

ASSESSMENT OF ENERGY RECOVERY FROM MUNICIPAL SOLID WASTE: BALANCING INCINERATION POTENTIAL WITH RECYCLING INITIATIVES

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ABSTRACT

Municipal Solid Waste [MSW] management is a critical environmental and public health issue, especially in developing urban areas where waste generation is increasing due to higher consumption rates. This study assesses the potential of energy recovery from MSW in Suleja, Nigeria, using incineration technology. Landfilling remains the predominant disposal method, contributing significantly to greenhouse gas emissions. The waste characterization was conducted according to ASTM D5231, and the mass of waste disposal was determined using the bulk density method. The combustible waste fraction was calculated using the percentage composition of combustible waste. The calorific values of the MSW were determined using a bomb calorimeter, and the gross calorific value [GCV] and net calorific value [NCV] were calculated. The energy potential was estimated using the calorific values and the mass flow rate of MSW. This research evaluates the calorific value of MSW, finding it sufficient to justify energy recovery via incineration. The average calorific value without recycling is 21.8 MJ/kg, while with recycling, it is 16.32 MJ/kg. The energy production potential ranges from 11.2 to 17.2 MW, with an average of 14.7 MW of heat. Incorporating recycling options reduces the available energy output but promotes environmental sustainability. The findings suggest that adopting waste-to-energy technologies can enhance energy security and reduce environmental pollution in urban setting. It is therefore recommended that policy makers invest in incineration facilities and support recycling initiatives to maximize the dual benefits of energy recovery and environmental sustainability.

Keywords: Solid waste, Environmental, Public health, incineration, greenhouse, gas emissions

1 INTRODUCTION

Municipal Solid Waste [MSW] refers to the common garbage or refuse generated in an urban area. It typically includes everyday items discarded by the public such as food scraps, paper, bottles, and appliances. The management of MSW involves collecting, treating, and disposing of waste material in a way that is in accordance with public health, conservation, economic, aesthetic, engineering, and other environmental considerations. Effective MSW management practices can help reduce environmental impacts and promote sustainability [1]. In many developing cities around the world, the shortage of energy and environmental degradation are currently two vital issues affecting sustainable development [2]. There has been an increase in the general spending and consumption habit of people, the consequence of which is an increase in the quantity of municipal solid wastes (MSW) being generated particularly in urban areas [3]. Landfilling of solid waste has been and continues to be among the most common practices of solid

waste disposal. This is particularly true for Jordan, where approximately 3.3 million tons of municipal solid waste [MSW] is annually generated, with 90% of the generated amount disposed into landfills [4]. In most cases, “waste” is still seen as “trouble” rather than a resource [5]. Landfills throughout the world are contributing to the global warming problem. This is due to the existence of the most important greenhouse gases in landfill which are methane and carbon (IV) oxide [6]. The emission of methane from dumpsites remains a significant source of global environmental pollution concern (7). Municipal solid waste disposal sites act as sources of secondary pollution of the environment [8]. The city like most other cities in Nigeria experiences inadequate electricity supply. Hence the need for this research, to assess the technical and economic potentials of recovering energy from the MSW generated in Yola using incineration as the technology of choice [3]. Development of renewable energy is important to modern society because climate change induced from fossil use has resulted in severe and possibly irreversible environmental impacts such as sea level rise, desertification, diminished land productivity, and increased possibility of extreme events. Therefore, the utilization of renewable and clean energy not only increases regional energy security but also alleviate the environmental risk [9]. Waste to energy technology is of particular interest in recent years because the feedstock supply is relatively stable [10]. The heating/calorific value of municipal solid waste (MSW) is essential in selecting or designing the appropriate waste to energy (WTE) systems. [11] demonstrate that combustion with energy recovery could be used as a treatment method due to the characteristics of Brazilian MSW as a solid fuel, such as a lower heating value of 7.22 ± 1.76 MJ/kg, moisture content of $49.19 \pm 10.05\%$, and an ash content of $14.23 \pm 6.71\%$. This highlights that in some regions of the country, there is the possibility of using auxiliary fuels for waste combustion. In this way, MSW combustion facilities could contribute an additional 3% of electrical energy to the national energy matrix from the use of at least 67% of the MSW collected. [3] found that the average calorific value of the MSW disposed of in the city’s dumpsite is 1,515.67 kcal/kg. If incineration is used as the preferred waste-to-energy technology, a total of 3,748.60 kW of electrical energy could be recovered from the dumpsites studied. The economic analysis conducted showed that energy recovery via incineration has an average internal rate of return (IRR) of 252%. [10] indicated that energy conversion efficiency and net social benefits are highly dependent on the composition of the wastes. [2] illustrated that a high-power potential of over 10,000 MW can be obtained by adopting the incineration process, starting with data from 2016 with an exponential increase over the years. [12] found that the gross calorific value (GCV) was evaluated as 9,085 kcal/kg and the net calorific value (NCV) was evaluated as 9,067 kcal/kg. Furthermore, the power generation potential was enumerated using 10 and 50 tons of combustible MSW to arrive at 966 kWh and 4,832 kWh, respectively. Utilizing MSW for energy generation aligns with efforts towards environmental sustainability and could improve the basic electricity supply in Nigeria.

