CEST 2023

18th International Conference on Environmental Science and Technology

Athens, Greece, 30 August to 2 September 2023

Plastic waste utilization: Challenges and opportunities for waste-to-energy in Baguio City, Philippines

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Abstract. Amounts of residual wastes, such as plastics, paper, and textiles, in urban areas have drastically increased over the years, which hence requires sustainable waste management schemes. Refuse derived fuel (RDF) provides a solution in addressing minimizing waste disposal in landfills and providing energy, particularly in developing nations. In this study, waste-to-energy (WtE) potential from residual wastes in Baguio City was assessed. With an experimental value of 13.738 MJ/kg, it revealed a percentage error of 20.748% when compared with predicted values from an energy regression model. However, ANOVA results revealed that the energy, moisture, and ash content were all statistically comparable to reports across RDF-related studies.

Keywords: ***plastic pollution; residual waste; RDF; sustainability; waste-to-energy***

1. Introduction

Urban waste generation is considered one of the major concerns to date. In the Philippines, notable cities such as Manila, Cebu, Davao, and Baguio have had great economic development in the past years. However, alongside this development is the high population density and consumption rate. The latter relates with the affluence observed in major cities, even in a developing country (Lunag et al. 2019; Atienza 2020)

Solid waste pollution has become a major problem in our society, from its carbon footprint in production to its devastating effects as wastes in the environment. The UN sustainable development goals, particularly numbers 12 (pertaining to responsible consumption and production) and 14 (pertaining to sustainable use and protection of water resources) directly addresses the impacts of waste pollution, respectively. Furthermore, waste materials that have dissolved and degraded over time, such as microplastics, have been recognized as a global threat, affecting air, land, and water ecosystems (Walker 2021).

The human consumption pattern has changed over the years. In modern times, people have heavily relied on food delivery, e-commerce, and logistics. Products, such as food, clothing, gadgets, and furniture, to name a few, can be delivered to a nearby local facility or even at our doorsteps. This entailed the use of plastics and paper mainly for packaging, to ensure the quality of the products upon delivery. Another area where the use of single-use materials is often observed is the healthcare service sector, where the gloves, gowns, and masks are mainly composed of polymeric material. In addition, the increase in producing hand sanitizers and alcohols for sanitation and hygienic reasons have contributed to the manufacturing of plastic containers (Pincelli et al. 2021; Sarkodie and Owusu 2021). Considering its sole purpose, the packaging has a short product lifetime, thus creating a large influx of residual waste generation. In cases where recycling has already been maximized, diverting the wastes to other alternative medium presents a sustainable path towards effective waste management. One way is through converting waste into useful energy using refuse derived fuel (RDF).

RDF is a type of waste-to-energy (WtE) method where the materials are pre-processed and formed into more manageable and combustible material for energy, such as briquettes and pellets (Gumisiriza et al. 2017). This is a more appealing approach as it packs in more energy content in the range of 18 megajoule per kilogram (MJ/kg) in pellet form, as compared to direct incineration, where municipal solid waste (MSW) are directly burned for a lesser energy content at around 9.1 MJ/kg (Zhao et al. 2016). While the concept WtE plant using RDF is promising for urban cities such as Baguio, factors such as environmental, social, and economic may hinder it from coming into fruition. Incineration is still prohibited under the Philippine ESWM Act, alongside potential air pollutants it may produce, enforced through Philippine Clean Air Act or RA 8749. Social acceptability may also be affected due to the protection of several cultural and heritage sites that can be destroyed if WtE plants are installed. Finally, the financial and technical capability of the city government may be a factor for such proposed projects, given a large portion of the budget is often allocated for collection, hauling, and transportation of waste to the landfill. Fortunately, some private corporations have shown interest in building WtE plants with consideration of properly mitigating air pollutants. In 2019, the Philippine National Oil Company-Renewables Corporation (PNOC-RC) proposed to install a WtE facility in Itogon, Benguet, a nearby town from Baguio City (Rivera 2019). Regardless of the hurdles, RDF presents a sustainable waste management with co-benefit of energy production.

Overwhelming residual waste generation in urban areas such as Baguio city have led to the conceptualization of this study. This study aims to assess performance parameters of residual waste in the city and its comparison with an established model. Experimental values were compared with regression model values formulated by Liu et al (Liu et al. 1996). It is noted that no regression model was created in this study and that the authors have made use of an existing model for validation purposes. Finally, results from the samples was compared with related literature to determine the significance of the study.

