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Pelletised fuel production from palm kernel cake

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ABSTRACT

Biomass is an important source of renewable energy. Worldwide, the palm oil industry generates large amounts of waste materials, such as shells, fibres and palm kernel cake, which can be used for power generation. Processing the palm kernel cake into a uniform fuel through pelletisation will be an attractive option — assessing the suitability of this process was the main objective of this research. Extensive analytical and pelletisation tests were performed to evaluate the physical properties of pellets produced from this material. The variables explored included the pelletisation pressure, temperature, fuel moisture and the effect of binders, which all had significant effects on density and tensile strength. The most favourable conditions for pellet production were a pressure of 9338 psi/64.38 MPa, a temperature of 80–100 °C and a fuel moisture content of 7.9%. These pellets had densities of 1184–1226 kg/m^3 and tensile strengths of 930–1007 kPa. Adding small amounts of caustic soda (1.5–2.0wt%) to the palm kernel cake under these conditions increased the tensile strength to 3055 kPa, whereas starch additives were not found to be effective binders. It is estimated that the production of palm kernel cake pellets with 2 wt.% of the caustic soda binder would cost approximately £28–47/tonne.

1. Introduction

To overcome the issues associated with global warming, promoting biomass as a source of renewable fuel is vital, since the use of these energy resources is important in protecting the environment. Wood, energy crops, agricultural/forestry residues and the organic components of municipal and industrial wastes are major sources of biomass fuel. Each of them has specific properties that determine their performance and characteristics as a fuel.

The Malaysian palm oil industry has grown tremendously over the last four decades and is currently the world's second largest palm oil producer and exporter [1]. Malaysia has declared that biomass is the fifth fuel in its energy mix, which reduces the demand for fossil fuels [2,3]. Solid oil-palm waste materials (including the shells, fibres and its kernel) are produced during the palm oil milling process. Currently, most of the wastes generated are left to decompose in the plantation areas and are used as soil conditioners [4]. For every ton of oil-palm fruit being fed to the refining process, about 0.07 tons of palm shell, 0.103 tons of palm fibre and 0.012 tons of kernels are produced as solid wastes [5]. Waste from the palm oil industry, particularly the palm kernel cake (PKC) is abundant and can help meet the energy demand, if managed properly [6]. However, the research that has been carried out on the utilisation of PKC for energy production is very limited.

1.1. Fuel pelletisation

Pelletisation is a process of compacting loose material to form a densified, homogeneous product. Pellets are often favoured for fuel applications because of their enhanced physical properties, as well as being easy to feed and handle. According to Grover and Mishra [7], the most influential parameters in the selection of raw materials are the moisture content, ash content, flow characteristics and particle size. Most pelletisation processes involve either compression of extrusion techniques.

Nasrin, et al. [2] investigated the physical and chemical properties of pellets made from palm oil biomass. It was found that the conversion of a mixture of empty fruit bunches and PKC into a uniform fuel, such as pellets, can improve their properties and value, including the energy content, by reducing the moisture levels by 5% and 38% respectively.

Other studies have investigated the pelletisation of a range of other biomass fuels. Bhattacharya, et al. [8–10], for example, studied several biomass wastes and found that there were marked improvements in the combustion characteristics of pelletised biomass compared to the loose, raw material. Ryu, et al. [11] evaluated the quality (density, swelling, tensile strength and durability) of spent mushroom compost-coal tailing pellets. It was found that both materials were significantly influenced by the moisture content, where the optimum to produce good quality pellets was 10% for the coal tailings and 20% for the spent mushroom compost. Pelletisation at pressures exceeding 6000 psi (>41.37 MPa) did not show any significant improvements in density or strength from those made at 6000 psi (41.37 MPa). Finney,

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et al. [12] later evaluated caustic soda and maize starch binders for these materials, in addition to inherent binders. They found that pellet tensile strength increased significantly by adding small amounts of either binder (up to 1 wt.%). The overall quality of the pellet could be further improved by pelletisation at elevated temperatures (45–75 °C), which softened the lignin components of the biomass, acting as a natural binder.

O'Dogherty, et al. [13] studied the energy required to form a pellet made from straw. They found that the specific energy increased linearly from 11 to 24 MJ/t for a pellet density range of 300–600 kg/m^3. Trezek, et al. [14] studied the specific energy required to produce pellets from the light fraction of municipal solid waste. They found that most of the energy consumed was for material deformation; to overcome die friction required about 51.84 MJ/t of energy at a moisture content of 15%. Mani, et al. [15] determined the energy requirements for briquetting corn stover at different pressures and moisture contents. It was discovered that the specific energy consumption (12–30 MJ/t) was dependent on briquette density. Almost half of the total energy required in the compaction of the corn stover was used to overcome the surface friction.

