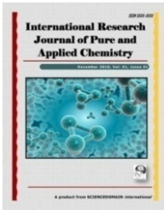

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Determination of Nitrogen and Sulphur Oxides Produced During Combustion of the Jatropha Cake as a Measure of the Level of Pollution When the Cake is Used as a Fuel

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Authors' contributions

This work was carried out in collaboration between the three authors. The study was designed and conducted under authors LRMN and TN direction and management. Author SM conducted the studies, collected data, performed the statistical analysis, and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Jatropha cake is a promising renewable energy source after proving difficult to be used as feedstock. Its possible use as a combustible fuel makes the Jatropha cake pellet important as a source of potentially harmful gases to the users and the environment. This makes it imperative to determine the level of pollution caused by the Jatropha cake bio-pellet so as to take the necessary precautions to prevent the hazards that may be associated with its use as fuel if necessary. Jatropha cake samples were burned in a furnace to determine the amount of nitrogen oxides (NO_x) and sulphur dioxide (SO_2) produced during complete combustion. The effect of temperature on the production of these gases was investigated by altering the furnace temperature from 300°C to 1200°C. NO_x and SO_2 were collected in a mixture of aqueous ammonia and hydrogen peroxide

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and quantified as nitrates and sulphates respectively. The results showed that the production of NO_x and SO_2 generally increased with increasing temperature with the highest amount of NO_x at 1200℃ and that of SO_2 at 800℃. The amounts of NO_x and SO_2 were 0.02mg/kg and 0.15mg/kg respectively. It was observed that the Jatropha cake pellet is a more environmentally friendly source of energy than the fossil fuels.

Keywords: Jatropha cake; nitrogen oxides; sulphur dioxide; renewable energy; pollution.

1. INTRODUCTION

The *Jatropha curcas* plant has been used as a source of biofuel in some countries including Zimbabwe. The plant has been popularly known to be a source of biodiesel, which has been regarded as a potential alternative fuel for partial substitution of petro-diesel so as to reduce the dependence on fossil fuels [1]. The use of biomass as a source of energy has become important due to the continuous depletion of fossil fuels. Biomass can be used as a renewable energy source, or converted into another type of energy producing product. Although biomass is said to be carbon dioxide (CO_2) neutral, combustion of these sources releases the following measurable pollutants; carbon monoxide (CO), hydrocarbons (C_xH_y), nitrogen oxides (NO_x), sulphur oxides (SO_x), soot, dust, and particles [2,3] which may be used to estimate health risks.

The Jatropha plant produces fruits with 1-4 seeds [4]. The dry seed contains about 38-42% weight of oil which can be extracted by chemical or mechanical means. The mechanical extraction yields 30% - 38% of crude oil which may be used as crude or after its trans-esterification [5]. The by-product from mechanical extraction of oil from Jatropha seeds is the cake from which biogas may be obtained, and it constitutes about 50% of the original seed weight [6]. The seed cake has a heating value which is comparable to that of wood (16MJ/kg) [7]. A trial found that 1 kg of briquettes took around 35 minutes for complete combustion, giving temperatures in the range of 525^oC-780^oC [6]. A comparison between the heating value of *Jatropha curcas* solid waste (cake seed, shell and husk) showed the following: for the cake seeds it was 17.28 MJ/kg, for the shells it was 15.74 MJ/kg and husk was 16.92 MJ/kg [6]. The heating value of the *Jatropha curcas* solid waste makes it attractive to be made into bio-pellets or briquettes, and used as fuel for cooking in place of firewood or other sources of energy.

Recovery of energy from biomass by combustion has become important worldwide because it is thought to cause less air pollution than the fossil fuels. However, combustion of all kinds of materials result in emissions that may be harmful to the environment, combustion devices and human health [8,9]. Coal can produce up to 5.8 mg/m^3 SO_2 and 1.8 $mg/m^3 NO_x$. Biofuels have been shown to contribute NO_x and SO_x to the atmosphere [10]. Exposure to emissions, mainly CO, NO_x, SO_x, suspended particulate matter and hydrocarbons is of serious public concern because of diseases of the respiratory system such as lung infections [11].

