Journal of Environment Sciences (2024), **Volume X**, 125-130
https://doi.org/10.3126/jes.v10i1.66979

Energy Recovery from Municipal Solid Waste by Production of Refuse Derived Fuel

Luna Thapa[1], Krishna Raj Shrestha[1,2], Tejendra Regmi[1] Haikam Ghising[3]
[1]Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal
[2]Center for Energy and Environment Nepal, Kathmandu, Nepal
[3]Goldengate International College, Tribhuvan University, Nepal
[*]Correspondence: thapaluna1@gmail.com

Abstract

Waste to energy options can present an opportunity for effective waste management and addressing the energy crisis. This study aimed to produce Refuse Derived Fuel (RDF) from combustible Municipal Solid Waste (MSW), primarily plastics and paper. Cylindrical briquettes were manufactured from shredded raw materials using a screw extruder. The study examined the energy content, physical properties, and proximate analysis of the produced RDF. The briquettes exhibited a high calorific value of 6,736 Kcal/kg. Experimentation on briquette combustion was conducted in a pottery kiln in Thimi, Bhaktapur, revealing that RDF outperformed fuelwood both in terms of quality and quantity. The RDF shows promising potential due to its high calorific value and favorable combustion properties when supplied with air. However, the study recommends further analysis of the combustible characteristics of MSW.

Keywords: *Energy content, municipal solid waste,* refuse *derived fuel*

Introduction

Municipal Solid Waste (MSW) consists of combustible and decomposable component with energy potential (Sodari & Nakarmi, 2017). Waste to energy option can be viewed as an opportunity for waste management and resolving the energy crisis. Various methods of energy recovery exist, including anaerobic digestion, gasification, combustion, pyrolysis, refuse-derived fuel (RDF), and landfill gas recovery (Suthapanich, 2014). Research suggests an increasing interest in utilizing fuel derived from municipal solid waste, with the aim of improving environmental pollution management while simultaneously providing sustainable energy resources (Churkunti, 2015). The conversion of waste not only prolongs the lifespan of landfills but also provides alternative energy resources by utilizing the waste (Shrestha & Singh, 2011). In Nepal, plastic waste accounts for 16% of urban waste generation, amounting to 2.7 tons of plastic garbage produced daily (ADB, 2013). Within Municipal Solid Waste (MSW), the heating value of plastic bags can be equivalent to that of kerosene in terms of energy content (Heejoon et al., 2006). In this regard, the production of RDF stands out as one of the waste-to-energy options that can be leveraged to manage waste effectively and address the energy crisis. Utilizing alternative fuels in industries such as cement and brick manufacturing holds significance in conserving fossil fuels and reducing CO_2 emissions (Kara et al., 2009).

The RDF refers to the high calorific fraction derived from processed MSW, which includes materials such as plastics, paper, and other combustible matter (Gallardo et al., 2014). The calorific value of RDF is approximately 4000 Kcal/kg (Thirugnanam & Pragasam, 2014). The RDF is commonly produced through a process involving the sorting, shredding, and pelletizing of MSW to create a dense fuel (Krizan et al., 2011). The RDF is considered a renewable energy source and is utilized as a Clean Development Mechanism (CDM) enhancer to promote sustainable development (Nithikul, 2007). Energy can be extracted directly from solid waste as heat, or the waste can be processed into stable RDF for further utilization. Most of the MSW generated globally consists of paper and plastic materials. These components are particularly efficient in managing high energy content, ignitable elements, and flammability compared to other waste constituents. By combining these two materials in appropriate proportions and utilizing briquette technology to create compact forms, a fuel alternative to coal can be produced (Psomopoulos, 2014).

Nepal, as a developing nation, faces challenges in effectively managing its municipal solid waste. Environmental concerns are increasingly prominent, particularly in urban areas, where improper utilization of resources and technology exacerbates the issue (Shrestha & Singh, 2011). On the other hand, the widespread use of fossil fuels has led to escalating energy-related issues on a daily basis. Therefore, waste-to-energy could emerge as a significant alternative for recovering and repurposing MSW, often converted into RDF, a form of solid waste fuel. This approach could represent one of the most viable solutions for managing MSW while also partially addressing energy demands. The objectives of this study were to produce RDF and assess its fuel properties and energy potential. It investigates how employing such fuel in a furnace influences combustion and pollution emissions.

