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Review

Value-added utilization of oil palm ash: A superior recycling of the industrial agricultural waste

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ABSTRACT

Concern about environmental protection has increased over the years from a global viewpoint. To date, the infiltration of oil palm ash into the groundwater tables and aquifer systems which poses a potential risk and significant hazards towards the public health and ecosystems, remain an intricate challenge for the 21st century. With the revolution of biomass reutilization strategy, there has been a steadily growing interest in this research field. Confirming the assertion, this paper presents a state of art review of oil palm ash industry, its fundamental characteristics and environmental implications. Moreover, the key advance of its implementations, major challenges together with the future expectation are summarized and discussed. Conclusively, the expanding of oil palm ash in numerous field of application represents a plausible and powerful circumstance, for accruing the worldwide environmental benefit and shaping the national economy.

Contents

1. Introduction

Lifeblood for billion of people, oil palm industry has been one of the most successful stories of the world agricultural sector abroad the nations. Arising from the steep enrichment of globalization and metropolitan growth, today oil palm has demonstrated a wide spectrum of implications, almost every part of its plant [1]. With the prices of the crude petroleum and world's demand for oils and fats escalating to an unprecedented height every other day, the amount of biomass produced by an oil palm tree, inclusive of the oil and lingo-cellulosic materials is on an average of 231.5 kg dry weight/year [2]. For each bunch of the fresh palm fruit, approximately 21% of palm oil, 6–7% of palm kernels, 14–15% of palm fibers, 6–7% of palm shells and 23% of empty fruit bunches can be obtained [3]. This has inspired a growing interest in the utilization of oil palm waste as a renewable source of energy or feedstock for a large variety of downstream products. The potentiality is further strengthened and driven by the insight that oil constitutes only 10% of the palm production, while the rest 90% is the biomass [4].

In the early cultivation, it was a common practice to dispose oil palm waste by uncontrolled tipping or dumping, an operation in which waste is spread over the estates ground or tipped to fill in low economic value open dumps on selected pieces of land (inundated swampland, abandoned sand mines and quarries), without taking care of the surrounding environment, nor considering any precautions to compact, cover and prohibit the spreading of contaminants into the underlying waterways [5]. Lately, the departure of the concept of generating energy from oil palm waste, in the forms of palm leaves, palm fronds, palm trunks, empty fruit bunches, palm shells, palm fibers and palm stones [6], has received stern encourages and considerations worldwide (Table 1). During the combustion

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Table 1
Energy database for the oil palm biomass [7].

Palm waste	Heat value (kJ/kg)
Empty fruit bunches	18,795
Fiber	19,055
Shell	20,093
Palm kernel cake	18,884
Nut	24,545
Crude palm oil	39,360
Kernel oil	38,025
Liquor from (EFB)	20,748
Palm oil mill effluent (POME)	16,992
Trunk	17,471
Petiole	15,719
Root	15,548

at 800–1000 °C, oil palm ash, one of the largest readily available but most under-utilized biomass resource, collected from the particulate collection equipment attached upstream to the stacks of oil palm waste-fired boilers tends to be formed, varying considerably according to the burning technique, temperature regime and gasification structures [8].

In Malaysia alone, the potential oil palm ash production is designated at 4 million tonnes/year [9], which striving towards huge criticisms and complaints, mainly attributed to its persistent, carcinogenic and bio-accumulative effects [10]. Increasingly, with the price of the ash disposal cost (either in landfills or ash ponds) hitting as high as $5/tonnes in developing countries and $50/tonnes in developed countries, the urgency of transforming the residue into a more valuable end product has been promulgated [11]. In view of the aforementioned, this bibliographic review attempts to postulate an initial platform in describing the distinct physiochemical properties, development and potential applications of the oil palm ash industry. The present work is aimed at providing a concise and up to date picture of the present status of the oil palm waste enhancing sustainable and renewable energy. The prospects towards utilization of oil palm ash as renewable sources together with its comprehensive literature has been highlighted and outlined, to familiarize the knowledge deficiencies regarding oil palm ash industry.

2. Characterization and utilization of oil palm ash as a novel adsorbent

Over the past several decades, intensive wide spread contamination of atmosphere and surface water related to adverse industrial operations has intensified an aesthetic attention for many environmentalists [12]. A developing research by the invention of a wide range of treatment technologies (precipitation, coagulation–flocculation, sedimentation, flotation, filtration, membrane processes, electrochemical techniques, biological process, chemical reactions, adsorption and ion exchange) with varying levels of success has accelerated a dramatic progress in the scientific community [13–19]. Of major interest, adsorption process, a surface phenomenon by which a multi-components fluid (gas or liquid) mixture is attracted to the surface of a solid adsorbent and form attachments via physical or chemical bonds, is recognized as the most efficient and promising fundamental approach in the wastewater treatment processes [20].

A notable trend in the development of activated carbon, an adsorbent with its large porous surface area, controllable pore structure, thermo-stability and low acid/base reactivity has been witnessed [21], owning to its superior ability for removal of a broad types of organic and inorganic pollutants dissolved in aqueous media, even from gaseous environment [22]. Despite its prolific use in adsorption processes, the biggest barrier of its application by the industries is the cost-prohibitive adsorbent and difficulties associated with regeneration [23]. Realizing the complications, a growing explorations to evaluate the feasibility and reliability of natural, renewable and low-cost materials as alternative adsorbents in the water or air pollution control, remediation and decontamination processes (bamboo dust, peat, chitosan, lignite, fungi, moss, bark husk, chitin, coir pith, maize cob, pinewood sawdust, rice husk, sugar cane bagasse, tea leaves, and sago waste) has been exerted [24–26].

