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Assessment of Energy Recovery Potential of Refused-derived fuel in Moradabad City, Uttar Pradesh, India

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Abstract
The increasing generation of municipal solid waste (MSW) has highlighted the need for sustainable waste management practices. Refuse-Derived Fuel (RDF) presents a viable solution by converting non-recyclable, combustible components of MSW into an alternative fuel source. This study evaluates the energy recovery potential of RDF, focusing on its calorific value, environmental benefits, and role in reducing landfill dependency. RDF can be utilized in industrial processes such as cement kilns, thermal power plants, and waste-to-energy facilities, offering a cleaner alternative to conventional fossil fuels. This study emphasizes RDF's potential to contribute significantly to energy sustainability and waste management in urban settings, with specific insights into its applicability in Moradabad city. The energy recovery potential of MSW is 1513 KWh/tons with 30% energy conversion efficiency.

***Keywords*: Refused-derived fuel, Energy Recovery, Municipal Solid Waste, Heating Value**

1.INTRODUCTION

Incineration is the most common and effective way to recover energy from MSW(Ibikunle et al., 2020) . Modern air pollution control (APC) systems remove fly ashes, gases, heavy metals, and dioxins from flue gas in numerous stages, and incineration is an efficient waste-to-energy solution (Vehlow, 2015). However, the composition of MSW varies greatly, and it might contain organic waste, polymers, metals, glass, and other things. Understanding this composition is critical to optimizing the incineration process. The physical and chemical properties are critical for an efficient incineration process. The proximate, ultimate, and heating values of MSW must be determined before the incinerator may be operated. The proximate analysis entails determining the waste's moisture content, ash content, volatile matter, and fixed carbon. These elements have an impact on the combustion process and the effectiveness of energy recovery. In the ultimate analysis the elemental composition is determined (for example, carbon, hydrogen, nitrogen, sulfur, and oxygen). It aids in understanding the combustion properties and potential emissions created during incineration. A bomb calorimeter can be used in the presence of abundant oxygen to evaluate the heating value of waste. The calorific value (or heating value) is important because it influences how much energy can be extracted from trash. Heating value can be classified into two types: higher and lower. HHV may be calculated using a bomb calorimeter, indicating that more energy can be retrieved, making the waste more suited for incineration as an energy recovery method. It is recommended to RDF for energy recovery whenever material recovery is not possible(Affairs, 2018).

1.1 Refused derived fuel

Municipal solid waste, which is commonly referred to as trash or rubbish, is an undesired, non-hazardous material that is continuously produced by humans. From the previous few decades to the present, municipal solid waste disposal has been a difficult task because of the growing human population. Municipal solid waste may be separated into three categories: combustible, non-combustible, and material with high moisture content(Caputo & Pelagagge, 2002). Refuse Derived Fuel (RDF) made from biomass, paper, textiles, wood, synthetic polymers, and other flammable wastes is an alternative energy resource for implementing a waste-to-energy plan

In refuse-derived fuel, plastic and paper make up 50–80% of the major fractions; organics, wood, and textiles comprise up the remaining fractions (Yang et al., 2021). RDF has a greater heating value (HHV) and lower pollutant emission values, is easier to store and transport, and has significantly decreased idle waste volumes(gizem AYAS, 2021). The utilisation of refuse-derived fuel as an energy source aligns with the 7th Sustainable Development Goal: affordable and clean energy(Dada & Mbohwa, 2018). Processing the combustible part of MSW produces Refuse Derived Fuel (DF) and Cement Industry can play a crucial role in using RDF as an alternative fuel in cement kilns(Affairs, 2018).

2.OBJECTIVES

To estimate the energy recovery potential of RDF using incineration on the dry basis

2.1 Materials and Methods

Moradabad city is the administrative center of the Moradabad district in Uttar Pradesh, India. It is a city with a population of 887871 people and a land area of 75 square kilometers. Geographically, Moradabad City spans between 28°47'20" to 28°54'3" N Latitude and from 78°41'59" to 78°48'23" E Longitude in the western region of Uttar Pradesh. On the banks of the Ramganga River, a branch of the Ganga River that flows northeast of the city is where the city is situated. Moradabad City, known for its brass industry and vibrant markets, generates a substantial amount of solid waste daily. The city's increasing population and industrial activities contribute significantly to its waste production.

