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Oil palm shell use as alternative biofuel

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Abstract. This study describes analysis of utilisation of shells from the palm oil nuts as a pellet substitute. The analysis of shells from palm nuts processing comprised of the following aspects: analysis of possible utilisation of palm shells as a substitution for standard pellets, assessing physical and chemical properties and emissions released during combustion of palm shells. The performed palm shells´ physical and chemical examination offers opportunity to make conclusion that pellet substitutes based on palm shells are, in comparison to standard woody pellets, of similar or better physical and chemical properties and reach requirements of European standard EN 14961 for solid biofuels. Because it is a waste material from one of the most important oil plants, it is produced in high amounts in tropical zones of many developing countries. It could be successfully used by the commercial companies as a source for small, medium and large scale energy installations.

Key words: oil palm, oil palm shell, solid biofuel, waste, pellet, biomass.

INTRODUCTION

With increasing consumption of biofuels the demands on researchers to develop new sorts of biofuels are growing in parallel. Utilisation of waste from one of the major oil crops – oil palm is an interesting alternative to existing biofuels.

There are two species belonging to the Arecaceae or Palmae (also known as Palmaceae) that are called palm tree. They are used in commercial agriculture for production of palm oil. The African Oil Palm Elaeis guineensis (guineensis refers to its country of origin) is native in West Africa, occurring between Angola and Gambia, while the American Oil Palm Elaeis olifera (from English oliferous, meaning ‘oil-producing’) is native to tropical Central and South America (Lotschert & Beese, 1983). The production of palm oil is directed especially at the food industry and (recently) for production of biodiesel (Mekhilef et al., 2011). The oil contains high amount of beta-carotene. It is used as cooking oil and for production of margarine. Palm oil is also used for biodiesel production, as either a simply processed palm oil mixed with diesel, or processed through transesterification to create a palm oil methyl ester blend which meets the international EN 14214 specification, with glycerin as a by-product (Queiroz et al, 2012).

Waste material from palm oil production such as palm shells is produced in huge amounts with little utilisation. In general, the fresh fruit bunch contains (by weight) about 21% palm oil, 6–7% palm kernel, 14–15% fiber, 6–7% shell and 23% empty fruit bunches (Husain et al, 2002). According to FAO, the world production of palm oil was 45 million tons in 2009 (FAO, 2013). Estimated world production of palm shells is 10 million tons per year.

Currently, palm oil shells are cofiring with coal in thermal power plants to produce electricity and heat. Reinforcement of unpaved road surface in plantations is also a very common utilisation of palm oil shells (Mekhilef, et al., 2010). Other interesting minor use of palm oil shells is utilisation as an additive to concrete to reduce its weight. Studies show that concrete made with a mixture of palm shells is up to 19% lighter than normal concrete (Shafigh, et al., 2013).

The research problem

Over the past several years there was observed a significant growth in demand for fuel pellets. According to increasing sales of boilers for biomass combustion there is an expectation of the continuation of the growing consumption of solid biofuels. Pellet producers are facing many problems, there is huge growth in the consumption of pellets, on the other hand there is a lack of input material such as sawdust and wood shavings and a disproportionate increase in the price of this input material.

An interesting option for how to partially satisfy the demand for pellets is the production of a pellet substitute based on palm shells.

MATERIALS AND METHODS

The research conducted on oil palm shells produced the following results:

- physical and chemical properties according to standard EN 14961-1;
- emission composition released during combustion as compared to the standard woody pellets.

Research material

Palm shells were obtained from BOR Technology Ltd a company involved in the solid biofuel business and intending to import oil palm shells for large-scale energy plants (co-firing with coal in thermal power plants).

Characterisation of properties for pellet substitute

All measurements were carried out with samples at room temperature (20–22 °C). Moisture and ash contents were determined in heating oven Memmert model 100–800 according to standards EN 14774 and EN 14775.

Calorific value was determined according to standard EN 14918 as follows:

<u>Gross calorific value:</u>

Gross calorific value is the amount of heat per unit of weight released by a complete combustion of the fuel in the pressure vessel built in the calorimeter under compressed oxygen at 25 °C. It is Laget MS 10 A calorimeter according to standards EN 14918. In the calorimetric vessel the sample is totally burned and the values of temperature jump were converted to the net energy value. Standard equation (EN 14918, 2010) is used as:

$$Q_{gr}=dT_k \times T_k - (c_1 - c_2)/\mathrm{m}\ [\mathrm{J\ g^{-1}}] \quad (1)$$

where dT_k – temperature jump [°C]; T_k – heat capacity of calorimeter [J °C $^{-1}$]; c_1 – repair of benzoic acid [J]; c_2 – repair of the heat released by burning spark fine wire [J]; m – mass of material sample [g].