Combustion of biofuels such as wood, agricultural waste and dried animal manure in cooking stoves has been shown to be the largest source of black carbon emissions and greenhouse gases in the South Asian region [9]. In a study by Pandey et al. [12] rural areas in developing countries had high morbidity and mortality rates from acute respiratory infections owing to the high levels of indoor air pollution due to biofuels. It has also been found that continual exposure of the early man to campfires used as heat sources in enclosed areas contributed to increased incidences of nasal cancers [3,11]. Most of the information on the gaseous and particulate pollutants from wood is available [8,9] but very little is known about the components of the gases and the amounts that are produced during combustion of the Jatropha cake.

Since the Jatropha cake is a promising source of energy, its use as a combustible fuel makes it an important source of air pollutants. As a fuel that will probably be used for cooking among other uses, Jatropha cake has a high potential to be used indoors at domestic level. It is important to determine the level of pollution possible if Jatropha cake is used as a fuel so as to protect the environment and the health of the users. Knowing these levels of pollution with respect to SO_x and NO_x, may assist in taking the necessary precautions to prevent the dangers that may be associated with its use. This study sought to quantify the amounts of nitrogen oxides and sulphur dioxide produced during combustion and to determine the effect of combustion temperature on the production of these gases.

2. MATERIALS AND METHODS

2.1 Methodology

The seeds that produced the cake used in the study were obtained from Mutoko. The cake was obtained by mechanical extraction, using a hand press machine to remove the oil from the seeds. A random 5kg sample was taken to the lab where it was crushed and pulverised to obtain a homogeneous sample.

The homogeneous sample was dried, weighed and total moisture loss determined [13]. The total volatile organic compounds were determined by ignition of a 1.0 g sample in a furnace at 550℃. Soxhlet extraction was used for the determination of the oil from 1.0 g of the Jatropha cake, the solvent used was n-hexane. After extraction, a rotary evaporator was used to remove the solvent from the oil which was then weighed [14].

An IKA C5003 bomb calorimeter was used for the determination of the calorific value. The oxygen pressure was 25 atmospheres; the temperature was 20±0.2℃.

The kjehldahl method was used for the determination of nitrogen content of the cake [13]. The sulphur content was determined by combustion of the sample in an IKA C5003 bomb calorimeter. The washings were collected and titrated with standard sodium carbonate followed by neutralization with aqueous ammonia. Solution was boiled, filtered and 10 ml of concentrated HCl was added. 10% Barium chloride was added whilst boiling the solution. Solution was then covered and precipitate allowed to settle for an hour after which it was filtered through an ash-less filter paper. After several washings, the filter paper and sample was placed in a weighed crucible and ignited [15].

A double tube sulphur furnace from Leonara Light Industries was used for the combustion of Jatropha cake samples and collection of NO_x and SO_2. The gases were collected in a mixture of 14% aqueous ammonia solution and 1% hydrogen peroxide. A UV-Visible spectrophotometer was used for the determination of the oxidized forms of nitrogen and sulphur (NO_3^- and SO_4^{2-} respectively).
Nitrate was measured spectrophotometrically at 410 nm by measuring the intensity of the yellow color developed by reaction of phenol-disulfonic acid with nitrates [16]. A blank was also carried out to minimize errors. Chloride interference was removed by precipitating with silver sulphate. Sulphate was measured spectrophotometrically at 420nm using turbid metric method [17].

3. RESULTS AND DISCUSSION

The experiments showed that oil remaining in the Jatropha seed cake from the mechanical extraction was about 10.83% of the weight of the cake, which falls in the range 10-12% found by other researchers [18]. The heating values of the cake presented in (Table 1) imply that Jatropha cake is useful as an energy source for use with wood or as its substitute. The same can be said with reference to sawdust or paper briquettes [7]. The calorific values for the Jatropha seed cake and de-oiled Jatropha seed cake are 17.96±0.29 MJ/kg and 17.00±0.18 MJ/kg respectively. The calorific value of the Jatropha seed cake is lower for the oil-free cake by about 1.00 MJ/kg compared to that of the cake with oil. It is evident that the remainder of the oil in the cake contributes to the heating value of the samples [18], this makes the process of oil removal unimportant if the cake is to be used as a source of fuel since the high oil content gives a greater calorific value.