2 MATERIALS AND METHODS

2.1 The Study Area

Suleja local government area was established by the local government reform of 1976 from the defunct Abuja native authority. Suleja lies between Latitude $9^{\circ}12'1.17''$ N and Longitude $7^{\circ}10'20.25''$ E (Figure 1). It shares boundary with Gurara to the North-West, Tafa to the East in Niger State and Gwagwalada, Zuba to the south, in Federal Capital Territory. Suleja is about 20Km North of Abuja the Federal Capital of Nigeria and about 100Km North East of Minna the State Capital of Niger State [13] as shown in Figure 1. According to 2006 provisional population census, Suleja Local Government has a population of 216,578 and covers a land mass area of 118,910 Sq.km with 2,142 Density/Square Kilometer [14]. Suleja has tropical climate and summers are much rainier than the winters in Suleja. The average annual temperature is 26.3°C and the average rainfall is 1328 mm. The driest month is December. The highest precipitation occurs in September; with an average of 272 mm. March is the warmest month of the year with average temperature of 29.0°C . The lowest average temperature is in August and is about 24.5°C [16]. The method of waste management is landfilling in open landfills at Dikko and Rafin Sanyi dumpsites [17].

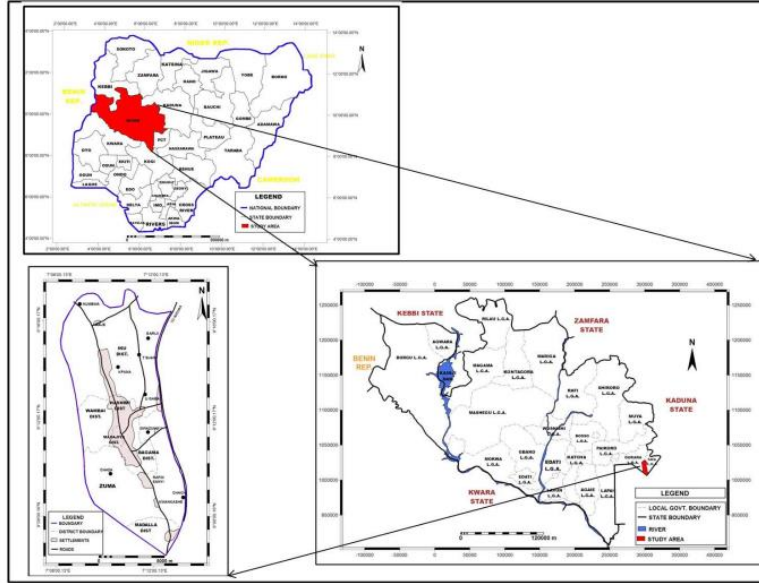


Figure 1. Map of Suleja [15]

