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ENERGY VALUE IN BIOMASS AND PLASTIC COMPONENTS OF MUNICIPAL SOLID WASTE

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Abstract

Burning potencies of constituents of municipal solid waste (MSW) indicate energy value stored in them. A significant portion of biodegradable as well as non-biodegradable waste is still80 not recycled and most of them are either burnt or dumped in the landfills. The scope of this work is to study the energy value of selected biomass (dry garden leaves) and two plastic materials, low density polyethylene (LDPE) and polystyrene (PS), collected from an educational campus in Varanasi, India. Cow dung which is still used as domestic fuel in dry cake form in many parts of the country, has also been included. Two pellet batches of biomass, one each of Ashoka (Saraca Asoca) tree leaves and Cow dung, two pellet batches of plastic, one each of low density polyethylene (LDPE) and polystyrene (PS); and twelve biomass-plastic blended pellets have *been prepared and tested. Proximate analyses and higher heating values (HHVs) were measured and compared with the gross calorific values (GCVs) of various grades of Indian non-coking thermal coals. The results indicate that on blending of biomass materials with plastics in 1:1 ratio, the HHV of mix exceed GCV of grade A non-coking coal. A 2:1 ratio gives material with heating values higher than grade C coal. Other tested mix proportions also produced heating values exceeding D grade coal. Thus, it appears feasible to produce secondary fuel using components of MSW for domestic consumptions. This is a non-conventional and renewable source of energy. This may partly reduce the dependence on fossil fuel (like coal) and provide an alternate reuse pathway for such materials.*

Keywords

Biomass, Plastic Waste, Reuse, Proximate Analysis, Higher Heating Value (HHV)

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1. Introduction

Depositing wastes with high biodegradable content in landfills lead to the production of liquid and gaseous emissions even after the closure of the landfill as a result of the microbiological activity (Pinto et al., 2014). Diversion of waste streams such as biomass, papers, plastics and other solid materials from municipal landfills not only reduces the load reaching there; it also has other positive impacts for environment.

Coal and oil are the major sources for meeting the energy requirements in India (Annual Report, 2013-14).With high economic and industrial growth, energy demand is also increasing in the country (Soppimath & Hudedmani, 2017). Because of limited availability and environmental concerns related with use of non-renewable sources of energy, other renewable options need to be explored and examined (Kumar, Kumar, Baredar & Shukla, 2015).

Biomass is a renewable source of energy. However, biomass normally have low heating values in the range of 5.6 – 20.5 MJ/kg (Parikh, Channiwala & Ghosal, 2005; McKendry, 2006). Fossil fuels, which are common sources of domestic energy have heating values in the range 25-33 MJ/kg) (Fuel, n.d.). Dry garden-leaves constitute a significant portion of Municipal Solid Waste (MSW) generated in academic and administrative campuses. Cow dung has conventionally been used as domestic fuel in dried cake form. Rathore (2015) evaluated the calorific values of fifteen species of dry leaves commonly found in academic campuses. The values ranged between 13.7 MJ/kg to 17.7 MJ/kg. Ashoka (*Saraca Asoca*) tree leaves collected in air dried form has an average calorific value of 16.3 MJ/kg. Cow dung in pellet form was found to have a calorific value of 14.0 MJ/kg. Low density polyethylene (LDPE) and polystyrene (PS) are forms of plastics which are commonly used packaging materials in India. In absence of good recycle and reuse options, a significant portion of these materials end up in municipal solid waste, which are either burnt in the streets after primary collection or on reaching to landfills. Plastics have a heating value of 41.4 - 46.3 MJ/kg (Subramanian, 2000) which is significantly higher than that of coal. Sharma (2016) attempted to find the heating values of twelve waste materials including LDPE and PS commonly present in municipal solid waste streams in India. The observed values (44.7 MJ/kg and 40.0 MJ/kg for LDPE and PS respectively) were found close to those reported in literatures.

Refuse-derived fuel (RDF) and Solid recovered fuel (SRF) are the terms in use in contemporary scientific works. RDF is more used for unspecified waste after a basic processing to increase the calorific value and therefore this term usually refers to the segregated, high calorific fraction of municipal, commercial or industrial wastes. SRF refers to a waste-derived fuel meeting defined quality specifications in terms of both origin (produced from non-hazardous waste) and levels of certain fuel properties. In comparison with conventional fuels, both these types of secondary fuel show waste of inherently varying quality and an increased level of waste-specific contaminants (Rotter et al., 2011). Recovered Energy Fuel (REF), Packaging Derived Fuel (PDF), Paper and Plastic Fraction (PPF) and Processed Engineered Fuel (PEF) are the other terms vividly in use (Thorin, Boer, Belous & Song, 2012).

