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**ARTICLE**

**Research Article**

**Characterization of palm kernel shell for materials  
reinforcement and water treatment**

**1**

Edmund C. Okoroigwe, Christopher M. Saffron  
and Pascal D. Kamdem

Full Length Research Paper

## Characterization of palm kernel shell for materials reinforcement and water treatment

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As developing nations strive for economic sustainability, effort is geared towards exploiting biomass materials that could have alternative uses to their conventional low valued uses in order to achieve this goal. It is because of this that palm kernel shell, a byproduct of oil palm processing, is characterized for its application in construction and water treatment industries. The materials physical and chemical properties determined using standard methods show that it can find useful application in light weight construction as material filler and as sorbent material for industrial water treatment. The results of the x-ray photo spectrometry (XPS) and x-ray diffraction (XRD) reveal that the palm kernel shell (PKS) contains surface elements, morphology and crystalline qualities well required of material fillers in construction and adsorption industries. These can add to the market values of palm kernel shell as against its direct combustion and wastage of the material at oil palm processing mills.

**Key words:** Oil palm kernel shell, characterization, adsorbent, x-ray diffraction, micro porosity.

### INTRODUCTION

In Indonesia, Malaysia and several West African countries, oil palm is commercially cultivated in plantations where trees are grown on a 25 to 30 year rotation followed by removal and replanting (Durst et al., 2004). In Nigeria, oil palm is an important tree because of the value of the crude palm oil, fronds, stems and leaves. Because of the magnitude of this industry, several residues are co-produced with palm oil. These include: the empty fruit bunch (EFB), palm fruit fiber (PFF), palm oil mill effluent (POME) and palm kernel shell (PKS). Whereas oil palm is chiefly cultivated for palm oil (PO) and palm kernel oil (PKO), the PKS (as residue) has

been regarded as 'waste' from palm oil processing by Obeng et al. (1997), Lartey et al. (1999) and Ibadode and Dagwa, (2008). It has been shown that approximately 15 to 18 tonnes of fresh fruit bunches are produced per hectare per year and PKS comprises about 64% of the bunch mass (Obisesan, 2004; Adewumi, 2009). In the developing world, waste PKS is either burned to supply energy at palm oil mills or left in piles to compost.

Many of the residues of oil palm harvesting and processing are valued for various applications. PKS has been laid on roads to improve vehicular traction

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along plantation farms where there are no tarred roads. In a few communities, women have sold PKS as a source of heat for cooking; though much accumulates in piles when more is produced than utilized. PKS is commonly used in combustion processes, especially at oil mills as boiler fuel to generate heat and electricity (Yusoff, 2006) although PKS alone is not well regarded as a fuel due in part to smoke emissions (Yusoff, 2006; Walubengo, 1989). As a result, it is often combined with wood fuels, like sawdust or wood, to improve the calorific value of the biomass feed to the boiler (Kuti, 2007). Though its combustion value is substantial, the process of burning PKS releases significant volatiles and particulates which pose pre-ignition and pollution concerns. Instead of combusting PKS for energy, alternative products like concrete filler for infrastructure materials and bio-carbon for water treatment have been considered to establish new markets for this resource.

One of such options is production of activated carbon from PKS. Ogedengbe (1985) investigated the use of both charred and non-charred PKS for filtering effluent from sedimentation tanks of a water treatment plant. A dual media filtration unit composed of charred PKS and fine sand resulted in long filtration cycles and good water quality. The effluent from non-charred PKS beds also reduced the turbidity of the effluent except that the water had the odor and taste of palm nuts. As with other forms of activated carbon, the use of PKS for water treatment depends upon its surface composition and chemical functionality. Characterization of PKS is needed to assess its applicability for treating a wide range of wastewaters.

Physically, PKS is relatively dense when compared to other biomass varieties, which has positive implications for transporting it for processing. Its high porosity supports its use in water treatment, but because of residual oleic acid, pyrolysis should first be employed to create a biocarbon sorbent. Compositionally, PKS is high in lignin, hemicellulose and silica-containing ash, resulting in a material with a large heating value that is unfortunately prone to forming particulate matter upon combustion. As such, alternative use as filler in infrastructure materials is recommended to fully take advantage of the natural strength properties that this composition provides. Though conversion to energy at power plants with sufficient pollution abatement equipment downstream of combustion remains an option, several characteristics of PKS support its use as material filler and sorbent for water treatment, both of which are greatly needed by the developing nations of the world.