2.2 Waste Characterization

The municipal solid waste composition was determined according ASTM D5231. The mass of volume disposed is determined as daily, monthly, or annually in kilograms or tonnes. The municipal solid waste disposal rate is determined either by direct measurement using weighbridge or from the total volume disposed. If the total volume disposed is known, the mass can be obtained using the bulk density. The bulk density is given by the following equation [18].

$$\rho_{\text{bulk}} = \frac{M_2 - M_1}{V_1} \quad (1)$$

Where ρ_{bulk} is the bulk density in kg/m^3 , M_2 is the mass of filled container and M_1 is the mass of empty container. The amount of waste disposal rate can be determined using the following equation [18].

$$W_{\text{disposed}} = \rho V \quad (2)$$

Where; W_{disposed} is the mass disposed in kg, ρ is the average bulk density in kg/m^3 and V is the volume in m^3 . However, not all the wastes are combustible, as such the total mass of combustible waste can be computed from the following equation.

$$W_{\text{cd}} = P_c \times W_d \quad (3)$$

Where; W_{cd} is the mass of combustible waste disposed in kg/day, P_c is the percentage composition of combustible waste and W_d is the total waste disposed in kg/day. The amount of waste disposed of the combustible waste with recycling is obtained using the equation.

$$W_{\text{dr}} = P_{\text{cr}} \times W_d \quad (4)$$

Where; W_{dr} is the mass of combustible waste with recycling disposed in kg/day, P_{cr} is the percentage composition of combustible waste with recycling and W_d is the total waste disposed in kg/day.

2.2 Calorific Values

The waste sample were collected and sorted manually to remove the inorganic materials e.g. Glass, metals. Each constituent was cut and grinded; A sample of 1g were then placed into the bomb calorimeter. The bomb calorimeter was assembled, and the cap was securely tightened. Oxygen was then injected into the bomb calorimeter until the pressure reached 25 atm. The bomb calorimeter was placed into an adiabatic calorimeter bucket containing water with a fuse (ignition) wire of about 7cm long passing through the

sample with both ends of the wire attached to two electrodes of the bomb calorimeter. A thermometer was placed inside the water jacket after bomb calorimeter as connected to a power source. The stirrer was then started and allowed to run five minutes before the temperature reading was taken. The fire button was then pressed at the fifth minutes of the experiment. At the end of the fifth minutes, a stop watch was started and the temperature was recorded at one-minute interval. Subsequent temperature readings were recorded continuously until the difference between successive readings became constant for at least three successive times. After the last temperature reading was taken, the calorimeter was stopped. The cover was lifted and components were removed and wiped with a clean cloth. The results obtained from the experiment were used to calculate the calorific value of the municipal solid waste as described in the manual [19] (Parr 6310 Bomb calorimeter manual, 1960). The overall calorific value of the heterogeneous waste in kJ/kg was obtained using the equation [20].

$$CV_{gross} = \sum mCV_{n i} = 1 \quad (5)$$

Where CV_{gross} is the gross calorific value of the MSW, m is the percentage composition of MSW constituent and CV is the calorific value of component.

2.2.1 Energy potential

The electrical energy potential was determined using the equation given by [1].

$$E_o = \frac{E_i \times \eta}{3600} \text{ kWh/day} \quad (6)$$

Where; E_o is the electrical energy output, E_i is the energy input and η is the conversion efficiency.

$$E_i = \dot{m} \times CV \quad (7)$$

Where; E_i is the energy input, m is the mass flow rate of MSW in kg/day and CV is the calorific value in kJ/kg.

3 RESULTS AND DISCUSSION

The amount of combustible waste and combustible waste for Suleja MSW are presented in Figure 2. The highest amount of waste disposed was on day 9 in September with about 100 000 kg and the lowest amount was on the 10th day of both November and December as shown in Figure 2. In January, low amount of waste disposal was recorded with values slightly above 80 000 kg/day. Generally, on the average about 80 000 kg of waste is disposed daily.