Simultaneously, oil palm ash, an abundantly available throw-away waste from the fired-boiler furnaces, has currently emerged to be an ideal adsorbent in the wastewater treatment processes and as air purifier in cleaning of atmosphere contaminants [27]. Table 2 lists previous researches in the utilization of oil palm ash as novel adsorbents for different applications. The findings will provide a two-fold advantage with respect to environmental management. First, huge loads of oil palm waste could be partly reduced, converted to useful, value-added adsorbents, and second, the low-cost adsorbent, if developed, may overcome the wastewaters and air pollution at a reasonable cost, solving part of the global agricultural refuse and wastewater treatment problem [1,32].

In particular, the recycling and polishing of wastewater comprising trace quantities of zinc ions has been initially advocated by Chu and Hashim [34] in 2002, illustrating a competent removal of 97% corresponding to an adsorption capacity of 0.01 mg/g. At lower pH values, isotherm linearity was demonstrated progressively raised, ascribed to the hindering and competitive effects (between zinc ions and protons) for finite number of active binding sites within the ash particles. Lately, a separated study utilizing oil palm ash with sulfuric acid modification was individually examined by Hameed et al. [31] and Ahmad et al. [32] for the treatment of acid green 25 and direct blue 71 dyes molecules, denoting an adsorption capability of 181.80 mg/g and 400.01 mg/g. In Malaysia, a comparative investigation has been undertaken by Hasan et al. [30], which complying a chitosan-oil palm ash composite beads for the discrimination of reactive blue 19 dyes, accomplishing an adsorption of 423.50 mg/g with an early concentration of 500 mg/L.

Table 2
Previous researches in the utilization of oil palm ash as novel adsorbents for different applications.

Adsorbate	BET surface area (m^2/g)	Treatment/modifications	Removal (%)	Maximum adsorption capacity (mg/g)	Reference
Sulfur dioxide gas	8.60	Slurred with CaO and $Ca(OH)_2$	100	–	[9]
Sulfur dioxide gas	10.20	Slurred with CaO and $Ca(OH)_2$	100	5.06	[28]
Sulfur dioxide gas	8.60	Slurred with Calcium oxide (CaO) and hydroxide [$Ca(OH)_2$]	100	–	[29]
Reactive blue 19 dye		Composited with chitosan	–	423.50	[30]
Acid green 25 dye	5.36	Sulfuric acid	–	181.80	[31]
Direct blue 71 dye	5.36	Sulfuric acid	–	400.01	[32]
Disperse blue	–	–	99	47.20	[33]
Disperse red			99	48.60	
Zinc ions	23.4	Nitric acid	97	0.01	[34]

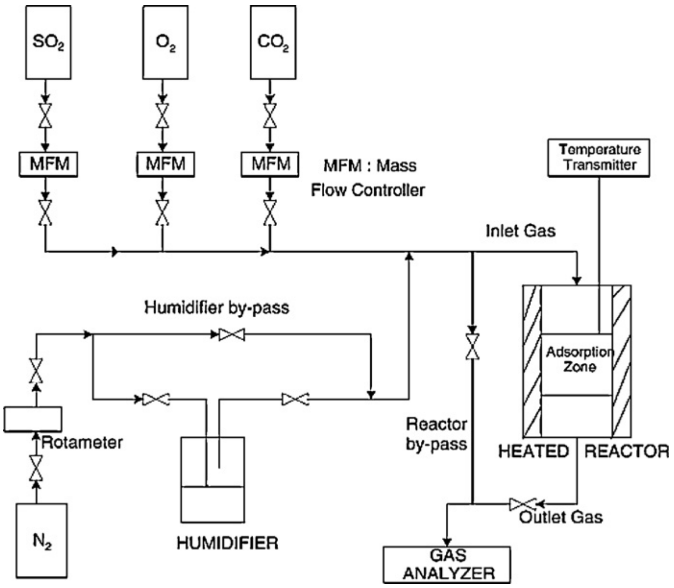

Fig. 1. Schematic diagram of the experimental set-up for desulfurization activity [7].

Coinciding in coping the steep emission of sulfur dioxide, which presents a multiple, carcinogenic and acute toxicity, recently, the manipulation the oil palm ash with the slurry calcium oxide and hydroxide in the gases adsorption process, is gaining huge momentum and popularity around the globe (Fig. 1). In the perspective, gas sulfur dioxide has been identified as a major air pollutant, mainly hinges of its accumulative and detrimental effect to the survival of aquatic life, ecology and food chains, by imposing a significant influence on the mobilization and attenuation towards the formation of acid rain and urban smog, resulting in visibility impairment, buildings damages, silicosis syndrome, fatigue, bronchitis, shortness of breath, smell sense alteration, loss of appetite (respiratory failure) and even death [7,27]. A substantial amount of adsorption studies have been abounded, reporting a 100% gas removal, equivalent to a 5.06 mg/g adsorption capacity [9,27,29,35]. Under the co-treatment process, pozzolanic phenomenon begins with the elution of silica and alumina from ash particles by alkaline water (rate-limiting step), succeeding by the reaction with calcium oxide and hydroxide in the formation of calcium aluminium silicate hydrate compounds. Hereby, the existence of calcium sulfate is believed may contribute a synergy effect in providing a large attachment surface area for capturing of sulfur dioxide and serving as suppression for the exponential growth of calcium hydroxide crystals [35].