The samples of RDF were collected from the Trenching ground (Ramnagar Mazra Ahatamali landfill) near Dear Park. The transfer station receives MSW from 9 Zones in MMC and then transfers it to the trenching ground. Around 330 tonnes/day of MSW is generated in Moradabad city. Special permission was obtained from the supervisor concerned about the trenching ground to conduct the sampling. A 100 kg sample of RDF was collected from each truckload discharge and reduced to 6.25 kg utilizing the coning and quartering process(Anders, 2008). Representative samples were manually separated and weighted using an electronic weighing for each specified waste component. Representative samples were collected from each segregated waste component and analysed in the laboratory on the dry basis.(Warid & Ahmad, 2024)

3. CHARACTERIZATION OF MUNICIPAL SOLID WASTE

To assess the energy recovery potential of MSW by thermal conversion, it's essential to understand the fundamental physicochemical properties of waste components(Aleluia & Ferrão, 2016). The obtained samples underwent laboratory analysis to determine moisture content. The materials were ground at room temperature to create a more uniform mixture. Plastic samples were chopped into smaller sizes since they could not be ground, but paper, cardboard, and textile samples were combined to create a uniform combination of wool-like materials. The produced samples were placed in sealed containers for further analysis. All analyses were performed using standard methods.

Table 1 Methods and equipment

Analysis	**Equipment**	**Methods**	**References**
Moisture content	Hot air oven	IS:1350 Part 1	IS 1350-1 (1984)
Proximate Analysis			
Ash content	Muffle furnace	IS:1350 Part 1	IS 1350-1 (1984)
Volatile matter	Muffle furnace	IS:1350 Part 1	
Fixed carbon		[100-(%VM + %Ash)]	
Ultimate analysis			
Carbon(C)	Elemental analyser (Elementar Vario micro cubes, GmbH/Germany)	IS:1350 Part-4/Sec-1	IS 1350-4-1 (1974)
Hydrogen(H)		IS:1350 Part-4/Sec-1	IS 1350-4-1 (1974)
Nitrogen(N)		IS:1350 Part-4/Sec-1	IS 1350-4-1 (1974)
Oxygen(O)		ASTM D 3176	ASTM D 3176-15
Sulphur (S)		IS:1350 Part-3	IS 1350-3 (1969)
Calorific value(HHV and LHV)	Bomb calorimeter	IS 1350 Part-2	IS 1350-2 (1975)

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3.1 Proximate Analysis

A proximate analysis is performed to determine the heating value of municipal solid waste fuel. It is done to ascertain the gross components of municipal solid waste's moisture, volatile matter, fixed carbon, and ash. The proximate analysis of MSW samples followed IS 1350 and ASTM standards methods for coal and coke analysis. Based on the samples received, the proximate analysis determines moisture content, volatile matter, ash content, and fixed carbon.

3.1.1 Moisture Content: To determine the moisture content of each MSW fraction, 100 g was dried in an oven at 105 °C until a consistent weight was attained. The sample was cooled in a desiccator and weighed after cooling. The moisture was determined using the eq.1

$$Moisture\ content(wet\ basis) = \frac{(Wet\ weight - Dry\ weight)}{wet\ weight} \times 100 \qquad \text{Equation 1}$$

3.1.2 Volatile matter: To evaluate volatile matter, a dried sample of MSW components was ignited in a closed crucible at 950°C for 7 minutes in a muffle furnace. The crucible was allowed to cool in a desiccator before the weight was measured. The percentage of volatile matter is the difference between the dry weight of the sample before burning and the residue that remained in the crucible after burning, as determined by eq.2

$$Volatile\ matter = \frac{weight\ of\ residue}{Dry\ weight} \times 100 \qquad \text{Equation 2}$$

3.1.3 Ash Content: To evaluate the ash content, a dried sample of MSW components was ignited in an open crucible at 550°C in a muffle furnace for two hours, was determined using eq 3

$$Ash\ content = \frac{weight\ of\ residue}{Dry\ weight} \times 100 \qquad \text{Equation 3}$$

3.1.4 Fixed Carbon: The percentage fixed carbon was obtained by subtracting the percentage of volatile matter and ash content from 100 (eq 4)

$$Fixed\ carbon(\%\ of\ dry\ weight) = [100 - (\%\ of\ VM + \%\ of\ Ash\ content)] \quad \text{Equation 4}$$

3.2 Ultimate Analysis

The final analysis was performed to ascertain the elemental composition of MSW components, including the amounts of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S)(Shi et al., 2015). The ultimate MSW analysis is crucial because the percentages of C, H, and O give an indication of the fuel's thermochemical conversion capability, while the percentages of N and S help determine how MSW as a fuel would affect the environment (Vargas-moreno et al., 2012). The findings of the elemental analyser were expressed as percentages of C, H, N, and S, and the percentage of O was computed as [100 – (sum of % of C, H, N, S, and Ash content)] (Boumanchar et al., 2019)