Gug, Cacciola & Sobkowicz (2015) studied the effect of varying proportions of recyclable plastics: polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET) and polystyrene (PS) with domestic solid waste (DSW) for various mechanical and thermal properties. Thus, it appears that although harnessing of energy value inherent in components of municipal solid waste (MSW) has drawn significant attention of scientific community, a systematic study of use of biomass blended with plastics still appears unexplored.

The focus of this study is to examine the possibility of proportioning biomass and plastic materials in such a way that the heating value of the product compare well with that of coal, which has conventionally been used as fuel for many domestic thermal applications. Accordingly, Ashoka (*Saraca Asoca*) tree leaves and Cow dung have been taken as representative biomass. Non–PVC plastics, such as LDPE and PS obtained from MSW segregation have been selected to be examined for enhancing the heating value of mixed combinations. Proximate analyses of each batch of pellets prepared through hand mixing of these ingredients in different proportions were done and higher heating values (HHVs) were found. The results were compared with reported gross calorific value (GCV) of Indian thermal coals.

2. Material and Methods

2.1 Materials

The materials used in the present study were Saraca Asoca Leaves, Cow dung, LDPE and PS. Saraca Asoca Leaves were collected from residential and academic blocks while Cow dung was collected from agricultural research farm. LDPE & PS were collected from hostel premises of IIT (BHU) campus, Varanasi. Saraca Asoca Leaves and Cow dung used in this study were already dried in natural environment. Thus thermal drying was not required. The biomass and plastics were first grinded to a size of approx.0.5-1 cm and then physically hand mixed in various proportions as shown in Table 1. The respective samples were formed into hand pressed pellets and preserved for analyses.

2.2 Test Methods

2.2.1 Proximate Analysis

The proximate analysis is an important characterization method to determine the grade and fuel quality of coal and biomass (Beamish, 1994; Garcia, Pizarro, Lavin & Bueno, 2013). The proximate analysis for samples was performed as per ASTM standard. The burning tests in this study were performed in air without purge gas.

2.2.1.1 Moisture Content (MC)

Higher moisture content negatively affects fuel heating value, and can affect physical stability of the pellet. This test was performed to investigate the moisture content in the pellet in accordance with ASTM D3173 (ASTM, 2011a). The samples moisture content was determined from the following equation

$$W_M(\%) = \frac{W_i - W_d}{W_i} X\,100 \qquad (1)$$

where W_M is the percent moisture in analysis sample (%), W_i is the initial weight of sample used (g) and W_d is the weight of sample (g) after drying at 105 ^{o}C for 1 h.

Table 1: *Individual and blended materials prepared for analyses*

S.No.	Materials	Nomenclature	Material Proportion by weight (%)			
			Saraca Asoca Leaves (S)	***Cow dung (C)***	***LDPE (L)***	***Polysterene (P)***
1	Saraca Asoca Leaves only	100S	100	—	—	—
2	Cow dung only	100C	—	100	—	—
3	LDPE only	100L	—	—	100	—
4	Polystyrene only	100P	—	—	—	100
5	Leaves and LDPE	75S25L	75	—	25	—
6	Leaves and LDPE	67S33L	67	—	33	—
7	Leaves and LDPE	50S50L	50	—	50	—
8	Leaves and Polystyrene	75S25P	75	—	—	25
9	Leaves and Polystyrene	67S33P	67	—	—	33
10	Leaves and Polystyrene	50S50P	50	—	—	50
11	Cow dung and LDPE	75C25L	—	75	25	—
12	Cow dung and LDPE	67C33L	—	67	33	—
13	Cow dung and LDPE	50C50L	—	50	50	—
14	Cow dung and Polystyrene	75C25P	—	75	—	25
15	Cow dung and Polystyrene	67C33P	—	67	—	33
16	Cow dung and Polystyrene	50C50P	—	50	—	50

2.2.1.2 Ash Content (AC)

The ash content was carried out to analyze residue remaining after burning the pellet according to ASTM D3174 (ASTM, 2011b). The residual ash weight percentage was determined using the following equation:

$$W_A(\%) = \frac{W_b}{W_i} X\ 100 \qquad (2)$$

where W_A is percent ash in analysis sample (%), W_b is the weight of ash after burning the sample (g) under 720 ^{o}C for 3 h after heating gradually to 420 ^{o}C over 1 h, and W_i is the original weight of sample (g) used.