In addition to energy production and water treatment, PKS can serve as a filler to reduce the costs of building and road-making materials. For instance, Okafor (1988), Okpala (1990) and Alengaram et al. (2008) have independently worked on determining the potential of PKS as a concrete reinforcement agent. According to Okafor (1988) PKS can produce concrete with

compressive strength not exceeding 30 MPa, but compares well with conventional aggregates such as granite for concrete grades of 25 MPa and less. Similarly, Okpala (1990) has shown that PKS is suitable for light-weight structural applications, while PKS mixed with concrete shows good sound absorption capacity and low thermal conductivity. The mechanical properties, such as crack width, deflection, ultimate strength, concrete strain and steel strain of PKS concrete were compared with those of normal weight concrete by Alengaram et al. (2008). This work shows that even though the flexural strength of the PKS concrete was 15% lower than that of normal weight concrete, its compressive strength was 6 MPa more than the targeted 30 MPa. These results show that PKS can be used in light weight structures up to loads of 36 MPa.

Road-making is another application that can potentially benefit upon using PKS as material filler. It is recommended that for heavily trafficked roads, PKS can replace aggregates of stone dust and bitumen in 10% blends with asphalt (Ndoke, 2006). Complete replacement of traditional aggregates is possible for lightly trafficked roads in rural settings. Even the partial displacement of bitumen will reduce the human and ecosystem toxicity levels associated with roadways, as bitumen contains polyaromatic hydrocarbons, several of which are known carcinogens. Though PKS is typically either burned or abandoned, the present study suggests its use as a valuable co-product water treatment and as filler for building and construction materials. The efficacy of PKS for the above applications, water treatment and materials reinforcement depends upon its composition and surface chemistry. Hence, there is need for a comprehensive characterization of PKS to assist in deciding amongst its possible applications. In this investigation, both compositional and surface characteristics of PKS are measured using analytical devices and established methods with the objective of informing potential users and marketers of its intrinsic value for sustainable economic development.

## MATERIALS AND METHODS

Palm Kernel Shells used in this investigation were obtained from Nsukka urban where the mean annual rainfall of 1,981 mm (Anyadike, 1992) favors commercial oil palm production in the area, as is common within Southern Nigeria. The sample used was a mixture of palm kernel shells from *Dura* and *Pisifera* species since the varieties are not usually sorted during palm oil processing. Prior to experimentation, the PKS were sun dried in open air at ambient temperature of 31°C. They were transferred to cellophane bags and sealed. They were further crushed using Willey Milling Machine to a particle size of 425 µm passing sieve 40. The moisture content was determined using ASTM D4442-92 standard at 105°C while ASTM D3174-04 was used for ash content determination at 950°C. X-ray diffraction (XRD) was used to measure PKS crystallinity and to reveal the compositional structure of the sample. XRD patterns were obtained on a Rigaku Rotaflex 200B diffractometer equipped with copper K $\alpha$  X-ray radiation and a curved crystal graphite monochromator operating at 45 kV and 100 mA.

**Table 1.** Bulk physical and chemical characteristics of palm kernel shell.

Property	Parameter	Value	
		Ar	db
Physical	Moisture content (%)	6.11	-
	Ash content (%)	8.68	
	*Bulk density ( $\text{kg}\cdot\text{m}^{-3}$ )	740	9.24
	*Porosity (%)	28	650
Chemical	C (%)	46.75	49.79
	H (%)	5.92	5.58
	O (%)	37.97	34.66
	N (%)	0.68	0.72
	S (%)	<0.08	<0.08
	Cl (ppm)	84	89
Structural carbohydrates	Hemicellulose (%)	26.16	
	Cellulose (%)	6.92	
	Lignin (%)	53.85	

ar (as received), db (dry basis), \*(Ndoke, 2006).