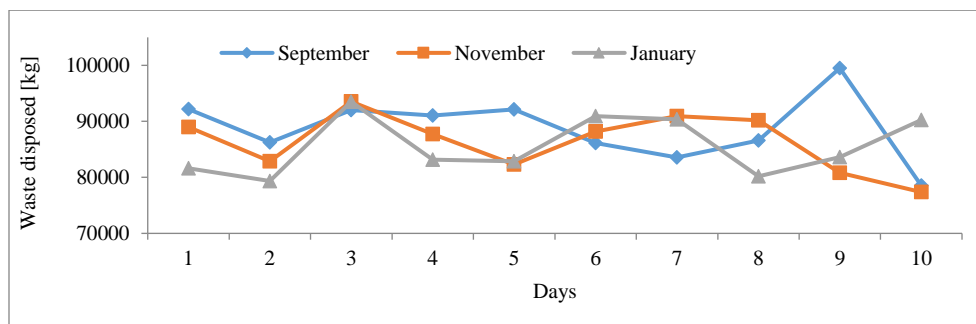


Figure 2. Daily disposal of waste

3.1 Daily disposal of combustible waste

The amount of combustible waste disposed was recorded in November with over 80 000 kg/day and the lowest was in January with about 60 000 kg/day as shown in Figure 3. The daily waste disposal shows no consistency. However, in September a greater number of combustible wastes were disposed predominantly exceeding 70 000 kg/day. The lowest amount was recorded mostly in January with values around 70 000 kg/day or even less.

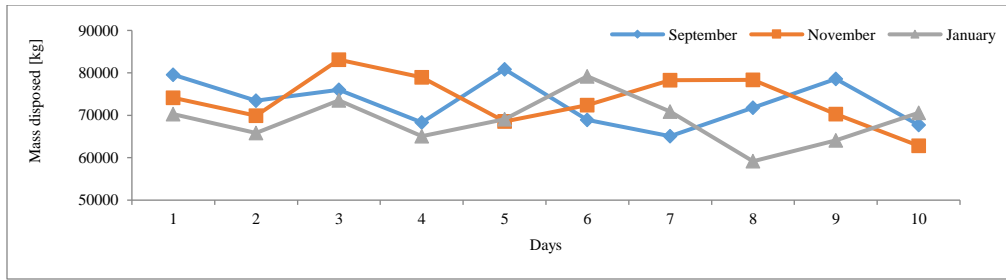


Figure 3. Daily disposal of combustible waste

From Figure 4, the highest amount of combustible waste with option for recycling disposed was on the 5th Day in January with about 32000 kg/day. In January, the amount disposed was less than 30 000 kg/day. However, in September and November, the amount was predominantly between 40 000 kg/day and 50 000 kg/day.