Morphological studies of the raw palm ash, medium particles ground palm ash and small particles ground palm ash are presented in Fig. 2(a)–(c) respectively. Typically, oil palm ash is characterized by a spongy and porous structure in nature, of which its main components are in the angular and irregular form, with a sizable fraction showing cellular textures [36]. Meanwhile, raw palm ash was evidenced consisting a rather spherical particles with a median size of 183.0 μm while medium and small particles ground palm ash were individually noted containing crushed shape structures with a median of 15.9 and 7.4 μm [37]. Table 3 and Fig. 3 exhibit the composition analysis of the oil palm ash coupled with its Fourier transform infrared (FTIR) transmission images. In most cases, the chemical elements of oil palm ash are found to be silicon dioxide, aluminium oxide, iron oxide, calcium oxide, magnesium oxide, sodium oxide, potassium oxide and sulfur trioxide, fluctuating upon the varieties of proportion of irrigated area, geographical conditions, fertilizers used, climatic variation, soil chemistry, timeliness of production and agronomic practices in the oil palm growth process [36–42]. Whereas, the region between 1300 and 1400 cm^{-1} is related to the phenol and alcohol groups on the adsorbent surface, pre-supported by a prominent peak at 330 cm^{-1} which assigned to the appearance of –OH groups [Fig. 3(a)] [43]. Similarly, the stretching of Si–O groups alternating bound to the Al–O bonds detects a signal at 1050 cm^{-1} and band around 800 cm^{-1} is an indicative of the Al–O or Si–O–Al groups [Fig. 3(b)] [44].

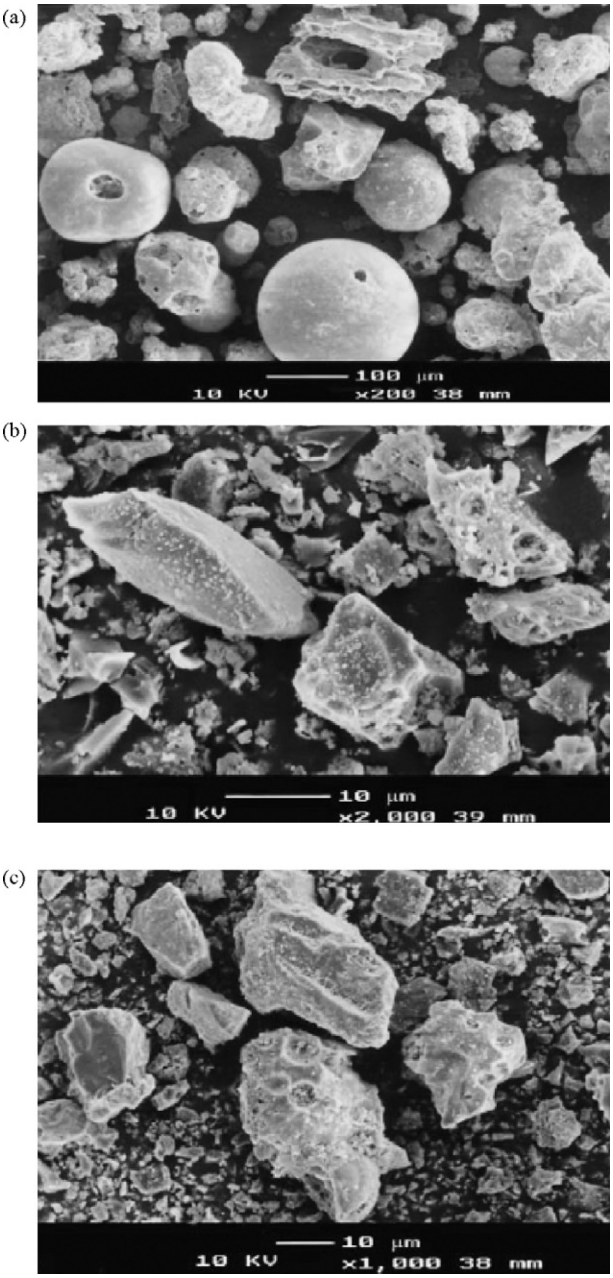

Fig. 2. Morphological studies of the raw palm ash (a) (200×), medium particles ground palm ash (b) (2000×) and small particles ground palm ash (c) (1000×) [37].

Fig. 4 displays X-ray diffraction (XRD) spectroscopy of oil palm ash in the adsorption of sulfur dioxide gas, reflected the quantitative presence of crystalline minerals, endorsed by vaporization, melting, crystallization, vitrification, condensation and precipitation processes during the combustion process [41]. In this respect, sylvite, a mineralized form of potassium chloride (KCl) was found at almost all prominent peaks. In contrast, potassium molybdenum selenium ($K_2Mo_3Se_{18}$) was observed at a broad hump along $2\theta = 20^\circ$

