, Pazouki K, Norman R. Sustained impact of the activities of local crude oil refiners on their host communities in Nigeria. Heliyon, 2020;6(6):e04000.
DOI:10.1016/j.heliyon.2020.e04000.
178. Onakpohor A, Fakinle BS, Sonibare JA, Oke MA, Akeredolu FA. Investigation of air emissions from artisanal petroleum refineries in the Niger-Delta Nigeria. Heliyon 2020;6: e05608.
DOI.org/10.1016/j.heliyon.2020.e05608.
179. Rouzitalab Z, Maklavany DM, Jafarinejad S, Rashidi A. Lignocellulose-based adsorbents: a spotlight review of the effective parameters on carbon dioxide capture process, Chemosphere. 2019; 125756.
180. Ahmadi R, Ardjmand M, Rashidi M, Rafizadeh M. Enhanced gas adsorption using an effective nanoadsorbent with high surface area based on waste jute as cellulose fiber. Biomass Conversion and Biorefinery;2021.
DOI.org/10.1007/s13399-021-01370-8
181. Wang J, Pu Q, Ning P, Lu S. Activated carbon-based composites for capturing CO_2: a review, Greenhouse Gases: Science and Technology. 2021;11 (9): 1 – 17.
182. Jung JH, Shon BH, Yoo KS, Oh KJ. Physicochemical characteristics of waste seashells for acid gas cleaning absorbent, Korean Journal of Chemical Engineering. 2000;17: 585–592.
183. Hart A, Onyeaka H, Eggshell and seashells biomaterials sorbent for carbon dioxide capture;2020. Accessed June 12th 2021.
Available:https://www.intechopen.com/books/carbon-capture/eggshell-and-seashells-biomaterials-sorbent-for-carbon-dioxide-capture
184. Sacia RE, Ramkumar S, Phalak N, Fan LS. Synthesis and regeneration of sustainable CaO sorbents from chicken eggshells for enhanced carbon dioxide capture. ACS Sustainable Chemical. Engineering. 2013;1:903−909.
185. Ma KW, Teng H. CaO powders from oyster shells for efficient CO_2 capture in multiple carbonation cycles, Journal of the American Ceramic Society. 2010;93(1):221-227.
DOI.org/10.1111/j.1551-2916.2009.03379.x
186. Boey PL, Maniam GP, Hamid SA. Performance of calcium oxide as a heterogeneous catalyst in biodiesel production: A review, Chemical Engineering Journal. 2011;168:15–22.
187. Salvi BL, Panwar NL, Biodiesel resources and production technologies – A review,

Renewable and Sustainable Energy Reviews. 2012;16:3680–3689.
188. Marinković DM, Stanković MV, Veličković AV, Avramović JM, Miladinović MR, Stamenković OO, Veljković VB, Jovanović DM. Calcium oxide as a promising heterogeneous catalyst for biodiesel production: Current state and perspectives, Renewable & Sustainable Energy Reviews. 2016;56:1387–1408.
189. Liu HS, Guo HS, Wang XJ, Jiang JZ, Lin H, Han S, Pei SP. Mixed and ground KBr-impregnated calcined snail shell and kaolin as solid base catalysts for biodiesel production, Renewable Energy. 2016;93: 648–657. DOI.org/10.1016/j.renene.2016.03.017.
190. Assabumrungrat S, Sonthisanga P, Kiatkittipong W, Laosiripojana N, Arpornwichanop A, Soottitantawat A, Wiyaratn W, Praserthdam P. Thermodynamic analysis of calcium oxide assisted hydrogen production from biogas, Journal of Industrial and Engineering Chemistry. 2010;16:785–789.
191. Acharya B, Dutta A, Basu P. An investigation into steam gasification of biomass for hydrogen-enriched gas production in presence of CaO, International Journal of Hydrogen Energy. 2010; 35:1582–1589.
192. Suttle NF, Mineral Nutrition of Livestock. 4thedition. CABI, Oxford, United Kingdom;2010.
193. Ali S, Dickerson R, Bennett C, Desroches J, London BP, Bixenman EP, Parlar M, Cooper S, Aberdeen B, Scotland J, Desroches S, Land TB, Foxenberg, Godwin K, Mcpike T, Pitoni E, Ripa G. High-Productivity Horizontal Gravel Packs, Oilfield Review. 2001;52 – 73.
194. Liang F, Sayed M, Al-Muntasheri GA, Chang FF, Li L. A comprehensive review on proppant technologies, Petroleum. 2016;2:26 – 39. DOI.org/10.1016/j.petlm.2015.11.001.
195. Arumugam A, Karuppasamy G, Jegadeesan GB. Synthesis of mesoporous materials from bamboo leaf ash and catalytic properties of immobilized lipase for hydrolysis of rubber seed oil, Materials Letters. 2018;225:113 – 116.

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