X-ray photoelectron spectroscopy (XPS) is used to determine the elemental composition of the PKS surface. A Perkin Elmer Phi 5400 ESCA system was used for this analysis with magnesium  $\text{K}\alpha$  X-ray source. Atomic concentrations were determined using previously determined sensitivity factors. All peaks were referenced to the signature  $\text{C}1\text{s}$  peak for adventitious carbon at 284.6eV. The structural carbohydrates and lignin were determined using the two-step, 72% sulphuric acid hydrolysis method developed by the National Renewable Energy Laboratory (NREL/TP-510-42618), 2008.

The anatomical structure of PKS was observed using a JEOL JSM-6400V (lanthanum hexaboride electron emitter) scanning electron microscope, after coating PKS samples with osmium (~10 nm thickness) in an NEOC-AT osmium coater. The digital images were acquired using Analysis Pro software version 3.2 (Olympus Soft Imaging Solution Corp., Münster, Germany).

## RESULTS AND DISCUSSION

Table 1 contains a compilation of several physical and chemical characteristics of the PKS sample that was used. From the table it can be shown that PKS has an appreciable bulk density for plant biomass, equal to  $740 \text{ kgm}^{-3}$  (wet) and  $650 \text{ kgm}^{-3}$  (dry). This may be advantageous to PKS users, as greater bulk density corresponds to reduced hauling costs. Moisture contents between 6 and 9% are normal after equilibration with the laboratory environment. These characteristics compare to those of similar barrier tissues such as coconut shell (ECN, 2008).

Structurally, PKS is composed mainly of lignin and hemicellulose as measured by the method devised by NREL. PKS was found to be nearly 54% lignin, which is higher than other shell residues such as coconut shell

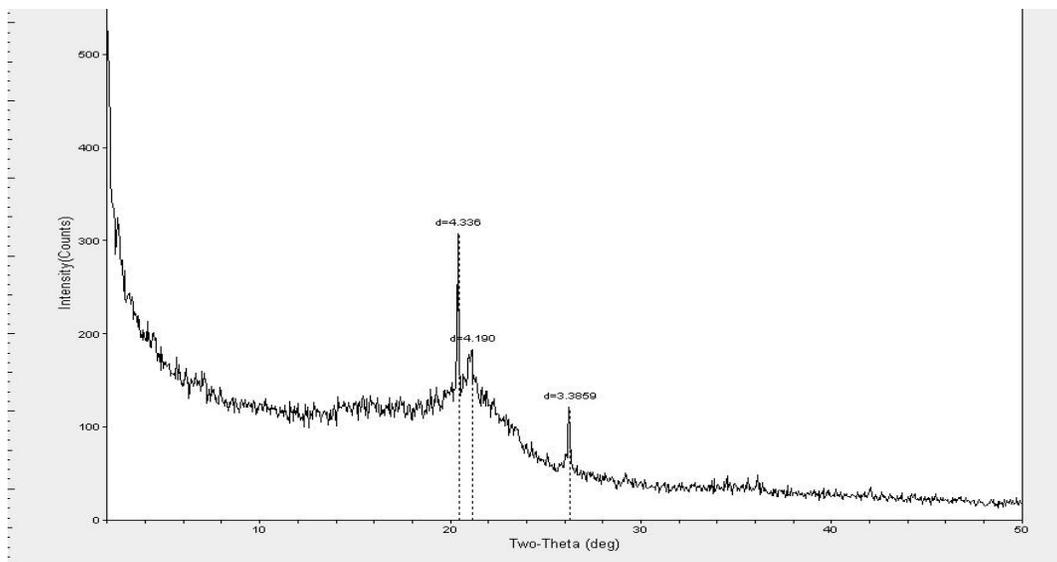
(ECN, 2008). This is similar to that obtained by Daud et al. (2004) as reported by Maedeh et al. (2011). The hemicellulose content is also consistent with shell residue material and the relatively large amount suggests that PKS could serve as a pentose sugar source provided that the high lignin content can be disrupted by pretreatment. Its structural properties support its use as low-cost filler for building and road making materials.

### X-ray powder diffraction (XRD)

The results of XRD displayed in Figure 1 show three crystal peaks corresponding to d-4.34, d-4.19 and d-3.39. A peak at d-4.34 and  $2\theta$  equal to 20.6 is likely silicon oxide, which is a component of PKS. Oleic acid, identified at d-4.19, is likely residue from palm oil and palm kernel oil. PKS is largely amorphous as its crystallinity is only 14.38%, which is indicative of its high lignin and hemicellulose contents. This quality may be useful in application of PKS as material filler. Okafor (1988), Okpala (1990) and Alengaram (2008) have shown that moderate strength concrete can be formed using PKS as filler.