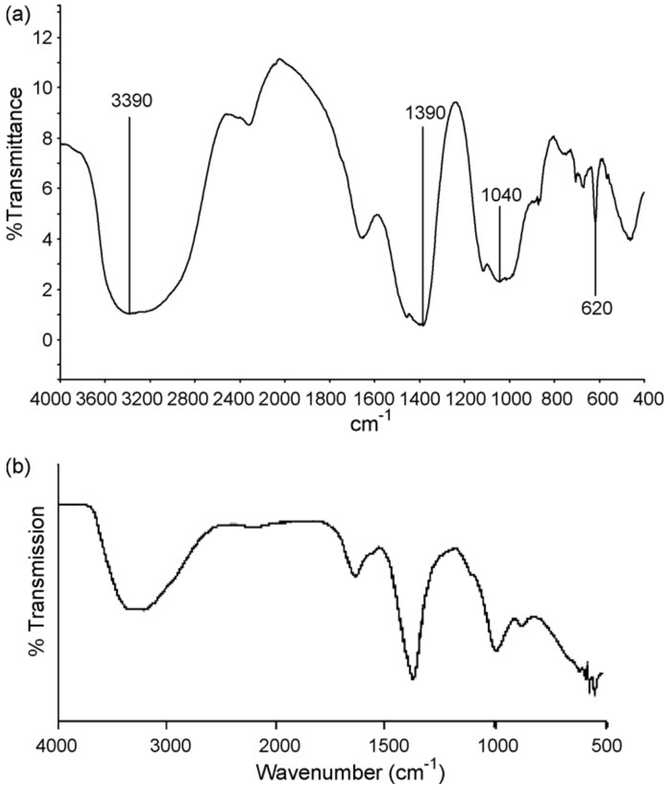

Fig. 3. Fourier transform infrared (FTIR) transmission images of the oil palm ash [43,44].

to $2\theta = 50^\circ$ which a marginal amount of xanthoconite (Ag_3AsS_3) was detected at intensive peaks of $2\theta = 29.6^\circ$ and $2\theta = 33.0^\circ$ [Fig. 4(a) and (b)]. Nonetheless, two main phases of silica (SiO_2) and microline ($KAlSi_3O_8$) were identified in the fresh hydrated oil palm ash while potassium sulfate hydrate ($K_2S_2O_3{\cdot}H_2O$) and potassium alum [$KAl(SO_4)_2{\cdot}12H_2O$] were noticed in the spent hydrated oil palm ash [28,44].

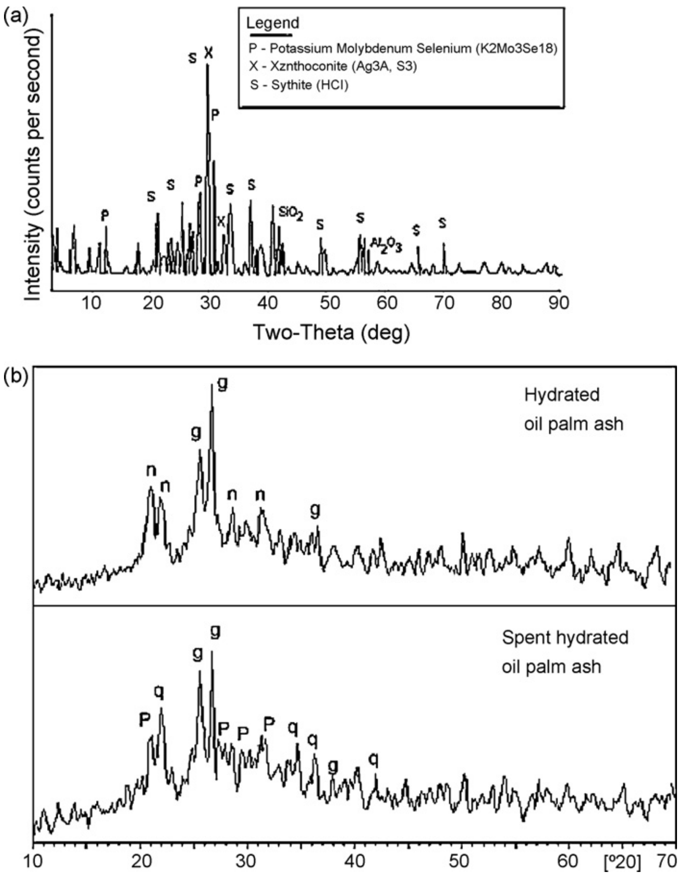

Fig. 4. X-ray diffraction (XRD) spectroscopy of the oil palm ash for the adsorption of sulfur dioxide gas [7,44].

3. Prevalence of oil palm ash as a viable concrete pozzalanic material

Within recent years, the exponential population and social civilization growth, changes affluent lifestyles and resources use, and

Table 3
Composition analysis of the oil palm ash.

Chemical constituents	Composition (%)						
	[36]	[37]	[38]	[39]	[40]	[41]	[42]
Silicon dioxide	63.6	57.7	65.3	57.8	65.3	57.7	43.6
Aluminium oxide	1.6	4.5	2.5	4.6	2.6	4.6	11.4
Iron oxide	1.4	3.3	1.9	3.3	2.0	3.3	8.4
Calcium oxide	7.6	6.5	6.4	6.6	6.4	6.6	4.8
Magnesium oxide	3.9	4.2	3.0	4.2	3.1	4.2	0.4
Sodium oxide	0.1	0.5	0.3	0.5	0.3	0.5	4.7
Potassium oxide	6.9	8.2	5.7	8.3	5.7	8.3	3.5
Sulfur trioxide	0.2	0.2	0.4	0.3	0.5	0.3	2.8
Loss on ignition	9.6	10.5	10.0	10.1	10.1	10.5	18.0
$SiO_2 + Al_2O_3 + Fe_2O_3$	66.6	65.5	69.9	65.7	69.9	65.6	63.4