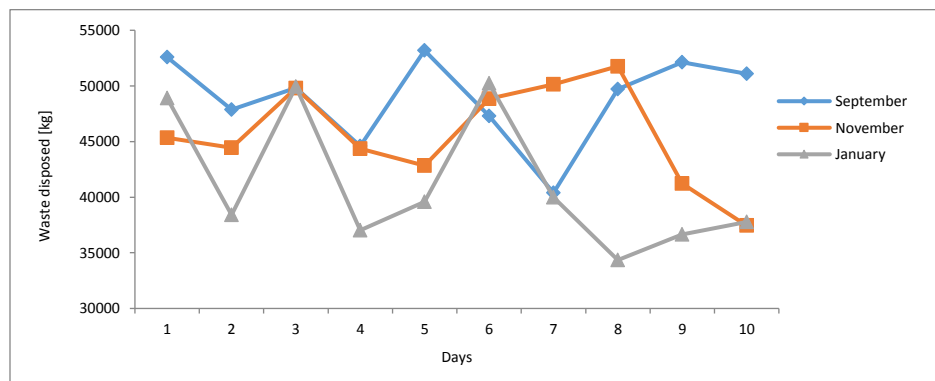


Figure 4. Daily disposal of combustible waste with options for recycling

3.2 Calorific value of Suleja MSW

The calorific value of Suleja MSW can be seen from Figure 5 to be highest in January for combustible waste while for combustible waste with recycling the highest was in November. There is a gradual increase in the calorific values from September to January for both combustible waste and combustible waste with recycling. The lowest calorific value for combustible waste was about 18 MJ/kg whereas the highest is about 25 MJ/kg. Moreover, the highest calorific value for combustible waste with option for recycling was about 21 MJ/kg and the lowest was 16 MJ/kg.

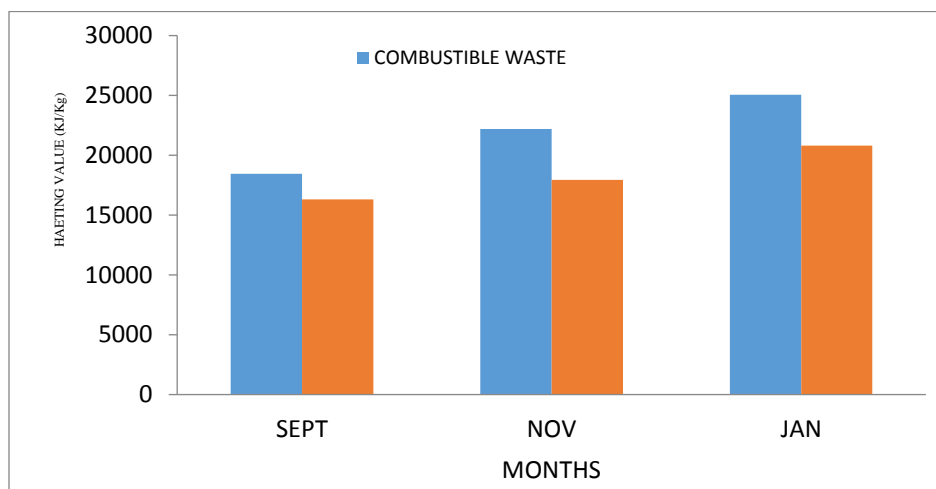


Figure 5. Average calorific values of Suleja MSW

3.3 Energy Output

The steam energy output in MW for Suleja MSW is shown in Figure 6. It can be observed from Fig 6 below, that the lowest energy output was in September, with energy values less than 12 MW of heat in some days and the highest was greater than 18.5 MW. However, most frequent values were within the range of 14-17 MW with an average of 14.7MW. It can also be observed that the energy output was higher in November and most notably January.

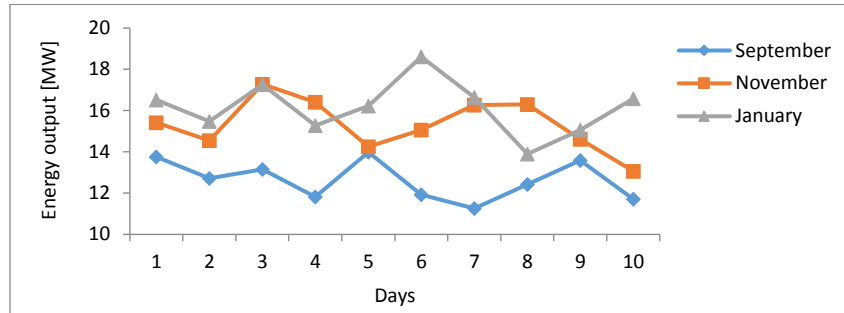


Figure 6. Energy output

Similarly, the energy output with option for recycling was also presented in Figure 7. From Figure 7, the energy output with option for recycling was also found to be lower in September with the lowest value being 6.1 MW whereas the highest value was obtained in January with about 9.8 MW of heat in form of steam, the most frequent energy values were between 7 to 8.5 MW.