### X-ray photo spectrum (XPS)

The XPS result (Table 2) and its spectrum (Figure 2) show the presence of other elements such as aluminum, silicon, calcium and iron, on the surface of PKS samples. Although, these elements are in trace quantity when compared with carbon and oxygen, they play significant

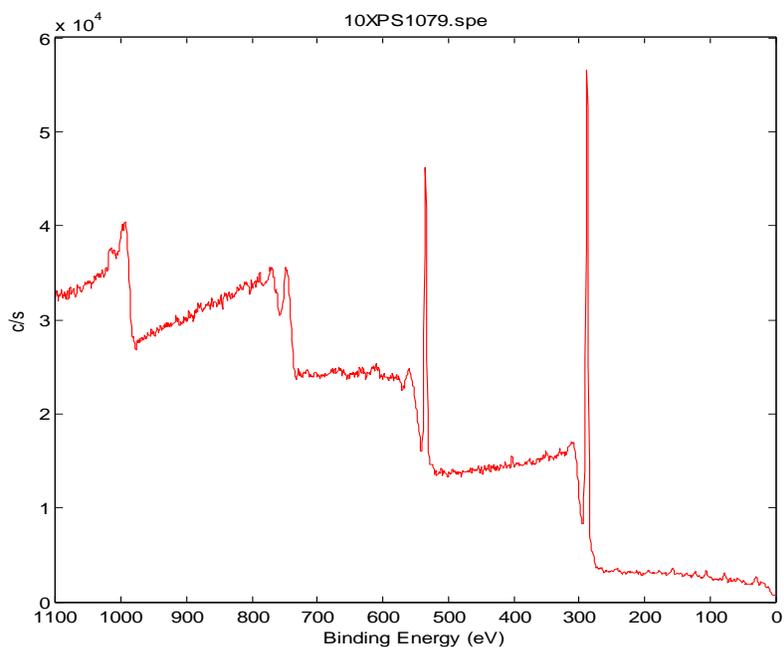


**Figure 1.** XRD of the palm kernel shell sample.

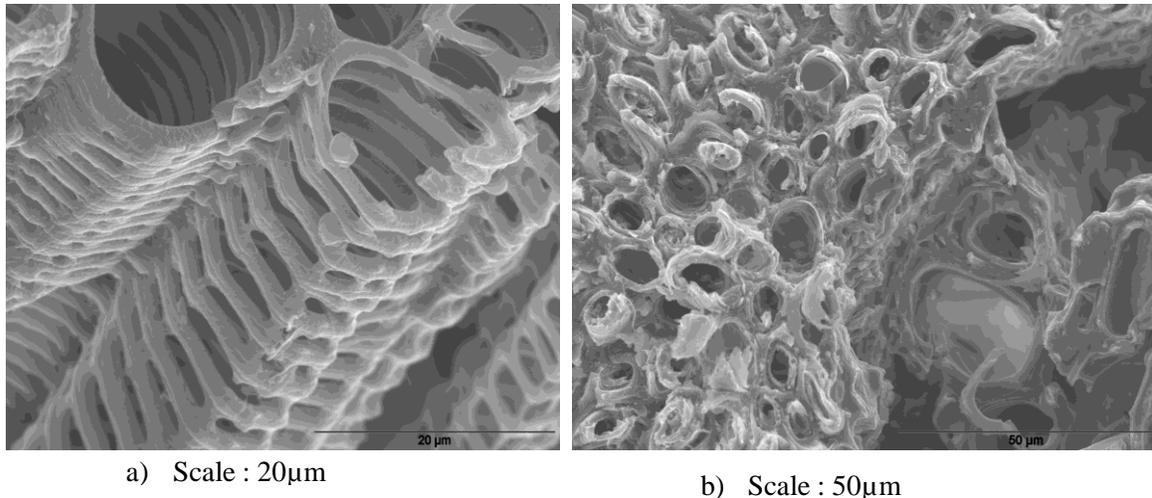
**Table 2.** The X-ray photoelectron atomic concentration table of palm kernel shell surface on mole basis showing the predominance of carbon and oxygen.

