Renewable Energy 63 (2014) 426–431

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Energy self-sufficiency of smallholder oil palm processing in Nigeria

Elijah I. Ohimain*, Sylvester C. Izah

Bioenergy and Environmental Biotechnology Research Unit, Department of Biological Sciences, Faculty of Science, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

ARTICLE INFO

Article history:
Received 11 June 2013
Accepted 1 October 2013
Available online

Keywords:
Biomass energy
Calorific value
Innovation
Oil palm processing
Smallholder

ABSTRACT

The study evaluated the contribution of various energy sources to the smallholder processing of oil palm in Nigeria. Ten small-scale palm oil processing mills were visited at Elele, River State, Nigeria for sample collection. The weight of the various solid wastes generated and utilized for boiling process were measured including EFB (empty fruit bunch), PPF (palm press fiber), PKS (palm kernel shell) and chaff, while the volume of diesel used for digestion was also measured. The processing of 1 tonne of FFB (fresh fruit bunch) in the mill yields 63.4–77.1 L of CPO while the following waste by-products were generated from the FFB; 24 to 31% EFB, 23 to 28% PPF, 10 to 12% PKS and 1.4 to 2.4% chaff. Out of the total biomass generated by the mills only 12.74–22.25% EFB, 24.43–33.38% PPF, 2.71–6.71% PKS and 15.12–49.04% chaff were utilized by the various mills for fruit boiling/sterilization, indicating that the majority of biomass wastes is unutilized in the mills. The volume of diesel utilized by the mills for digestion is quite low ranging from 0.6 to 0.8 L. The gross calorific values of the waste biomass are EFB 16.970–18.537 MJ/kg, PPF 16.472–21.037 MJ/kg and PKS 19.378–21.614 MJ/kg. The total energy utilized by the mills for processing 1 tonne of FFB ranged from 2179.43 to 3014.31 MJ. Out of these, biomass energy accounted for 98.22–98.75%, while fossil fuel accounted for the remaining 1.25–1.78%. The study concluded by suggesting innovative ways of substituting the <2% fossil fuel contribution with the direct use of pre-heated palm oil to fuel the digesters.

1. Introduction

Palm oil is an edible vegetable oil produced from the fleshy mesocarp of the oil palm fruit, *Elaeis guineensis* Jacq. In addition to being used as cooking and frying oil, it is also used industrially in the production of soap and pharmaceuticals [1,2], lubricants and biodiesel [3,4]. Mahlia et al. [21] reported that 90% of palm oil produced in Malaysia is consumed as food. The oil palm tree is unique in producing two different types of oil: crude palm oil (CPO) from the mesocarp and palm kernel oil (PKO) from the endocarp. Oil palm is a tropical forest crop that originated from West Africa [5], and it belongs to the family Palmae [6]. It requires an annual rainfall of 1800–5000 mm/year [2] and a temperature of 24–39 °C [7]. Oil palm is tolerant to a wide range of soil types with relatively low pH [8]. However, it is often regarded as the most productive and economic oil crop in the world [9–14]. An hectare of oil palm generates 10–35 tonnes of fresh fruit bunch (FFB) per year [15–17].

CPO can be extracted from oil palm fruits using either the dry milling or wet milling methods. Most large-scale mills (i.e. those processing 10–80 tonnes of FFB/h) make use of the wet milling method, while the small-scale processors use the dry milling method. The basic differences in both methods are in the manner of fruit sterilization/cooking. In large mills, the entire bunch is sterilized prior to threshing, whereas, in small mills, bunches are threshed/stripped prior to sterilization. Expectedly, the resultant empty fruit bunch (EFB) produced from the wet milling process is wet, but dry in the dry milling processes. While the large mills are fully mechanized, the small-scale mills are manual using human energy in most of their processing operations. Hence, energy use in small-scale oil palm processing is not often reported. However, large-scale oil palm mills require considerable energy for the production of process steam and lighting and for running the equipment in the mills. For instance, the power requirement to process 1 tonne of FFB ranged from 14.5 to 25 kWh [18–21]. The energy requirement of the mills is generated by using oil palm processing wastes to fire boilers, which drive steam generators to produce electricity to operate the large mills. Small-scale mills are typically not equipped to generate electricity, but use the processing wastes to directly fire boilers for fruit sterilization.

* Corresponding author. Tel./fax: +234 803 7306 520.
E-mail addresses: eohimain@yahoo.com, eohimain@gmail.com (E.I. Ohimain).

0960-1481/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.10.007

Typically, the processing of 1 tonne of FFB will yield 10–30% CPO, while generating the following wastes 12–14% fiber, 6–10% shell, 20–59% EFB and 60–70% palm oil mill effluent (POME) [18–23], depending on the variety of the oil palm and the processing method. In both large and small mills, these by-products are often generated in excess of the mill requirement; hence some of them are disposed into the environment leading to pollution and loss of potential energy resources. Some large-scale mill uses all the fiber and 50% of the shell to produce enough steam and electricity to process CPO. Hence, most of these mills not only are energy self-sustaining, but also they can supply excess electricity to the national grid [18,19]. In addition to electricity generation via steam cycle, most large mills are able to use anaerobic digestion to produce biogas from POME, which can also be used to generate electricity via gas turbine.