Materials and Methods

This study was grounded in experimental research aimed at evaluating energy recovery from Municipal Solid Wase (MSW). A cylindrical shaped sample (Figure 1) from the prepared materials was produced using a screw extruder briquetting machine (Figure 2) at a temperature of 300°C. Plastic proportion was kept optimum up to 50% as per the literature. The prepared briquette (Figure 1) was undergone proximate analysis, energy content and fuel combustion assessments in the laboratory.

The raw materials, including wrappers and papers, were gathered from households and waste transfer stations and transported to the laboratory. Combustible fractions such as packaging plastics, cardboard, newspapers, and noodle wrappers were sorted for use in the briquetting process. Plastic and paper waste were shredded using a shredding machine to reduce them to smaller pieces, ideally less than 5 mm in size. These materials were then mixed in the appropriate ratio using a hammer mill. The RDF was produced from a mixture of plastics (50%) and paper (50%) using a screw extruder briquetting machine at a temperature of 300°C.

Laboratory Analysis

The proximate analysis, which included assessing moisture content, ash content, volatile matter content, and fixed carbon content, was conducted.

Determination of Moisture Content (MC) Test: A porcelain crucible was preheated in an oven at 110°C for 1 hour. And the dish was taken out from the oven and cooled in the Desiccator. 1gm of the sample was weighted into the crucible. The sample was oven-dried at about 110°C for an hour. The weighing was done in mass balance. Then the calculation for Moisture content (MC)

$$\text{MC (\%) of sample} = \frac{\text{Initial wt (g)} - \text{Final wt(g)}}{\text{Initial wt(g)}} * 100$$

Determination of Ash Content (AC) Test: The ash content is the insoluble residual inorganic matter remaining in the sample after combustion. A sample of one gram was weighed into the crucible and heated in the muffle furnace (without lid) for 1 hour at 815°C, after which it was removed and allowed to cool in a desiccator and re-weighted. The incombustible residue constitutes the ash content was calculated as follows.

$$\text{Ash content (\%) of sample} = \frac{\text{Wt of sample after heating (g)}}{\text{Wt of sample taken (g)}} * 100$$

Determination of Volatile Matter Content (VMC): The amount of volatile matter was determined in a muffle furnace by heating closed crucibles (with lid) at the temperature of 900°C for seven minutes. A sample of one gram was weighed into the crucible then contents were heated in the furnace at 900°C for 7 minutes with the lid on. The loss in weight for the volatile matter present in the coal and briquettes were equal to the loss in the weight were calculated as:

Volatile Matter Content =*100

Determination of Fixed Carbon Content: Fixed carbon is the solid combustible residue that remains after a coal particle is heated and the volatile matter is expelled. The fixed-carbon content of coal is determined by subtracting the percentages of moisture, volatile matter, and ash from a sample.

Fixed Carbon Content (%) = 100- MC (%)- Mean AC (%)-VMC (%)

Determination of Calorific Value: It indicates the amount of heat that is released when the sample is burned. The calorific Value of samples was determined using the Toshniwal Bomb Calorimeter. A Bomb Calorimeter measures the amount of heat generated when materials of a certain mass are burnt in a sealed chamber known as a Bomb provided with an atmosphere of pure Oxygen gas. The heat energy measured in a bomb calorimeter may be expressed either as calories (cal), British thermal units (Btu) or Joules.

Figure 1: Production of Briquette

Figure 2: Screw Extruder

Combustion Test Methods: A test was arranged to examine the combustion characteristics in a double cross-draft kiln. Initially, 2 kg of briquettes were placed in the tray of the combustion chamber. Subsequently, 1 kg of briquettes was consistently added as the temperature inside the insulator chamber increased, reaching up to 700°C. A blower was employed continuously to supply air. Emission readings were recorded after one hour of combustion.

