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Compaction of palm kernel shell biochars for application as solid fuel

Alireza Bazargan [a,b,*], *Sarah L. Rough* [b], *Gordon McKay* [a,c]

[a] Department of Chemical and Biomolecular Engineering, Hong Kong University of Science and Technology, Clearwater Bay, Hong Kong

[b] Department of Chemical Engineering and Biotechnology, New Museums Site, Pembroke Street, University of Cambridge, Cambridge CB2 3RA, UK

[c] Division of Sustainable Development, College of Science, Engineering and Technology, Hamad Bin Khalifa University, Qatar Foundation, Doha, Qatar

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ABSTRACT

Palm oil is the most widely sold oil across the globe. The production of palm oil results in vast amounts of biomass waste. The palm kernel shells (PKS) can be used for energy production through gasification or combined heat and power (CHP). After gasification, some PKS remains as charred residue. In this manuscript, briquettes/pellets are produced from these biochars. The palm kernel shell biochars (PKSB) show very high calorific value exceeding typical values for biomass. The effects of water content, compaction pressure, feed particle size, compaction retention time, and the use of starch as a binder have been studied. The tensile crushing strength, impact resistance, and water resistance (immersion tests) show that the starch binder is imperative for suitable briquette quality. The use of starch increases the tensile crushing strength from less than 40 kN m^{-2} to more than 800 kN m^{-2} in the weakest (longitudinal) orientation. The tensile crushing strength of the starch-bound briquettes increases as their water content evaporates during storage and curing. It is speculated that the evaporation of water from the starch-bound sample allows for better cementing of the starch and PKSB particles.

1. Introduction

In recent years, due to the dwindling reserves of fossil fuels on one hand and the many benefits associated with biofuels on the other, utilizing biomass as a source of energy is on the rise. Densification of biomass into briquettes, pellets, cubes etc. is a method employed for increasing the intrinsic density of materials from 40 to 200 kg m^{-3} to 600–800 kg m^{-3} for more favourable employment [1]. Because of the uniform shape and size of densified products, they can more easily be handled and used in standard combustion equipment. There are various books and review articles which have favourably compiled information regarding biomass densification [1–3].

On the other hand, the most widely traded edible oil around the globe is palm oil. The production of palm oil has more than doubled in the past two decades. In obtaining edible oils from palms, a large amount of residue is produced.

* *Corresponding author*. Department of Chemical and Biomolecular Engineering, Hong Kong University of Science and Technology, Clearwater Bay, Hong Kong. Tel.: +852 23587132.
E-mail addresses: bazargan@ust.hk, ab2201@cam.ac.uk (A. Bazargan).

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Nomenclature

Roman

D	diameter of sample [m]
F	maximum force applied to break sample in tensile strength test [N]
h	height of sample [m]
n_d	number of drops in impact resistance testing
n_p	number of pieces of broken sample in impact resistance testing

Greek

ε	porosity
ρ_a	apparent density [kg/m^3]
ρ_t	true density [kg/m^3]
σ	tensile crushing strength [N/m^2]

Abbreviations

CHNS	carbon hydrogen nitrogen sulphur
CHP	combined heat and power
HHV	higher heating value [J/kg]
IRI	impact resistance index
LHV	lower heating value [J/kg]
PKS	palm kernel shell(s)
PKSB	palm kernel shell biochar(s)
XRF	X-ray fluorescence

One such residue is the palm kernel shell (PKS). PKS is reported to have a high calorific value allowing it to be used as fuel in cogeneration plants to generate both heat and electrical power. The heating value of the shell has been reported as 17.4 MJ kg^{-1} [4] with a higher heating value of 23.0 MJ kg^{-1} [5]. Calculations show that the shell and the fibre residue alone from palm oil production can provide more than enough steam and electricity for the entire palm oil mill [6].