Net calorific value:

Net calorific value is gross calorific value minus the heat of vaporisation of water, resulting from the fuel during combustion. Standard equation is (EN_14918, 2010):

$$Q_v = Q_{gr}\text{-}24{,}52 \times (W+8.94 \times H_h) \text{ [J g}^{-1}\text{]} \qquad (2)$$

where W – water content in the sample [%]; H_h – hydrogen content in the sample [%]; Q_{gr} – gross calorific value [J g^{-1}].

The total contents of carbon, hydrogen and nitrogen were determined by instrumental methods according to standard EN 15104. Sample of known mass was burned in oxygen; the result was ash and gaseous combustion products. These combustion products mainly consist of carbon dioxide, water vapor, elemental nitrogen and / or oxides of nitrogen, acids of sulphur and halides. Procedures and calibration were determined according to the manufacturer's specifications of the device. Total contents of carbon, hydrogen and nitrogen, as analysed, were expressed as a mass fraction.

The total contents of sulphur and chlorine were determined according to standard EN 15289.

The ash melting behaviour was determined by use of standard EN 15370–1 The ash was ground down to maximum particle size of less than 0.075 mm. A sufficient quantity of the prepared ash was moistened with demineralised water so that a paste was made; it was pressed into the mould with pressure about 1.5 N mm^{-2}. The pieces prepared for testing were put into a furnace and dried at maximum temperature 150 °C (below the expected shrinkage starting temperature). The allowed temperature rising gradient during the tests can be 3–10 °C min.$^{-1}$. During the test a picture has to be taken at least every 10 °C. States of ash melting behaviour are:

- Deformation temperature (DT), which is the temperature at which the first edges rounding takes place due to melting. The rounding is noticeable on the specified test specimen.
- Hemisphere temperature (HT) is the temperature at which the test specimen forms approximately a hemisphere.
- Flow temperature (FT) is the temperature at which the height of the test specimen becomes half of the height of the test specimen at the tests beginning, i.e. the temperature when the ash becomes fluid.

Bulk density was determined according to standard EN 15103. For solid biofuels tests the maximum particle size up to 12 mm was used and the vessel had dimensions: height: 228 mm and inner diameter: 167 mm. Sample was put into the vessel and dropped from 150 mm, this was repeated three times. After this the vessel was filled to the brim with the tested material and it was weighed.

Emissions

The emissions were determined by the portable emission analyser Testo 350 XL. Emissions from burning palm shells were tested in a boiler for standard pellets combustion made by company Kovo Novák model KNP 5, with fixed-bed combustion, rated capacity of stove is 18 kW. Treatment of shells included only sieving by sieves with holes of 15 mm diameters to remove particles bigger than 15 mm to ensure proper operation of screw conveyor. As a reference fuel standard 6 mm wood pellets with known chemical and energetic properties were used, with known chemical and energetic properties. Dosage by screw conveyor was calibrated according to known net calorific value for each fuel to achieve the same energy input 18 kW.

For emission analysis a versatile exhaust gas system Testo 350 XL was used. The Testo 350 XL flue gas analyser is equipped with gas sensors for O_2, CO_2, CO, NO, NO_2.

The result's statistical analysis was carried out using Microsoft Excel 2007 and StatSoft Statistica 10. The analysis included a pair-wise F-test to assess when variance homogeneity could be assumed. Box plot was used to express results.

RESULTS AND THEIR DISCUSSION

Physical and Chemical Characteristics

Physical properties of pallets substitute based on palm oil shells are characterised by moisture content (M), Ash content (A), Net calorific value (Q), Carbon (C), Hydrogen (H), Nitrogen (N), Sulfur (S), Chlorine (Cl), Deformation temperature (DT), Bulk density (BD), Volatile matter (VM). The results are summarised in Table 1.

Table 1. Physical and chemical characteristics of pellets substitute based on palm oil shells

Physical and chemical characteristics	unit	value
Moisture content (M)	%	7.5
Ash content (A)	%	3.3
Gross calorific value (Qqrs)	MJ kg^{-1}	21.41
Net calorific value (Qnet)	MJ kg^{-1}	20.61
Carbon (C)	%	42.6
Hydrogen (H)	%	5.2
Nitrogen (N)	%	0.01
Sulfur (S)	%	0.06
Chlorine (Cl)	%	0.01
Deformation temperature (DT)	C	1,345
Bulk density (BD)	Kg m^{-3}	608
Volatile matter (VM)	%	60.2

The carried out research indicates that palm shells are material of very low moisture content (7.46%), and because of residual oil content do not tend to intake water. Such amount of humidity is good for direct combustion. Their ash content reaches 3.3% which is higher when compared to woody pellets (1.5%), it is comparable to herbaceous biomass (3–10%) (EN 14961-1, 2010).