Suspended Particulate Matter (SPM), Carbon monoxide (CO), Carbon dioxide (CO_2), NOx, and SOx were monitored during the experiment. The SPM levels were measured using gravimetric determination, while a Flue Gas Analyzer was employed to measure the other parameters at stack emissions. Stack emission variables were assessed by SMS Environment & Engineering Pvt. Ltd. The average concentration of emissions was measured, with readings taken approximately every 45 minutes.

Results and Discussion

Physical characteristics of fuel

The physical characteristics of the sample briquettes from each production batch were randomly measured to determine density. Table 1 presents the characteristics of RDF.

Table 1: Physical description of RDF

Parameter	Description
Color	Blackish
Shape of Briquette	Hollow Cylindrical
Outer Diameter	40.7 mm
Inner Diameter	19.08 mm
Length	79.5 mm
Weight	0.0479 kg
Density	531.7649 kg/m^3

Fuel Characteristics

The average results of the proximate analysis, obtained from triplicate analyses, are depicted in Figure 3. According to the proximate analysis, the mean moisture content of raw materials (plastics) is low, with plastics at 2.38%, paper at 8.05%, and the briquette samples ranging from 3.04% to 5.16%. The lower moisture content is conducive to enhancing the heating value of the fuel (Krizan et al., 2011).

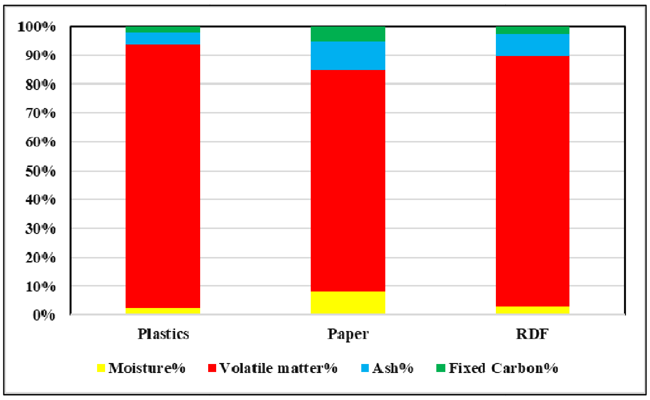

Figure 3: Proximate analysis of Produced RDF

The volatile content of plastics was estimated to be 91.35%, while that of paper was 76.77%. The RDF samples in this study predominantly consisted of volatile matter (VM), ranging up to 84.81%. This finding is consistent with the volatile matter content observed in the RDF sample, which was 81.8% (Akdağ et al., 2016). This indicates that a significant portion of the solid product is converted into gaseous products. It's observed that an increase in volatile matter leads to a decrease in fixed carbon content.

With respect to the ash content of RDF, it represents the residue left behind after combustion. Plastics exhibit a low ash content of 4.24%, while paper has a higher ash content of 9.89%. The produced RDF displayed ash content ranging from 4.24% to 9.92%, consistent with findings of ash content ranging from 2.8% to 9.2% by weight (Kimambo & Subramanian, 2014). The sample containing 70% paper and 30% plastics recorded the highest value of 9.94% by weight. Plastics have a fixed carbon content of 2.03%, while paper has 5.29%. Ash content represents the mass of incombustible materials remaining after burning a given waste sample. It's observed that the ash content of briquettes decreases as the percentage of polyethylene in the briquette composition increases (Akowuah et al., 2012). The material remaining after the volatile components have been driven off is known as fixed carbon. The higher the fixed carbon content of a fuel, the longer the combustion process tends to be. For instance, Ajimara coal contains a fixed carbon content of 63.78%. The high percentage of fixed carbon in waste materials necessitates longer detention times on the furnace surface to achieve complete combustion (Bajracharya et al., 2016).