Table 1. Characteristics of the Jatropha seed cake

Parameter	Jatropha cake	Oil-free Jatropha cake
Heating value MJ/kg	17.96±0.29	17.00±0.18
Oil content %	10.83±0.65	- -
Moisture content %	6.55±0.58	7.25±0.10
Volatile matter (dry matter)%	90.90±0.003	90.90±0.00
Nitrogen %	2.70	2.80
Sulphur %	0.60	0.50

The moisture content of biomass has a great impact on its effectiveness as a fuel source [19]. The de-oiled Jatropha seed cake had high percentages of moisture. The high moisture content may have contributed to the low calorific values in addition to the lowering due to the absence of oil. The absence of oil may have promoted adsorption of water molecules from the atmosphere onto the cake samples, this effect was absent in the Jatropha cake with oil since oil and water do not mix.

The fuel was observed to ignite and burn often almost immediately upon entry into the furnace, as has been reported elsewhere during co-combustion with coal and paper, plastic waste [20]. Oxides of nitrogen (NO_x), primarily nitric oxide (NO) and nitrogen dioxide (NO_2) are formed by the oxidation of nitrogen, both in the fuel and in the air, with the fuel nitrogen being more reactive. Due to the small amount of element nitrogen in the fuel (~2.7%), the amount of NO_x observed was very little. At temperatures below 1000℃ the nitrate determined from NO_x produced was below 10ppm. The highest amount of sulphate determined for the SO_2 produced was below 2ppm, this also agrees with the small percentage of element sulphur in the fuel (~0.6%).

There is a general increase in the amount of sulphur and nitrogen oxides with increasing temperature (Figs. 1 and 2). The different amounts of NO_x produced are due to the different routes of NO_x formation; thermally generated, flame-generated, or fuel-bound NO_x. However, the major contribution of NOx at the low temperatures that were used and the short-lived flame was from the fuel-bound NOx. The initial high amount of NO_x in the oiled cake may have been due to some compound that could have been extracted by hexane with the oil or conversion of volatile nitrogen containing species NH_3 and HCN at the lower temperature [21].

The results also show that the amount of SO_2 increases with temperature for both the oiled and de-oiled Jatropha cake, then decreases from about 800℃. The decrease in SO_2 at temperatures above 800℃ may be attributed to the formation of an isomer of SO_2 [22] The isomer may have not been absorbed in the alkaline aqueous solution and could not be determined as as sulphate. Studies have shown that at temperatures above 500^0C, a thermally generated isomer of SO_2 is observed. It is also possible that at the high temperatures of the furnace, the SO_2 may have reacted with lime which may have been present in the cake and formed calcium sulphate ($CaSO_4$) [23] leading to a reduction in the SO_2 measured. It is possible that lime may have been picked up during harvesting of the seed or during storage of the cake, after the extraction of the oil. A factor that may have influenced the amount of NO_x and SO_2 is steam [24], probably from the moisture in the fuel samples. It has been found that high amounts of these oxides at high temperatures (>1600℃) are due to the oxidation of fuel elements and oxidation of elements in the combustion air [25]. Although such high temperatures were not used, there is a chance that oxidation of elements in the combustion air contributed to SO_2 and NO_x.