C1s	N1s	O1s	Al2p	Si2p	Ca2p	Fe2p
75.52	0.90	20.96	0.98	1.17	0.20	0.27

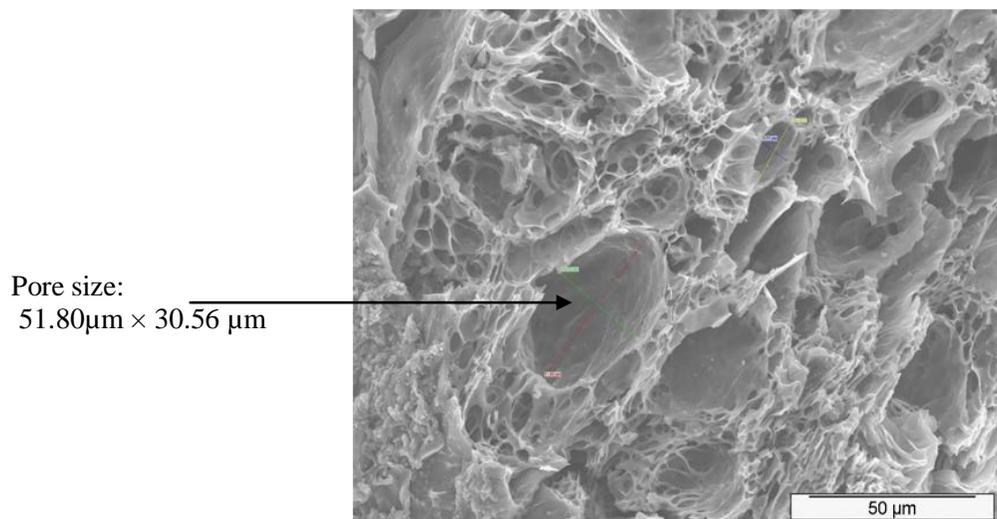
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 Sur1/Full/1 (Sat SG5)



**Figure 2.** XPS spectrum of the palm kernel shell.



**Figure 3.** SEM images of the palm kernel shell showing the natural pores in the shell.



**Figure 4.** Scanning electron micrograph of palm kernel shell after pyrolysis showing the porosity of the resultant char.

role in presenting the sample good for material filler in construction industry. It is the presence of silicon that gives the sample its crystalline property as presented by the XRD spectrum (Figure 1).

### Scan electron microscopy

Morphology and pore structure are important for expelling volatiles when subjected to thermochemical processes such as torrefaction, pyrolysis and gasification. The SEM images in Figure 3(a) and (b) reveal the porous and heterogenous structure of the heat-untreated palm kernel

shell. These micrographs reveal the micro pores through which the kernel exchanged fluids with the surrounding mesocarp. Thus PKS has potential as a sorbent material. After pyrolysis, an increase in macro porosity is observed in the SEM image shown in Figure 4 which is consistent with Uzun et al. (2010) for heat-treated tea waste. Guerrero (2005) shows that macro porosity increases after pyrolysis. Macro pores give access to the inner surface of the particle, while micro pores, created during activation (Cookson, 1978) are responsible for the large surface area of the activated carbon (Lartey et al., 1999). The high porosity of PKS char suggests that water treatment should be considered as an application of this

material. This has wide industrial applications in chemical, food and pharmaceutical industries as well as metal recovery and water treatment. Activated carbon is in high demand in African countries like Ghana (Lartey et al., 1999) and Nigeria (Adewumi, 2009) and the industry can create enormous job and business opportunities in communities where oil palm is produced.

## Conclusions

Palm kernel shell is characterized for use as a sorbent in water treatment technology, as a filler material in the construction industry. PKS has utility for a wide range of applications as alternative to direct combustion. As a source of energy, PKS has an appreciable heating value but suffers from smoke production during combustion. X-ray photoelectron spectroscopy reveals a higher carbon-to-oxygen ratio on the surface than in the bulk solid, implying that PKS may serve as filler in hydrophobic materials or as a sorbent for moderately hydrophobic contaminants. Other characterization results also support the application of the biomass in both construction material filler and water treatment agent in the food and beverage industry.