Chemical constituents	Composition (%)				
	[7]	[9]	[29]	[31]	[35]
Silicon dioxide	40.0	35.6	40.0	40.0	37.0
Aluminium oxide	6.1	4.8	6.1	6.1	14.3
Iron oxide	2.5	2.0	2.5	2.5	2.5
Calcium oxide	10.0	12.0	10.0	10.0	9.2
Magnesium oxide	6.4	7.2	6.4	6.4	6.1
Phosphorus pentoxide	8.2	6.8	8.2	8.3	6.2
Carbon	5.4	12.0	5.4	5.4	9.0
Potassium oxide	12.1	11.0	12.1	12.1	11.0
Others	2.0	1.7	2.0	4.4	0.7
S compound	–	–	–	–	1.0
Cl compound	–	–	–	–	2.9

Table 4
Lists of studies for the utilization of oil palm ash as a supplementary cementitious material in producing of high-strength concrete.

Properties	Result					
	[8]	[36]	[37]	[38]	[39]	[40]
Compressive strength	62.50	62.00	31.90	63.80	29.40	92.00
Expansion (%)	–	–	0.084	0.015	–	–
Fineness (cm^2/g)	–	–	–	–	–	–
Modulus of elasticity (GPa)	–	–	–	–	–	44.00
Water-to-binder (W/B) ratios	–	–	–	–	0.71	–
Soundness (mm)	–	–	–	–	–	–
Water absorption (%)	–	–	–	–	–	–
Water shrinkage (10^{-6} mm/mm)	–	–	–	494	–	–
Water permeability (10^{-12} m/s)	–	–	–	0.03	–	–
Chlorine ion diffusion coefficient (10^{-6} cm^2/s)	4	–	–	–	–	–

Properties	Result				
	[41]	[42]	[50]	[51]	[52]
Compressive strength	39.00	–	91.50	38.73	35.50
Expansion (%)	0.036	0.058	–	–	–
Fineness (cm^2/g)	–	519	–	1426	–
Modulus of elasticity (GPa)	–	–	47.90	–	–
Water-to-binder (W/B) ratios	–	–	–	0.66	–
Soundness (mm)	–	–	–	2.60	–
Water absorption (%)	–	–	–	6.64	–
Water shrinkage	–	–	–	–	–
Water permeability ($\times 10^{-12}$ (m/s)	–	–	–	–	–
Chlorine ion diffusion coefficient (10^{-6} cm^2/s)	–	–	–	–	–

continuing progress of the industrial and technologies has been accompanied by a sharp modernization and construction diversification. Hitherto, the deterioration and threatening of the concrete durability, governed by the percolation of carbonation, chloride and sulfates through fluid transportation [45] is interpreted as one of the most intransigent paradoxes around the world. Numerous mitigating approaches and imperative technologies have drastically been addressed and confronted. Particularly, the incorporation of fillers or pozzolanic substances contemplated for the improvement of concretes has prevailed to be a new growing branch in the civil engineering [39,46].

Ample ancient historical documents, the pioneering works regarding pozzalanic reaction was firstly proposed by Stanton in the 1940s, suggesting the adoption of finely ground 'Monterrey Shale' and pumicite [47]. A decade later, similar research has been advanced by the US Army Corps of Engineers, expressing the viability and usefulness of the artificial pozzolans (fly ash) [48]. The extent of effort has proliferated for the next 50 years, and today, a variety of scientific publications and manifestations covering the pozzolanic chemistry have been executed tremendously. Explicitly, the revolution of oil palm ash in the structural science has attracted a huge energetic focus, mainly correlated to its abundantly accessibility and low profitable commercial value [49].

Table 4 summarized lists of studies for the utilization of oil palm ash as a supplementary cementitious material in producing of high-strength concrete during the last 20 years. In most cases, the complimentary technique was reported remarkably depresses the water permeability, water-to-binder ratio (W/B) and drying shrinkage, while enhances the modulas elasticity, expansion, compressive and tensile strength, thus facilitating the diminishing of size and volume of concretes and enabling lighter and slender structures essential in the high-rise buildings [41,42,50–52]. In 1990, the early study conveying the idea of oil palm ash refinement has been conducted by Tay [52], signifying a compressive strength of 35.50 MPa. Relatively, Sata et al. [40] and Tangchirapat et al. [38] have assessed the emphases utilizing oil palm ash for partial substitution of portland cement, pointed out the advantages of grain and porosity amelioration, friction reduction (between cement and aggregates) and increase workability of the fresh concretes.

Upon the pozzolanic transformation, fine particles of oil palm ash attempt to occupy the voids between the cement and aggregates, while at the later ages, silicon dioxide prompts to react with the free lime or calcium hydroxide (generated from the hydration process) for the formation of calcium silicate hydrate compounds (interfacial bonding) [53]. In this respect, Tay and Show [51] has directed a fineness test related to the Le Chatelier's accelerated principle, achieving a marginal rise proportional to the amount of ash content ranging from 0.50 to 2.60 mm, well within the requirement specified by the American standard ASTM BS12. Accordingly, the initial and final setting time were determinate vary from 2 h 5 min to 2 h 45 min and 3 h 5 min to 4 h 5 min, which fulfilled both threshold limits permitted by the American standard ASTM C150 and British standard B.S. 12:1978 (delay effect).