2. Methodology

2.1. Baguio Profile

Baguio city is located in the northern part of the Philippines. It has become a center for education, industrial, and tourism, to name a few. Baguio city is known for its cool climate, making it a popular vacation spot during summer, notable events, and holidays. It is home to around 370000 residents, which are administered in 129 barangays (villages) within an area of 57.49 km2 (Andaya-Basilio and Caldona 2018).

As reported by Lunag et al (2019), the waste analysis and characteristics study (WACS) in Baguio city reported the average solid waste generation to be 0.4193 kg per day per capita. This comprises of biodegradables (41.67%), recyclables (33.78%), residuals (24.15%), and special waste (0.40%). It is noted that the classification of waste in the Philippines is based on the Ecological Solid Waste Management (ESWM) Act, commonly known as Republic Act (RA) 9003.

In terms of the current solid waste management schemes in the city, biodegradables are either composted in household backyards, treated through the Environmental Recycling System (ERS) or disposed at a landfill in Tarlac, a province outside Baguio city. Recyclables are segregated and collected through individual barangays, for selling. After all the valuable recyclables have been collected, residuals and special wastes are likewise sent to the landfill for disposal.

A common scenario in Baguio city and other urban areas in the Philippines is the piling of solid waste, particularly during the collection schedules. Several places have their own collection bins, such that in the central business district, while others (i.e. in residential areas) place the wastes by the sidewalks, depicted in Figure 1, causing objectionable appearance.

(a) (b)

Figure 1. Waste during collection schedule in (a) areas with collection bins, and (b) residential areas without bins.

2.2. RDF Data

The physical composition of the RDF were based on the study conducted by Victoriano and Duran [11]. Table 1 presents the composition and performance parameters measured from laboratory results. The physical compositions of the RDF were varied to determine different parameters.

2.3. Energy content regression model

The energy content of RDF and any fuel are affected by its composition in terms of physical and elemental aspects. Energy in terms of heating value (HV) have been correlated with the physical content of RDF, such as plastics, paper, textiles, biodegradables, and other trace components. On the other hand, ultimate analysis looks into elemental composition within the fuel, which are carbon, hydrogen, oxygen, nitrogen, sulfur, and ash (Liu et al. 1996). For the purpose of this paper, physical

Table 1: Performance parameters from the RDF

	Sample 1	Sample2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12
HV (MJ/kg)	14.093	14.093	14.093	14.093	14.093	14.093	14.093	14.093	14.093	14.190	12.909	10.920
Paper and cardboard	22.22%	50.00%	15.66%	36.23%	38.46%	45.16%	69.89%	16.83%	29.21%	35.63%	35.63%	35.63%
Plastic and rubber	48.48%	25.00%	56.63%	26.09%	42.86%	40.32%	30.11%	66.34%	62.92%	44.83%	44.83%	44.83%
Textile	0.00%	25.00%	18.07%	37.68%	18.68%	14.52%	0.00%	16.83%	7.87%	14.94%	14.94%	14.94%
Organics (wood, dried leaves)	29.29%	0.00%	9.64%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	4.60%	4.60%	4.60%
Moisture (%)	3.800	3.700	3.500	5.000	5.100	4.500	3.700	4.300	3.800	2.100	2.900	2.300
Ash residue (%)	5.200	5.200	4.500	5.300	4.500	5.700	5.700	5.300	4.500	4.900	5.600	3.800

composition is reported by the authors and have made use of the multivariable regression model generated by Liu et al (1996), expressed as

$$HV = 9336.633 + 117.906(R) + 33.077(P) + 20.391(G) - 156.091(M) \quad (1)$$

where HV is the heating value in megajoule per kilogram (MJ/kg), R is the plastic content in % by weight, P is paper content (% by weight), G is the garbage content (% by weight), and M is the moisture content (% by weight)

2.4. Energy content regression model

Several studies have reported RDF parameters with varying conditions. The authors have used 17 studies that report the heating values, moisture, and ash content for comparison purposes. Single-factor analysis of variance (ANOVA) is utilized to determine if the parameters in the Baguio City RDF are statistically comparative with other related studies.