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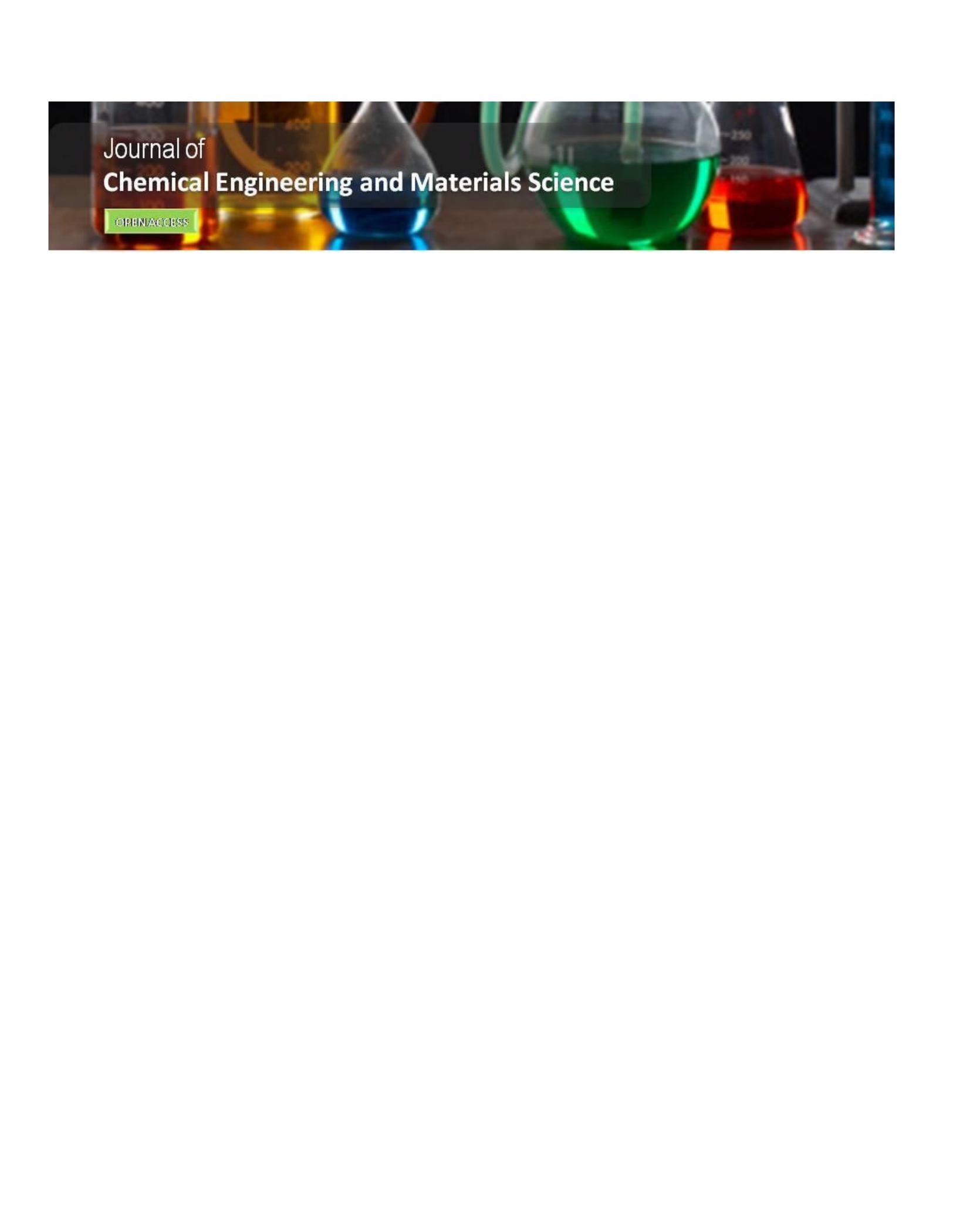
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## Conflict of Interests

The author(s) have not declared any conflict of interests.

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A photograph of various laboratory glassware including beakers, flasks, and a burette, each containing a different colored liquid (yellow, blue, green, red). The background is dark, and the glassware is illuminated from below, creating a dramatic effect. The text is overlaid on the left side of the image.

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