The smallholder oil palm processors in Nigeria are neither equipped with steam/gas turbine to generate electricity *in-situ* nor connected to the national grid. Electricity supply in Nigeria is of poor quality, insufficient and highly unstable [24,25], which is largely responsible for poor economic growth [26]. Only 40–45% of the country is connected to the national grid, and because most palm mills are located close to palm estates and other sources of feedstock, are not connected to the national grid. Even manufacturers in urban centers like Lagos, Ibadan, and Port – Harcourt that are connected to the national grid are dependent on self-generated electricity to power their operations [24]. Unlike in Malaysia, Indonesia and Thailand, the oil palm sector in Nigeria is dominated by small-scale processors who process 80% of Nigerian CPO using rudimentary equipment and gathering oil palm fruits from dispersed wild and semi-wild grooves [27]. The Nigeria smallholder processors use oil palm processing wastes (shell, chaff, EFB and fiber) directly to fuel boilers for fruit cooking, while diesel powered engine is used for digestion. All the other process operations are done manually. The contribution of biomass wastes as energy source for oil palms processing by smallholder processors has never been reported. Hence, this study is aimed at: (1) estimating the contributions of waste biomass to the total energy requirement of the mills (2) estimating the excess waste biomass that is potentially available for other purposes including generation of excess electricity and biofuels and (3) suggesting innovative ways that the waste biomass could be used as fuel for digestion, thus displacing diesel completely and becoming 100% energy self-sufficient.

2. Materials and methods

2.1. Sampling

Ten small-scale palm oil processing mills were visited at Elele, River State, Nigeria, from the 13th to 22nd April, 2012, for sample collection. Oil palm extraction process was observed. The weight of the various solid wastes generated including EFB, PPF (palm press fiber), PKS (palm kernel shell) and chaff was measured using weighing scale. The quantity of the solid waste used for boiling was also measured, while the volume of fossil diesel used for digestion was measured using a measuring cylinder.

2.2. Gross calorific value determination

The oil palm processing waste samples were pulverized in a pulverizer (Cyclotex mill), and about 0.5 g of crushed samples were weighed. Firing cotton was attached to the firing wire of the bomb using a forceps. The pressure gauge of the oxygen cylinder was set to 3000 MPa, and pressure was allowed to build up in the bomb. The bomb was taken out and loaded into the calorimeter (E2K Bomb Calorimeter: Digital Data System (Pty) Limited, Gauteng, South Africa) and readings were taken.

2.3. Energy use computation

The total energy used by each of the mill was obtained by first converting both energy sources (biomass and diesel) to a common energy unit (MJ). This was done by multiplying the weight of biomass used to fire the boiler with the calorific value obtained from the bomb calorimeter measurement and adding it to the product of the volume of diesel used for digestion and energy content of diesel (56.3 MJ/l) [28]. Hence, the proportion of each of the energy sources used for processing oil palm was computed. Based on the mass balance [22] of smallholder oil palm processing, the amount of excess biomass was estimated.

2.4. Data analysis

SPSS software version 17 (SPSS Inc, Chicago) was used to carry out the statistical analysis on the calorific value. A one-way analysis of variance was carried out at $\alpha = 0.05$, and Duncan's multiple range test was used to discern the source of the observed differences. Descriptive statistics (in proportion) was used to express the fraction of biomass and fossil fuel utilized by the processing mills.

3. Results and discussion

The method of oil palm processing in all the mills visited is basically the same (Fig. 1).

Rudimentary oil mill equipment is used by the smallholder processors for oil extraction (Supplementary Fig. 1). Wastes biomass by-products from the processing of oil palm fruits include EFB, PPF, PKS and chaff (Supplementary Fig. 2). The mills typically combine different proportions of the biomass and use it as fuel for sterilization of threshed palm fruits. The processing of 1 tonne (i.e. 1000 kg) of FFB in the mill yields 63.4–77.1 L of CPO while generating the following waste by-products: EFB (240.8–308.5 kg), PPF (238.4–281.8 kg), PKS (100.8–115.2 kg) and chaff (14.2–24.3 kg) (Table 1). This translated to 24–31% for EFB, 23–28% PPF, 10–12% PKS and 1.4–2.4% chaff. Several authors have similarly reported various proportions of by-products generated during the processing of 1 tonne of FFB. For instance, in Thailand, Prasertsan and Prasertsan [23] reported 20–30%, 12–13% and 6.8–7.4% for EFB, fiber and shell respectively for high oil yielding palm tree, but for low oil yielding varieties, the proportion was even higher. Pleanjai et al. [3] reported the EFB, fiber, shell and decanter cake account for 28.5%, 30%, 6% and 3% respectively of the FFB. Hambali et al. [29] reported 21% and 6.4% as EFB and PKS respectively. Mahlia et al. [21] reported that 14% fiber and 6% shell is produced during the processing of 1 tonne of FFB in Malaysia and Indonesia. Hence, the values recorded in this study are within the range reported in literature for EFB, but higher in PPF and PKS. Chaff is not reported by other authors. Mahlia et al. [21] reported 71% of wastes were generated, while 23.5% of CPO and 5.2% of kernel were the major products. Similarly, Chavalparit et al. [20] showed that only 22.8% of the raw material input consisted of valuable products (CPO and PKO). Since CPO processing generates large amount of residue in the oil mill, it becomes reasonable to use this resource to fuel processing activities in the mills. Apart from boiling and digestion, other unit operations in the smallholder oil palm processing is basically manual and without any fossil energy or electricity input. The energy input for processing 1000 kg of FFB to CPO is presented in Table 2. While the biomass is used for boiling, diesel is used to fuel Lister generators for digestion. The EFB, PPF, PKS and chaff utilized by the various mill ranged from 33.6 to 61.8 kg, 60.6 to