3. Results and Discussion

3.1. Heating value based on regression model

Regression models are often used to predict the heating values of combustible products, based on their composition. Based on the multivariable regression model of Liu et al (1996), the energy content contained in Baguio City MSW is computed to have an average of 10.829 MJ/kg. In this result, plastic content comprises the largest group in the composition at an average of 44.436 % by weight, followed by paper (35.881%), textiles (15.289%), and organics and others (4.394%). This coincides with the regression model by Liu (1996), where the plastics have the most influence in the energy content. Moreover, paper content also contributes greatly to the increase in energy content of the RDF samples, due to having carbon-based material inherent in it (Rezeai et al. 2020).

Table 2: Experimental and regression model heating value comparison

Sample	HV, MJ/kg	HV (Liu et al., 1996), MJ/kg	% difference
1	14.09324	10.87963	22.80251
2	14.09328	10.42052	26.06041
3	14.09325	11.05762	21.53957
4	14.09325	10.35279	26.54078
5	14.09328	10.74939	23.72685
6	14.09325	10.73239	23.84731
7	14.09327	10.59954	24.79006
8	14.09325	11.25768	20.12
9	14.09326	11.23592	20.2745
10	14.18987	10.89898	23.19182
11	12.90903	10.86813	15.80989
12	10.91999	10.88998	0.2748
Mean	13.73818	10.82855	20.74821

Comparing the regression model results and the experimental results as depicted in Table 2, the percentage error is found to be averaged at 20.748%. With variation between the model and experimental values, a percentage error of above five percent may not validate the model in this given instant. One factor seen is the type of fuel being analyzed and the regression model used, as the model of Liu analyzes MSW energy and the experimental value pertains to RDF.

3.2. Comparison of RDF parameters across other related studies

As presented from Table 1, the results of the HV for samples 1 to 9 were all equal at 14.093 MJ/kg, despite the varying composition of plastics, papers, textiles, and organics. It only changed in samples 10 to 12, where the compositions were constant. This scenario was also seen in the study of Garrido et al., (2017), where the varying mixture of sawdust, printed circuit board (PCB) waste, and automotive shredder residues (ASR) waste were analyzed to have 18.900 MJ/kg. Overall, the measured mean for the twelve samples is 13.738 MJ/kg.

ANOVA results are summarized in Table 3. The heating value of the Baguio city RDF is significantly comparable as with other RDF with other related studies, with a p-value of 0.080 and significance level of 0.10. Moisture and ash were also found to be comparable with other studies, with p-values of 0.001 and 0.005, respectively.

Table 3. Summary of ANOVA results of produced RDF with other related studies

Mean				Remarks	References
	Current study	Related literature	p-values		
Heating value (MJ/kg)	13.738	17.452	0.080	Significant *(p=0.10)	Miezah et al. 2015 Seng and Fujiwara 2018 Azam et al. 2019 Sprenger et al. 2018 Kers et al. 2010 Gendebien et al. 2003 Nithikul 2007 Bras et al. 2017 Deepika et al. 2018 Iqbal et al. 2019 Kimambo and Subramanian 2014
Moisture (%)	0.037	0.260	0.001	Significant	
Ash (%)	0.050	0.075	0.005	Significant	

4. Conclusion

In the Philippine setting, residual wastes category may contain plastics, paper, and textiles not deemed as valuable. These materials directly affect the energy potential in wastes. Refuse derived fuel (RDF) provides a solution in addressing minimizing waste disposal in landfills with the co-benefit of providing energy. In this study, waste-to-energy (WtE) potential from residual wastes in Baguio City was assessed. With an experimental value of 13.738 MJ/kg, it revealed a percentage error of 20.748% when compared with predicted values from an energy regression model. Based on the percentage error, it can be concluded that the MSW regression model employed does not validate and does not represent the experimental energy in RDF.

ANOVA results revealed that the energy, moisture, and ash content were all statistically comparable to reports across RDF-related studies. Despite the single-factor ANOVA results giving statistical significant output, running a multiple regression analysis gave high levels of p-values, thus giving no significant comparisons among the set values. This could be attributed to several factors, such as the equipment used for measuring the parameters, procedural errors, and number of trials done on varying compositions, to name a few. Thus it is recommended to perform a validation test first when conducting experiments. It is also recommended to create a multivariable regression model using experimental data in future studies with an increased number of samples.

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