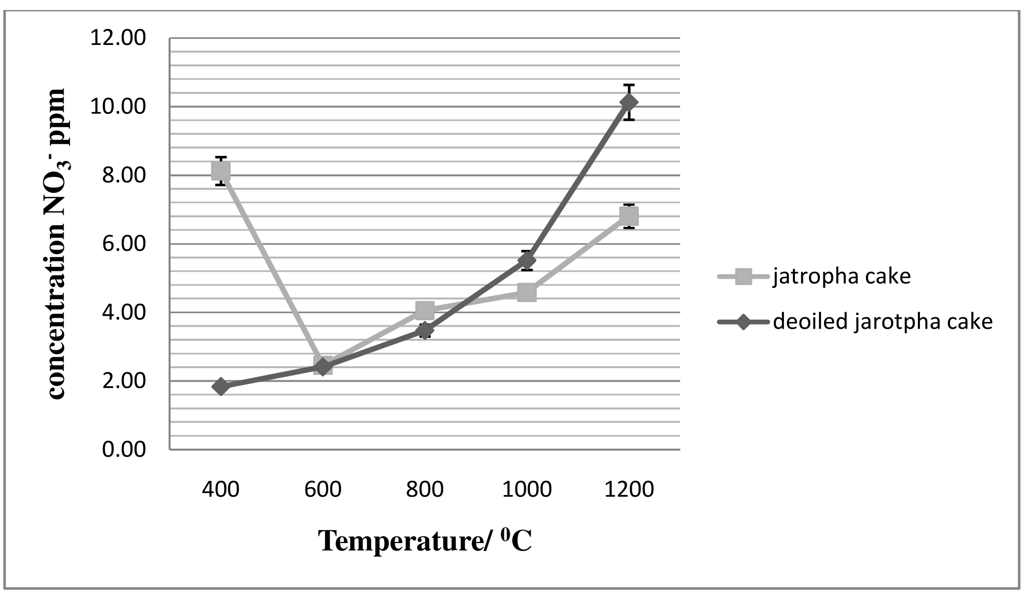

Fig. 1. The effect of temperature on the amount of NO_x produced during combustion

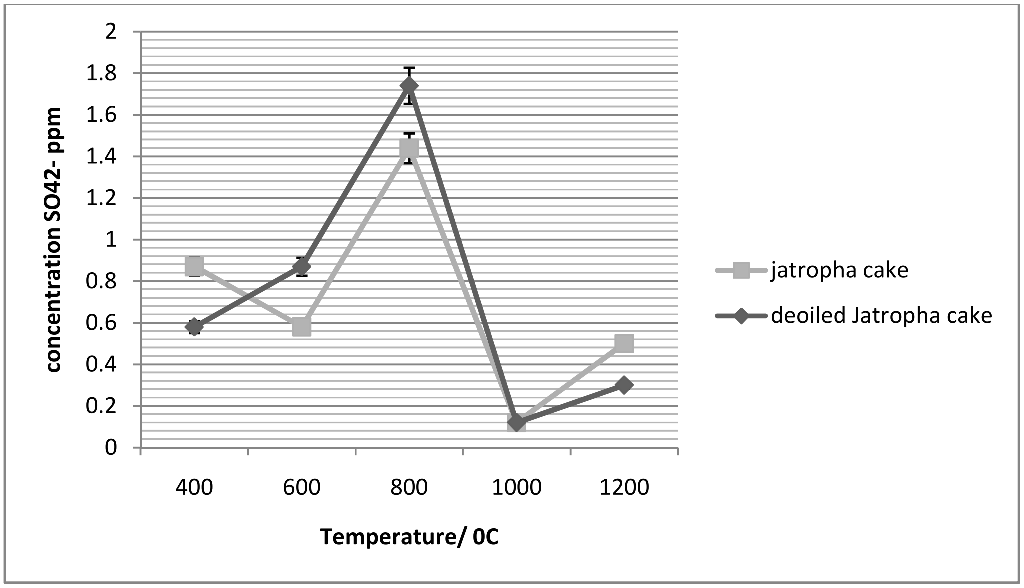

Fig. 2. Effect of temperature on the amount of SO_2 produced during combustion

4. CONCLUSION

In the study, it was found that the calorific value of Jatropha cake is 17.96MJ/kg, which is comparable to that of the wood sources that are currently available. The calorific value for the press cake (oiled) was higher than that of the cake after chemical extraction (de-oiled). It was also found that during combustion of the Jatropha cake, NO_x and SO_2 are emitted; the amount of SO_2 emitted during the combustion is greater than NO_x. Compared to other biomass fuels and fossil fuels the amounts of NO_x and SO_x produced during combustion of Jatropha cake are quite low, about 0.02mg/kg NOx being produced at the flame temperature of about 1000℃ and about 0.15mg/kg SO_2 at a temperature of 800℃. These values make the Jatropha cake friendlier to the environment when used as a fuel.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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