2.2.1.3 Volatile Matter (VM)

The percentage of volatile matter was determined by calculating the loss in weight from burning the pellet in an oxygen starved environment in accordance with ASTM D3175 (ASTM, 2011c). The weight loss percent was calculated as follows:

$$W_L(\%) = \frac{W_i - W_h}{W_i} X\ 100 \qquad (3)$$

where W_L is the weight loss percent in analysis sample (%), W_i is the initial weight of sample used (g), and W_h is the weight of sample (g) after heating at 925 ^{o}C for 7 min. The volatile matter percent was obtained using both the weight loss percent and moisture percent as follows:

$$W_V(\%) = W_L - W_M \qquad (4)$$

where W_V is the volatile matter percent in analysis samples (%).

2.2.1.4 Fixed Carbon (FC)

From the proximate analysis test results, the fixed carbon value may be calculated according to ASTM D5142 (ASTM, 2009) using the following equation:

$$F_C(\%) = 100 - (W_M + W_A + W_V) \ (5)$$

where F_C is the fixed carbon percent in the analysis sample (%).

2.2.2 Higher Heating Value (HHV)

The HHV of the pellets (precisely weighed to be 1.00 g ± 0.02 g) were measured by using Compensated Jacket Calorimeter (6100 Calorimeter, Parr Instrument Company, Illinois, USA). An average of three samples readings were recorded for result and analyses.

3. Results and Discussion

Proximate analyses and HHV Tests

Proximate analyses were carried out to find out the moisture content (MC), volatile matter (VM), fixed carbon (FC), and ash content (AC) of the selected materials. The results for individual and blended pellets are summarized in Table 2 and Table 3 respectively.

Table 2: *Proximate analysis and Higher Heating Values of selected biomass and plastic materials*

S. No.	Materials	MC (%, ar)	VM (%, db)	FC (%, db)	Ash (%, db)	HHV (MJ/kg, db)
1	Saraca Asoca Leaves (100S)	9.2	70.3	13.6	6.9	16.2
2	Cow dung cake (100C)	12.2	58.7	15.5	13.6	16.8
3	LDPE (100L)	0.3	99.2	0.12	0.4	44.7
4	Polysterene (100P)	0.3	99.3	0.17	0.3	40.0

ar – as received, db – dry basis

In general, PS and LDPE have very high volatile matter in the range 99.2-99.3%. However, moisture content, fixed carbon and ash content are found to be very small. Cow dung is found to have maximum moisture content, fixed carbon as well as ash content and minimum volatile matter content among these tested materials. Ashoka leaves have lower moisture content, fixed carbon as well as ash content, but higher volatile matter than Cow dung cake.

Table 3: *Proximate analysis and Higher Heating Values of Biomass-Plastic blended pellets*

S. N.	Material Combination	MC (%)ar	VM (%)db	FC (%)db	AC (%)db	HHV (MJ/kg)db
1	100S	9.2	70.3	13.6	6.9	16.2
2	75S25L	6.5	78.1	10.2	5.2	22.8
3	67S33L	6.1	80.2	9.2	4.5	**24.9**
4	50S50L	4.3	85.5	6.4	3.8	***29.3***
5	100S	9.2	70.3	13.6	6.9	16.2
6	75S25P	5.7	79.0	10.1	5.3	22.0
7	67S33P	5.8	80.8	9.1	4.3	**23.6**
8	50S50P	4.4	85.6	6.6	3.4	***27.2***
9	100C	12.2	58.7	15.5	13.6	16.8
10	75C25L	8.5	70.6	10.9	10.1	23.0
11	67C33L	8.2	72.8	9.8	9.2	**24.9**
12	50C50L	6.0	80.4	6.6	6.9	***29.1***

13	100C	12.2	58.7	15.5	13.6	16.8
14	75C25P	9.2	69.8	10.7	10.7	22.2
15	67C33P	8.1	72.7	10.1	9.1	**23.9**
16	50C50P	5.9	79.9	6.8	6.8	***27.6***

ar – as received, db – dry basis

For the biomass- plastic blended pellets, it is observed that as the proportion of LDPE is increased from 25% to 33% and 50%, moisture content, fixed carbon and ash content decrease and percentage of volatile matter increase in the mixed product. This also increases the HHV of the combination. Table 4 gives the reported Gross Calorific Value (GCV) of non-coking coals, which are normally used for thermal applications.