Lately, a broad range of penetration tests (chloride penetration, rapid chloride penetration, rapid migration and actual chloride penetration test) have been regulated by Chindaprasirt et al. [36], illustrating a dispersing resistant towards the depassivation of steel, reinforcement of interfacial zone and reduction of ion diffusivity and corrosion initiation period. Depending on the ash fineness and replacement level, incorporation at 40% of ash content promoted a reduction of charge to 1050 C (chloride penetration test), depth penetration at 4.5 mm (rapid migration test) and pores segmentation or larger nucleation sites for higher consumption of calcium hydroxide and hydration products precipitation (chloride penetration and actual chloride penetration test).

In a separated investigation carried out by Sata et al. [50], thermal treatment designated a deduction of energy release, recording the lowest peak temperature increase of 40 °C.

4. Emergence of oil palm ash in the biodiesel production, natural rubber manufacturing, sludge treatment and black soap processing industries

During the early of 1990s, the expansion of biodiesel industry, manufactured by the esterification of renewable oils, fats and fatty acids started as part of the government's diversified cautious policy in alternating the high consumption of crude petroleum oil and raising the socio-economic status of the population in the country [54]. Unfortunately, in terms of its sustainability, the conversion of biodiesel is currently encountering extensive perplexities associated with disproportion amount of impurities, limitation of yield, food versus fuel dispute and solid residues generation [55]. Recognizing the constrictions, in 2009, Chin et al. [43] has endeavored to advocate the transesterification of waste cooking in the attendance of oil palm ash. Result indicated the addition of palm ash catalyst may constitute a three phase system, oil-methanol-catalyst, thus creating a diffusion resistance within the viscous multiphase system, devoting the elevation of available active sites, reaction equilibrium and production yield.

On the contrary, Chun et al. [44] attempted the employment of oil palm ash as sludge chemical binders for stabilization of pH, reduction of contaminants mobility and improving of physical integrity via a combination of precipitation, encapsulation, chemisorption and ion exchange processes. Under the mixing stage, hydration occurred upon the contacting of binding mixtures with the water molecules, thereby stimulate a rapid setting, leading to the production of rigid calcium silicate hydrate (C–S–H) structure, with densely and packed silicate fibrils interlacing the mixture entrapping inert materials and unreacted grains [56]. Unconfined compressive strength (UCS) values for each sample at 28-day are noticeable higher than the 7-day of curing, clarifying the necessity of a longer period for the formation of calcium silicate hyrate (through diffusion of water molecules into the cementitious materials). Parallel to the route mechanism of the standalone ordinary Portland cement, leaching test elucidated tricalcium and dicalcium silicates reacted concurrently in water generating strength-enhancing tobermorite and calcium hydroxide, which subsequently contributing a soaring effect towards the alkalinity of the leachates [Eqs. (1)–(3)] [56,57].

$$2(3\text{CaO}{\cdot}\text{SiO}_2) + 6\text{H}_2\text{O} \rightarrow 3\text{CaO}{\cdot}2\text{SiO}_2{\cdot}3\text{H}_2\text{O} + 3\text{Ca(OH)}_2\,[\text{Tobermotrite}\,(\text{C–S–H})] \tag{1}$$

$$2(3\text{CaO}{\cdot}\text{SiO}_2) + 4\text{H}_2\text{O} \rightarrow 3\text{CaO}{\cdot}2\text{SiO}_2{\cdot}3\text{H}_2\text{O} + 3\text{Ca(OH)}_2\,[\text{Tobermotrite}\,(\text{C–S–H})] \tag{2}$$

$$\text{Ca(OH)}_2 \rightarrow \text{Ca}^{2+} + 2\text{OH}^- \quad (\text{Dissolutionofionsunderaqueouscondition}) \tag{3}$$

In the natural rubber processing industry, Ismail and Haw [58] have exhibited the possibility of oil palm ash as coupling agents for remedying the compatibility of hydrophilic and hydrophobic polymer matrix while enhancing its hardness, stiffness, brittleness and vulcanization curing rates. An upward trend in the maximum and minimum torque values together the tensile modulus stress were witnessed, primarily attributed to the additional friction and heat generation, existence of metal oxides and blockage or reduction in the elasticity, elongation and movement of rubber macromolecular chains [59]. Fig. 5 evident the appearance of oil palm ash as filler substances onto the natural rubber where Fig. 6(a)–(c) correlates the reduction of tensile strength to the poor adhesion of oil palm ash. Result anticipated smooth tensile-fracture surfaces in the absence of oil palm ash [Fig. 6(a)], while featured the filler pulling out phenomenon for higher detachment of ash particles [Fig. 6(b) and (c)], mainly executed by the agglomeration of poor wettability and heterogeneous dispersion influence.