The oil palm shell bulk density reaches high values which encourages transportation and storage. Other parameters are similar values to woody biomass (EN 14961-1, 2010).

Emissions

In our research emissions of CO_2, CO, NO, NO_2 were analysed. Emissions from pellet substitutes based on palm oil shells were compared to standard woody pellets of M = 8.6% and Q_{net} = 17.4 MJ kg^{-1}.

Comparison of the emissions is shown in figures 1–4:

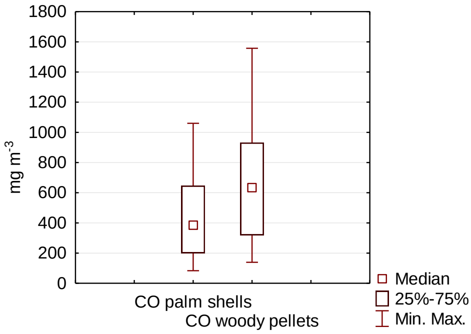

Figure 1. CO emissions of palm shells and woody pellets.

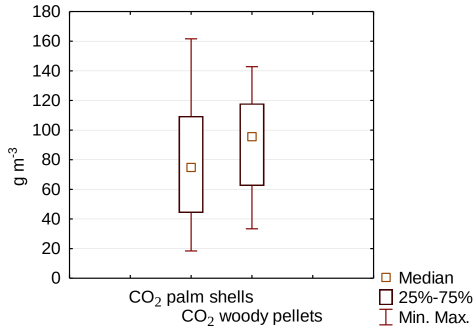

Figure 2. CO_2 emissions of palm shells and woody pellets.

Figs 1 and 2 show comparison of woody and palm shells CO and CO_2 emissions. The collected data show that CO emissions of woody pellets are about 65.15 higher than palm shells while the CO_2 emissions of woody pellets are about 27.65 higher than palm shells, it is caused by a lower content of carbon with higher calorific value of palm shells.

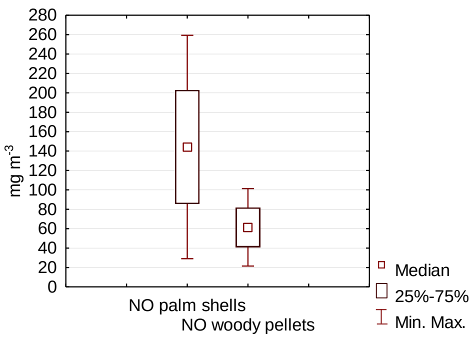

Figure 3. NO emissions of palm shells and woody pellets.

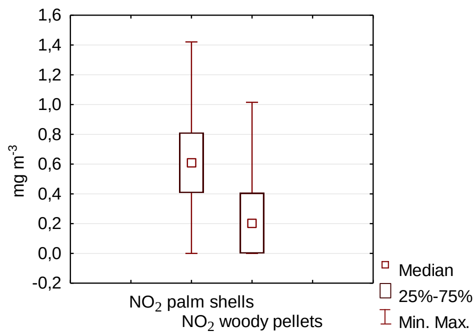

Figure 4. NO_2 emissions of palm shells and woody pellets.

Figs 3 and 4 show emissions of NO and NO_2 of palm shells and woody pellets; in this case the woody pellets reach better results than the palm shells, NO emissions of woody pellets are about 58% higher than emissions of palm shells while the NO_2 emissions are 67.2% higher. This is caused by oil content in palm shells. Optimisation of combustion chamber of boilers for palm shell combustion can be achieved with lower emissions. On the other hand, the study carried out shows that palm shells can be used continuously in boilers for standard pellets.

CONCLUSIONS

The research carried out has indicated that the pellet substitute is material of a very low humidity which reaches 7.46% and because of residual oil content does not tend to absorb additional moisture. Also the measured net calorific value (20.6 MJ kg^{-1}) is quite high in comparison to woody pellets (16–19 MJ kg^{-1}) and so is its bulk density; this contributes to facilitate transport and storage, because the shells occupy a relatively small space. Other properties reach standard values as compared to standard solid biofuels and are able to reach the limits of standard EN 14961–1.

The emission analysis shows that the CO and CO_2 emissions from palm shells are a little bit lower than emissions from wood pellets; however their NO and NO_2 emissions are much higher which is due to the presence of residual oil.

The performed analysis shows that it is possible to use palm shells in boilers designed for standard woody pellets combustion.

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