1.1. *Thermal pretreatment of PKS*

There are some disadvantages when using solid biomass such as PKS as fuels, namely their low energy density, low heating value, high moisture content, low carbon content, high oxygen/carbon ratio and hygroscopic nature, as well as soot formation, transportation difficulties and poor grindability [7]. In order to overcome these drawbacks, pretreatment processes are often necessary. The products of biomass thermal treatment can be divided into solid residues with high-density energy, referred to as 'biocoal' or 'biochar', and a volatile fraction. The volatile fraction can in turn be divided into condensable liquids (such as water, acetic acid, and tars) and non-condensable gases. The solid product of a thermal treatment process is dry and has no unfavourable biological activity such as biodegradation, allowing for long storage durations. The heat-treated solid is much more brittle than the original biomass, improving the grindability of the fuel [7–9].

Prior to thermal treatment, the materials are usually first refined, meaning that the unwanted fractions are physically removed. This is followed by a preheating step to dry the material. After the products are heat-treated they are usually cooled to avoid fire hazards. Densification in the form of pellets or briquettes is carried out to further increase the energy density of the solid fuel [10]. PKS have been heat-treated in several studies aiming at producing more satisfactory solid fuels. In one study, PKS was treated at temperatures ranging from 513 to 553 K for durations ranging from 1800 to 5400 s (30–90 min) [11]. The carbon content of the PKS increased at the expense of hydrogen and oxygen resulting in an increase of 5–16% in heating value. In another study, the oxygen/carbon ratio, hydrogen, and oxygen mass fractions were shown to decrease and the calorific value was shown to increase from 18.9 MJ kg^{-1} (raw) to 22.8 MJ kg^{-1} (after treatment at 573 K) [9]. A mass loss of 45–55% was observed for different conditions. The type and amount of gas released during the process is a function of the type of biowaste, temperature, and treatment duration. Different types of thermal treatment can be applied to PKS [12], such as torrefaction, mild thermal treatment in the presence of steam [13], and extreme pyrolysis at higher temperatures [14]. The production of hydrogen gas at elevated gasification temperatures is also an area of research [15–17].

1.2. *Background to PKS densification*

A number of densification studies regarding PKS have been reported [18,19]. It has been estimated that the production of durable pellets from palm kernel residues will cost less than £50 per 1000 kg [20,21]. Since PKS is composed of more than 50% lignin [22], densification may be aided by the high lignin content acting as a natural binder. Some authors have suggested that heating the biomass during compaction will be beneficial for the durability of the final product [23,24]. The positive effect of heating has been attributed to the glass transition temperature of lignin. Nasrin et al. [25] densified oil-palm biomass at operational temperatures of 423–523 K and pressures of 7 MPa without the use of binders. Under these conditions, the lignin content within the biomass was softened and resulted in particle bonding. Nonetheless, the study concluded that the addition of binders could be beneficial for the final quality of the briquettes. Once ignited, the briquettes generated about 130 W of thermal output [25].

To date, more than 50 organic and inorganic binders have been tested for densification [26]. In the case of starch, first, the water-starch solution is usually heated to sub-boiling temperatures until the mixture becomes sticky and gelatinous. The solid biomass is then mixed and coated with the binder before being densified. One study using a mixture of shells and fibres employed 10% starch and 50% hot water to enhance the densification process [27]. The compaction pressure was in the range of 5–13.5 MPa and the briquettes exhibited an average strength of 2.56 kN m^{-2} [27]. Glycerin has also been used as a binder for mixed palm biomass briquettes. The optimum mass ratio of raw material, water, and waste glycerol was found to be 50:10:40 [28]. Sing and Shiraz Aris [29] dried, pulverized, and sieved PKS and palm fibres to smaller than 50 μm before densification with the aid of paper and starch binders. In a study by Arzola et al. [30], raw PKS was densified using molasses at 15%, 20% and 25% as an added binder. As far as the durability was concerned, the binder content had great influence, yielding more durable pellets as