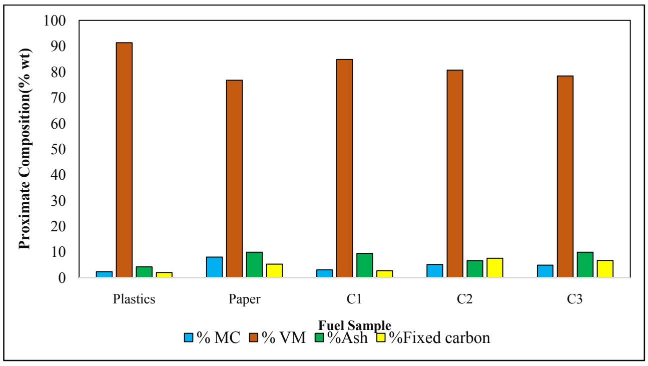

Figure 4: Proximate analysis of Produced RDF

The results depicted in the graph (Figure. 4) illustrate the overall proximate differences among the fuel samples. Parameters such as moisture content, ash content, volatile matter, and fixed carbon can offer valuable insights into the combustibility of the MSW (Zhao et al., 2016).

Calorific Value

The calorific values of polyethylene and paper samples were determined in the laboratory using a Digital Bomb Calorimeter (Figure. 5). The calorific value of the sample briquettes in the RDF varied from 6,789.15 Kcal/kg to 5,694.96 Kcal/kg, which is comparable to the calorific value range of 6,474 kcal/kg to 5,085 Kcal/kg (Kimambo & Subramanian, 2014). Moreover, the energy content of waste depends on its composition. RDF is comparable to coal with a minimum value used in electricity production in India, which is typically around 4,000 Kcal/kg (Thirugnanam & Pragasam, 2014). Similarly, the results obtained for all briquettes closely align with literature data for the coal used in Vertical Shaft Brick Kilns (VSBK), which typically has a calorific value of 7,168 Kcal/kg in its boulder form (Bajracharya et al., 2016). Studies conducted in Japan, India, and Germany have shown that pellets produced from waste materials have calorific values ranging between 12-20 MJ/kg. It's noteworthy that many of these countries are utilizing such pellets for electricity and heat production (Hlaba et al., 2017). According to Hlaba et al. (2017), solid waste typically possesses a calorific value ranging from 11-17 MJ/kg or even higher. Hence, it is highly recommended for use as RDF.

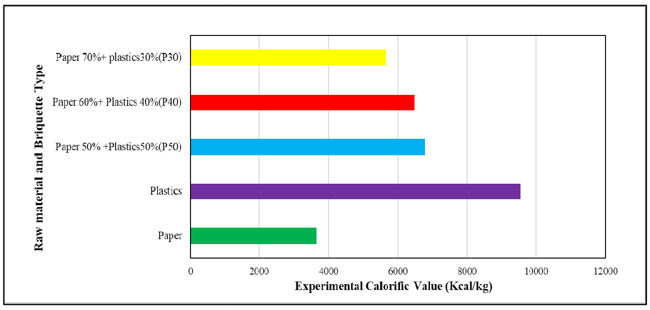

Figure 5: Calorific Value of the Sample

Combustion test

Emissions from the fuel briquettes were evaluated in a pottery kiln equipped with a cross-draft gasifier stove during testing, and stack emissions were recorded. The results include measurements of CO, CO_2, NOx, SOx, and SPM concentrations during various combustion phases, as detailed in Table 2. These results were compared to the national standard for stack emissions in Nepal applicable to brick kilns. The SPM concentration was assessed with an average value of 78.59 mg/Nm^3. It was found that the SPM concentration in pottery kilns was well below the existing standard for brick kilns promulgated by the Ministry of Government, which sets a maximum limit of 250 mg/Nm^3 for SPM emissions (MoFE, 2018).

Table 2: Test Result of Stack Emission

Parameters	Measured Value
Suspended Particulate Matters (SPM)	78.57 mg/Nm^3
CO_2	5.3%
CO	0.22%
NOx	14.4 mg/Nm^3
SOx	<0.02 mg/Nm^3

Conclusion

The quality of RDF hinges on key fuel parameters such as calorific value, proximate analysis, and combustion characteristics. RDF exhibited a high calorific value, low moisture content, high volatile matter, and low fixed carbon. Emission levels indicated an increase in CO emissions, while average permissible levels of SPM, NOx, and SOx were observed. The produced RDF could potentially be utilized for industrial applications with appropriate air pollution control technology. The study results suggest that combustible municipal solid waste could serve as an energy recovery option to address waste management challenges. Further investigations could focus on detailed combustion characteristics, efficiency, and fuel-to-air ratio optimization.