O%= [100 – (sum of % of C, H, N, S, and Ash content)] Equation 5

3.3 Heating Value

When municipal Solid waste is to be burnt, it's important to determine its thermal energy or heating value(Finet, 1987). The heating value is used to evaluate the energy content and incineration of waste components(Wang et al., 2021).The formulation of correlations for the prediction of the higher heating value (HHV) of MSW is a sustainable and cleaner technique based on data from specific regions where MSW is collected(Ibrahim et al., 2020). Among the various physicochemical properties of biomass fuel, the gross calorific value is one of the major fuel qualities showing the energy contents in fuel and a crucial parameter playing a prominent role in the process design and numerical modelling of energy systems(Williams et al., 2001). The MSW comprises combustible and non-combustible materials. Food waste has a low heating value due to its high moisture content. Yard waste has

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moderate heating value, varying according to moisture and type. Paper and cardboard have high heating values due to cellulose; plastic has a very high heating value due to hydrocarbons; textile has moderate to high heating value depending on the fiber type; and wood has a high heating value and varies according to moisture contents. The non-combustible components, like inert materials and ash, have some heating value due to unburnt carbon and contamination with carbonaceous materials. However, their contribution to the overall heating value is minimal. Moreover, their inclusion in the combustion process results in increased ash formation, which could complicate the waste management process and reduce the efficiency of energy recovery systems. The components, such as food waste, yard waste, paper and cardboard, plastic, rubber, and textiles, contribute more significantly to the energy that can be recovered through combustion, so in this study, combustible materials are used for evaluating the energy recovery potential of MSW through thermal conversion technique. A bomb calorimeter was used to quantify the total heat released after the complete combustion of a solid waste sample. To determine the HHV, 1 g of dried and ground material was burned in a constant volume adiabatic bomb calorimeter in the presence of excess oxygen, as per standard IS 1350-2 (1975).

3.4 Energy Recovery Potential

Thermal decomposition of organic matter produces heat energy, which is beneficial for MSW with high organic non-biodegradable waste and low moisture content(Chakraborty et al., 2013).The electrical energy potential from incineration can be calculated by the following formula(Chakraborty et al., 2013)

$$E = 1.16 \times LHV \times W \times \eta \qquad \text{Equation 6}$$

Where, E is the electrical recovery potential(KWh), LHV is the low heating value(cal/gm),W is the quantity of waste generated(tonnes),1.16 is the factor of conversion from kcal/gm to KWh and η is the electrical conversion efficiency.The electrical conversion efficiency in the plants ranges between 20-40% (Ibikunle et al., 2019).In this, the conversion efficiency taken as 30%.

4.RESULTS AND DISCUSSION

In this, Refused derived fuel are collected from the trenching ground. About 20% textiles, 20% Plastics/polythene and remaining is inert material.Proximate Analysis, Ultimate Analysis and Heating Value of RDF find out the dry basis. Moisture content is 14.59%, Volatile Matter is 42.21%, Fixed Carbon is 23.35% and Ash Content is 19.85%. The C, H, N, O and S are 10.38%,3.78%,0.57%,50.8% and 0.03%respectively. The HHV and LHV of MSW are 5431 and 5331 kcal/kg respectively.

Table 2 Component of Waste %

S.No.	Types of waste	% by mass
A	**Fuels**	
1	Wooden Pieces	1
2	Dry Leaves/Matter	0.5
3	Paper	2
4	Textiles	20
5	Polythene/Plastic	20
B	**Inert**	
6	Stone	4
7	Sand/Earth	45
8	Ceramics	0.4
9	Concrete/Bricks	1
C	**Recyclables**	
10	Glass	0.6
11	Rubber/leather/tire	1

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Table 3 Proximate, Ultimate and Heating Value of MSW

Proximate Analysis%	**Results**
Moisture Content	14.59
Ash Content	19.85
Volatile matter	42.21
Fixed Carbon	23.35
Ultimate Analysis%	
C	10.38
H	3.78
N	0.57
O	50.8
S	0.03
Heating Values(Kcal/kg)	
High Heating Value	4431
Low Heating Value	4311

4.1 Energy Recovery from RDF

In this study, the LHV of RDF was found to be 4311 kcal/kg; the MSW generated is 330 tons/day, and energy conversion efficiency is 30%.The typical heating values of Indian coal used in thermal plants ranges between 3500-4500 kcal/kg(Shri & Singh, 2013). The energy recovery is found to be 1513 KWh/tonne.

5 CONCLUSION

An accurate understanding of heating value is required for thermal conversion systems to be designed and run successfully. The physical composition of RDF has been determined by carrying out our sampling at the trenching ground, Moradabad city, India, in Oct 2023.The proximate, ultimate, and heating values were found on the dry basis. The LHV is 4311 kcal/kg. The conversion efficiency is 30%.The energy recovery is found to be 1513 KWh/tonne. This study evaluates the energy recovery potential of RDF, focusing on its calorific value, and role in reducing landfill dependency. RDF can be utilized in industrial processes such as cement kilns, thermal power plants, and waste-to-energy facilities, offering a cleaner alternative to conventional fossil fuels.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agencies.

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