1.2. Costs of pelletised fuel production

The costs involved with biomass fuel pelletisation have been studied extensively and there are guidelines on how to evaluate the costs of manufacturing biomass pellets [16–20]. Thek and Obernberger [19] outline the four main costs to consider for the production of fuel pellets: (i) the total capital costs, (ii) consumption costs, (iii) operating costs and (iv) any other costs. Thek and Obernberger [19] and Mani, et al. [21] stated that about one third of the total production costs for wood pellets are for the raw material and personnel. The drying (particularly involving very wet raw materials) and manufacturing processes were also considered as major contributions to the production costs.

A typical cost analysis for the production of fuel pellets includes plant capacity (t/h), hours of operation (h/day), total number of production days per year (days), electricity costs (currency/kWh), interest rate (%), average equipment utilisation period (year), labour wage (currency/h) and number of shifts [16]. Sultana, et al. [18] reported that the field and transportation costs contributed the most to the total pelletisation costs of wheat, barley and oat residues. The costs of producing one tonne of pellets from these residues were $170.89 (£116.34), $129.42 (£88.11) and $122.17 (£83.17) respectively. The typical costs for loading and unloading biomass in North America are reported as $5.45/tonne (£3.71/tonne) [18]. Transportation costs for moving corn stover bales about 64 km (40 miles) was estimated to be $54.57/dry tonne (£37.12/dry tonne) [22].

Mani, et al. [21] reported that the cost of producing sawdust pellets could be economically viable, about $51/tonne (£34.70/tonne) for a plant with a capacity of 45,000 tonnes/year. Chaiyaomporn and Chavalparit [23] evaluated the production costs of pellets made from a mixture of palm fibre and palm shell (80:20) with 10% moisture content. The analyses were based on three main factors, namely the cost of the raw materials, transportation and manufacturing. They found that the total production costs were around 1140 baht/tonne (£24/tonne).

1.3. Project objectives

The main objective of this research was to examine the effects of process parameters on the physical properties of palm kernel cake pellets, such as tensile strength, density and durability. The variables investigated included the pelletisation pressure, temperature, fuel moisture content and the effect of binders. An attempt was made to determine the optimum values of these parameters, which would result in the best pellet quality. This could help promote PKC as a source of renewable fuel in the future.

2. Materials and experimental methods

2.1. Materials

The palm kernel cake used for these tests was supplied by A.M.E Teras Marin Services Ltd. The sample was finely crushed, until the average particle size was 2 mm in diameter. The PKC has a bulk density of 623 kg/m^3 prior to pelletisation. Standard analytical tests were performed on this material. Table 1 shows the calorific value and the results of the proximate and ultimate analyses for the PKC. The material had a very high volatiles content (71.84 wt.%), with a small amount of fixed carbon (16 wt.%). The calorific value (18.67 MJ/kg) was lower than that of lignite (~28 MJ/kg), possibly due to the low fixed carbon content. The oxygen content was high, and although this was calculated by difference and may therefore contain some errors, this may also negatively impact the calorific value of the fuel [24]. The ultimate analysis indicates that PKC could be an environmentally friendly fuel, as it has a low sulphur content.

Elemental analysis was also performed on the PKC. Table 2 lists the main elements. High concentrations of potassium (K) and phosphorus (P) were found and are thought to be due to the presence of potassium nitrate (KNO_3) and phosphoric acid (H_3PO_4) that are used in fertilisers [24–26]. High alkali metal (potassium and sodium) contents in fuels can be problematic during combustion; this increases the alkali metal oxide content in the ash residues, lowering their melting/fusion temperatures and potentially leading to slagging and fouling [27]. PKC was found to contain only low levels of toxic and heavy metals, such as antimony (Sb), arsenic (As) and lead (Pb). Based on the material specifications provided by the supplier, the PKC also contained about 21% of protein and fat from the palm oil residue.

2.2. Pelletisation experiments

2.2.1. Experimental set-up

PKC pellets were manufactured using the compression pelletiser shown schematically in Fig. 1. This consisted of a stainless steel cylindrical pelletisation chamber (150 mm high, with an internal diameter of 26.8 mm) and a ram. The mould was fixed below the top plate and the ram was attached to the movable platform (hydraulic press). About 20 g of material was loaded through the top of the mould to the centre of the pelletiser. This pelletiser could compress the material up to a maximum pressure of 10,000 psi (68.95 MPa). Two rope heaters (OMEGA FGR-060, 250 W each) were used to heat the mould and a K-type mineral insulated thermocouple was connected to a temperature controller to manipulate the temperature, which had an operating range of ~20–300 °C.

2.2.2. Experimental conditions

The experiments were designed to investigate the effect of a range of parameters on PKC pellet properties. Firstly, the effect of the fuel moisture content was assessed, comparing three moisture contents.

Table 1
Experimentally-determined gross calorific value and proximate and ultimate analyses of palm kernel cake.

	Analysis	Palm kernel cake
Proximate (%, as received)	Moisture	7.92
	Ash	4.28
	Volatiles	71.84
	Fixed carbon	16.00
Ultimate (%dry, ash-free)	C	52.53
	H	5.65
	O	38.93
	N	2.86
	S	0.03
Gross calorific value (MJ/kg)		18.67