The hypothesis was further validated by the determination of fatigue life [Fig. 7(a)–(c)], presuming the inherent defects and cracks (in the presence of oil palm ash) which act as the stress concentration points propagating towards the catastrophic failure. In Nigeria, the assignation of oil palm ash in the production of traditional black soap (Fig. 8) has been revealed by Taiwo and Osiniwo

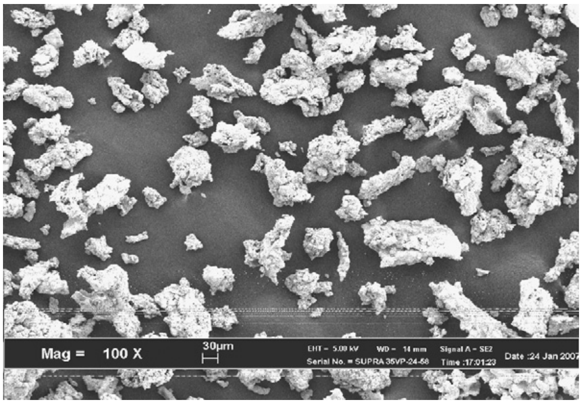

Fig. 5. The appearance of oil palm ash as filler substances onto the natural rubber (100×) [58].

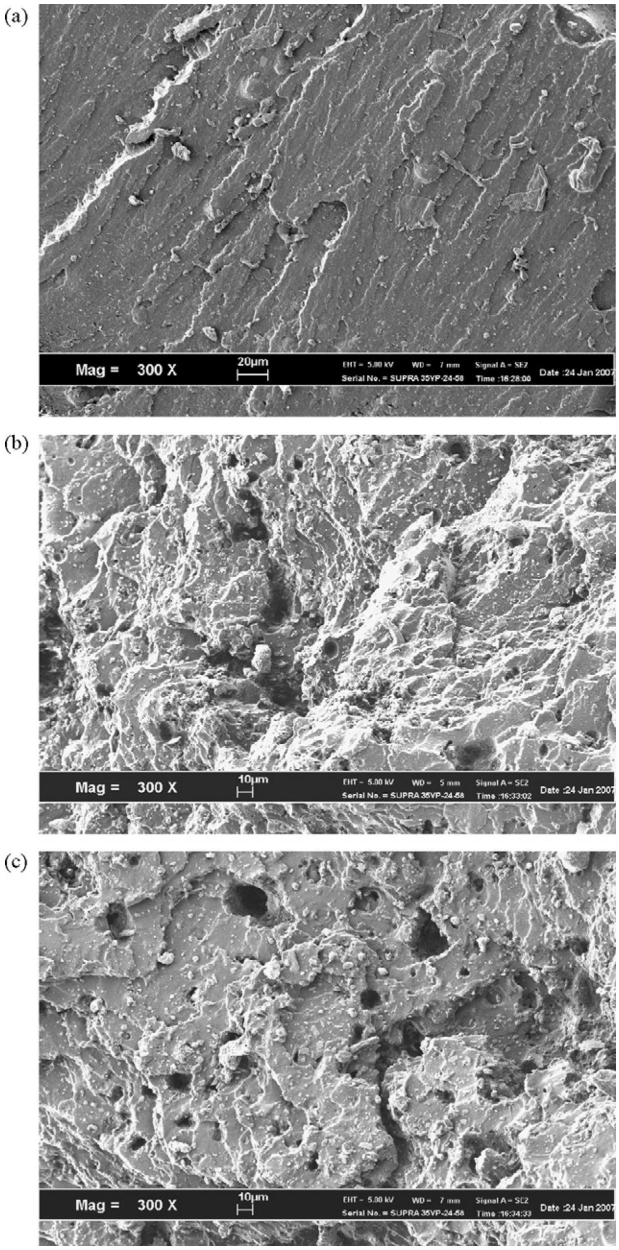

Fig. 6. Scanning electromagnetic micrographs (SEM) of oil palm ash filled natural rubber composites after tensile-fracture surface with (a) 0, (b) 10 and (c) 30 phr palm ash loadings (300×) [58].