References

ADB. (2013). *Solid waste management in Nepal: current status and policy recommendations*. Asian Development Bank (ADB).

Akdağ, A. S., Atimtay, A., & Sanin, F. D. (2016). Comparison of fuel value and combustion characteristics of two different RDF samples. *Waste Management*, *47*, 217-224.

Akowuah, J. O., Kemausuor, F., & Mitchual, S. J. (2012). Physico-chemical characteristics and market potential of sawdust charcoal briquette. *International Journal of Energy and Environmental Engineering, 3*, 1-6.

Bajracharya, N., Ale, B. B., Singh, R. M., & Bajracharya, T. R. (2016). Waste to energy: An assessment of application of the selective fuel for applications in industries using a mixture of “A” grade coal and municipal solid waste. *Journal of the Institute of Engineering*, *12*(1), 129-142.

Churkunti, P. (2015). *Combustion performance of Waste-Derived Fuels with respect to Ultra-Low Sulfur Diesel in a Compression Ignition Engine.* MS Thesis, University of Kansas.

Gallardo, A., Carlos, M., Bovea, M. D., Colomer, F. J., & Albarrán, F. (2014). Analysis of refuse-derived fuel from the municipal solid waste reject fraction and its compliance with quality standards. *Journal of Cleaner Production, 83*, 118-125.

Heejoon, K., Singh, R. M., & Tianji, L. (2006). Ecofuel-A blend of coal with plastic. *Journal of World Review of Science, Technology and Sustainable Development*, 49-57.

Hlaba, A., Rabiu, A. M., & Osibote, O. A. (2017). Refuse Derived Fuel Pellets as a Renewable Energy Source. *International Proceedings of Chemical, Biological and Environmental Engineering.*

Kara, M., Günay, E., Tabak, Y., & Yıldız, Ş. (2009). Perspectives for pilot scale study of RDF in Istanbul, Turkey. *Waste Management*, 29(12), 2976-2982.

Kimambo, O. N., & Subramanian, P. (2014). Energy efficient refuse derived fuel from municipal solid waste rejects: a case for coimbatore. *International Journal of Environment.*

Krizan, P., Matus, M., Soos, L. J. K. P. P., Kers, J., Peetsalu, P., Kask, U., & Menind, A. (2011). Briquetting of municipal solid waste by different technologies in order to evaluate its quality and properties. *Agronomy Research, 9*(Special Issue I), 115-123.

MOFE. (2018). Brick Kiln Stack Emission Monitoring in Kathmandu Valley. Ministry of Forest and Environment (MoFE), Government of Nepal.

Nithikul, J. (2007). *Potential of refuse derived fuel production from Bangkok municipal solid waste*. ME Thesis, School of Environment, Resources and Development, Asian Institute of Technology, Thailand.

Psomopoulos, C. S., Chatziaras, N., Ioannidis, G. C., & Karaisas, P. (2014). The role of the New Commission's proposal to minimize the Climate impacts of biofuel production in energy and transport sectors. *Fresenius Environmental Bulletin*, 23, 2687-2694.

Shrestha, A., & Singh, R. M. (2011). Energy recovery from municipal solid waste by briquetting process: Evaluation of physical and combustion properties of the fuel. *Nepal Journal of Science and Technology, 12,* 238-241.

Sodari, K. B., & Nakarmi, A. M. (2017). Electricity generation potential of municipal solid waste of Nepal and GHG mitigations. *Journal of the Institute of Engineering, 14*(1), 151-161

Suthapanich, W. (2014). Characterization and assessment of municipal solid waste for energy recovery options in Phetchaburi, Thailand. *Degree of Master of Science in Environmental Engineering and Management. Asian Institute of Technology School of Environment, Resources and Development*.

Thirugnanam, G., Pragasam, V. (2014). *Refuse Derived Fuel to Electricity*. Research gate.

Zhao, L., Giannis, A., Lam, W. Y., Lin, S. X., Yin, K., Yuan, G. A., & Wang, J. Y. (2016). Characterization of Singapore RDF resources and analysis of their heating value. *Sustainable Environment Research*, *26*(1), 51-54.