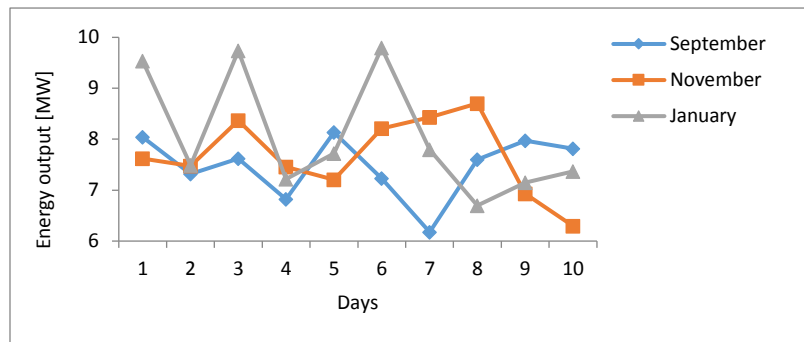


Figure 7. Energy output with option for recycling

It can be seen from Figure 7 that the waste disposed the amount of combustible waste disposed daily takes has a peak value of 83 000 kg/day lowest value of 59 000 kg/day. This is the daily mass flow rate of fuel for energy recovery. When plastics and paper were removed from the waste stream, about 50% of the waste was removed and about 41000-49000 kg/day (41 to 49 ton/day) were available for energy recovery. This is amount is significantly small. However, there are small scale incinerators that can be deployed. The activities of scavengers who picks plastics, papers and other materials will drastically reduce the amount of waste to be taken as fuel for energy production as such scavengers who resides at the landfills were employed in taking samples to avoid skewed results. Also, as plastics are removed the calorific values were also found to be dropping as such the energy production capacity will also drop. The calorific value was found to be increasing from September through January and might relate to the relative increase in the proportion of high calorie organic contents such as corn cob with 19.5 MJ/kg, groundnut shell 16.5 MJ/kg etc. in the waste stream during the harvest period [21]. The average heating [calorific] value of Suleja MSW is 21.8 MJ/kg which agrees with [22]. The calorific value is 9% higher than the 20 MJ/kg obtained by [23] for Benin metropolis, 11% lower than 24.51 MJ/kg for Numan [1] and 27% higher than the 17.1 MJ/kg average heating value for Nigeria [24]. Moreover, the calorific value is 320% and 118% higher compared to 5.6 MJ/kg and 10.1 MJ/kg obtained for Kano by [25, 26]. The large disparity may be due to the different methodologies employed by the two previous researchers. The calorific value reduces slightly to values

between 16-20 MJ/kg when plastics and paper were removed for recycling, as shown in Figure 4. The average calorific value with recycling is 18.34 MJ/kg. The above results indicates that 1000 kg (1 ton) of Suleja MSW has an energy value equivalent to 1200 kg (1.2 ton) of sub bituminous coal, 1360 kg of firewood 470-520 kg of diesel, 420 -520 kg of oil, 470-490 kg of petrol, 430-470 kg of liquefied petroleum gas [LPG], 400-520 kg of natural gas, 150-180 kg of hydrogen and 390-430 kg of methane.

4 CONCLUSIONS

The MSW of Suleja metropolis was assessed to determine its suitability for energy production. The maximum disposal rate recorded was 100 000 kg/day. The mass of the combustible waste was found to be about 82% of the total waste disposed. When option for recycling of plastics and papers are considered, the total mass of the waste available for energy recovery reduce to about 50%. The average heating value of Suleja municipal solid waste was found to be 21.8 MJ/kg without recycling and 16.32 MJ/kg with recycling. The calorific values were found to be higher than the minimum 7000 kJ/kg required to setup incineration plant. The average Energy production potential in form of steam is 11.2 – 17.2 MW with an average of 14.7 MW of heat and 6.2 to 9.5 MW with an average of 7.7 MW of heat when plastic and paper are considered for recycling. The heat energy generated in form of steam can be used in pharmaceutical, chemical and food industries. Furthermore, a steam turbine can be employed to convert such energy into electrical power.

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