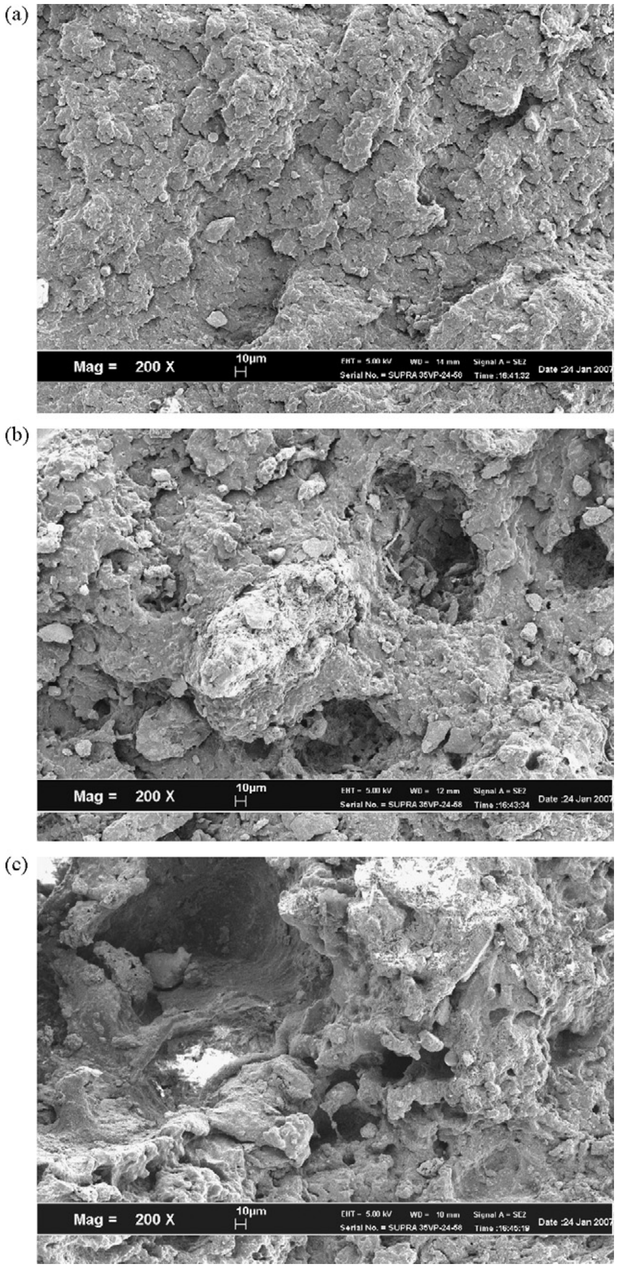

Fig. 7. Scanning electromagnetic micrographs (SEM) of oil palm ash filled natural rubber composites after fatigue fracture surface with (a) 0, (b) 10 and (c) 30 phr palm ash loadings (200×) [58].

[60], underlying the excellent solubility, consistency, cleansing and lathering ability, with large composition of potassium and sodium compounds as its key drivers (Table 5).

5. Major challenges and future prospects

The world is currently facing the worst environmental crisis in its entire history. For the past two decades, the enthusiasm of huge waste production and environmental preservation has been one of the most challenging topics, which have focused critical considerations towards the recycling and reservation of agricultural biomass resources [4]. Concomitant with the vital development of bio-fuel markets in the European Union [61] and growing food demand in Indonesia, India and China [62], the world palm oil production is forecasted at an annual increscent of 9%, which in Malaysia alone, more than 2.8 million hectares of land is under oil palm cultivation with a generation of 42 million tons of fresh empty fruit bunches, translating to around 17 million tons of biomass waste [7].

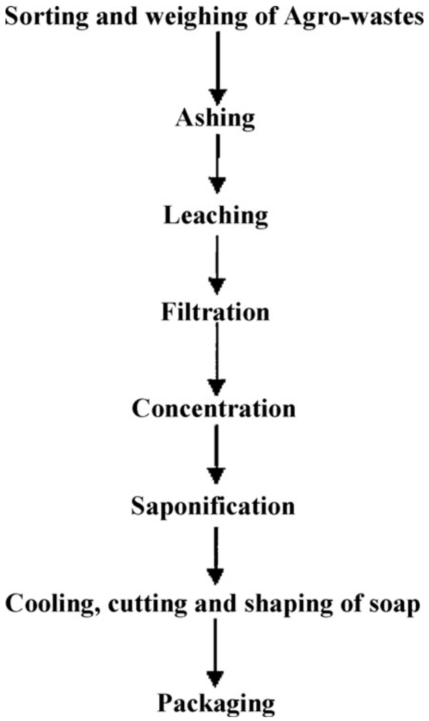

Fig. 8. Flow chart for the production of traditional black soap from agro-waste ashes [60].

In line towards achieving the status of green environmental policy and cleaner technology approach, the innovation of oil palm ash in enormous applications (adsorbent, concrete pozzalanic material, biodiesel production, natural rubber processing, sludge treatment and black soap industry) has seen a panacea and new menu to reconcile agriculture practices, for insuring long-term agricultural operations and sustainability of the cropping systems. Varying upon the alterations of time, place and context, environmental effectiveness, technological feasibility, social acceptability and economical affordability are usually the key factors deciding its flexibility, reliability and sustainable manner [5,14,23]. Although there has been some successful industrial-scale production of renewable resources from oil palm ash, generally the industry is still facing various challenges, the availability of economically viable technology, sophisticated and sustainable natural resources management, and proper market strategies under competitive markets.

Amidst these challenges, the enforcement and administration of strategic, corrective and transparent policies, mandates and standards ministering various contaminants from agricultural waste streams ought to be properly legislated and well-planned, inevitably affect the waste disposal practice of the oil palm ash industry [3,23]. In Malaysia, the enactment of the Environmental Quality Act of 1974 and the subsequent formation of the Department of Environment in 1976 was amended in 1985 to include the submission of Environmental Impact Assessment (EIA) reports on

Table 5
Sodium and potassium content in the oil palm ash [60].

Chemical compounds	Weight percent (%)
Potassium carbonate (K_2CO_3)	43.15 ± 0.13
Potassium hydroxide (KOH)	15.91 ± 0.10
Sodium carbonate ($NaCO_3$)	0.36 ± 0.04
Sodium hydroxide (NaOH)	0.13 ± 0.03

proposed development program to the Department of Environment (DOE) for approval [63]. Ultimately, full co-operation and joint venture between different parties (nations, states, local government, private sector and communities) from upstream till the bottom line with compatible technologies is a directive motivation for the race to the end line.

6. Conclusion

Throughout recent era, the world's accessibility oil reserves are gradually depleting, riding towards the overwhelming researches dealing with agricultural biomass waste utilization. Predictions for the next 20 years indicate an ascending impact in the agricultural waste production and, subsequently in ashes generation. Today, the growing discrepancy and limited success of remediation in field applications has raised apprehensions over the use of oil palm ash as a measure to the environmental pollution control. The evolution has turned from an interesting alternative approach into a powerful standard technique by offering a numbers of advantages. Although it is still in the infancy, a widespread and great progress of in this area can be expected in the future.

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