Table 4: *Grades of Non-Coking Coals*

Grade	**Gross Calorific Value (MJ/kg) (at 5% Moisture Level)**
A	Exceeding 26.98
B	Exceeding 25.28 but not exceeding 26.98
C	Exceeding 23.4 but not exceeding 25.28
D	Exceeding 21.27 but not exceeding 23.4
E	Exceeding 18.07 but not exceeding 21.27
F	Exceeding 16.16 but not exceeding 18.07
G	Exceeding 13.01 but not exceeding 16.16

Source: Ministry of Coal, GOI. (2014)

The comparison of HHV of various biomass-plastic blended mix with the reported GCVs of different grades of coal indicate that Ashoka leaves and Cow dung cakes individually have thermal values equivalent to around G or F grades of non-coking coals. When Ashoka leaves or Cow dung is mixed with either of LDPE or PS in 1:1 ratio, the HHV of resultant mix reaches above 25 MJ/kg which is comparable to GCV of C and above grade coals. Table 5 summarizes the characteristics of 1:1 ratio blended product, which show HHV higher than 25 MJ/kg.

Table 5: *Characteristics for 1:1 ratio blended product comparable with GCVs of Coal*

S.No.	Material Combination	MC (%)ar	VM (%)db	FC (%)db	AC (%)db	HHV (MJ/kg)db
1	50S50L	4.3	85.5	6.4	3.8	**29.3**
2	50S50P	4.4	85.6	6.6	3.4	**27.2**
3	50C50L	6.0	80.4	6.6	6.9	**29.1**
4	50C50P	5.9	79.9	6.8	6.8	**27.6**

ar – as received, db – dry basis

Cow dung appears to have higher fixed carbon as well as ash content than dry leaves of Ashoka tree. Cow dung also appears to retain higher moisture content and less volatile matter than dry leaves. Thus, out of two selected biomass (dry leaves and Cow dung), dry leaves appear to be a richer source of volatile matter, and from amongst the two blending plastic materials (LDPE and PS), LDPE appears a preferable choice in terms of thermal value. However, all these mixes give thermal values higher than grade A coal.

Figure 1 shows the values of HHVs for different combinations of tested materials. It is observed that by increasing the proportion of LDPE or PS from 25% to 33% and 50 % with biomass, the HHV increases from 16.2 MJ/kg to more than 23 MJ/kg. A 2:1 ratio mixing of biomass and plastic materials gives resultant heating value higher than grade C coal. This is indicated from the values in Table 3 also.

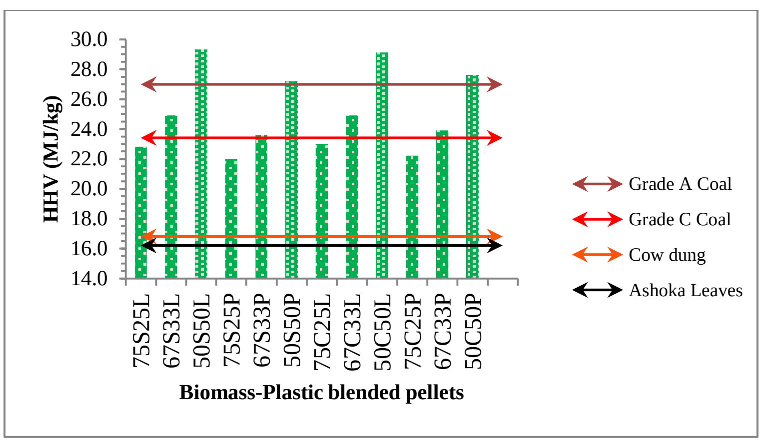

Figure 1: *HHV for different biomass- plastic blended pellets*

The proximate analysis results on individual and biomass- plastic blended pellets are presented in Fig. 2.

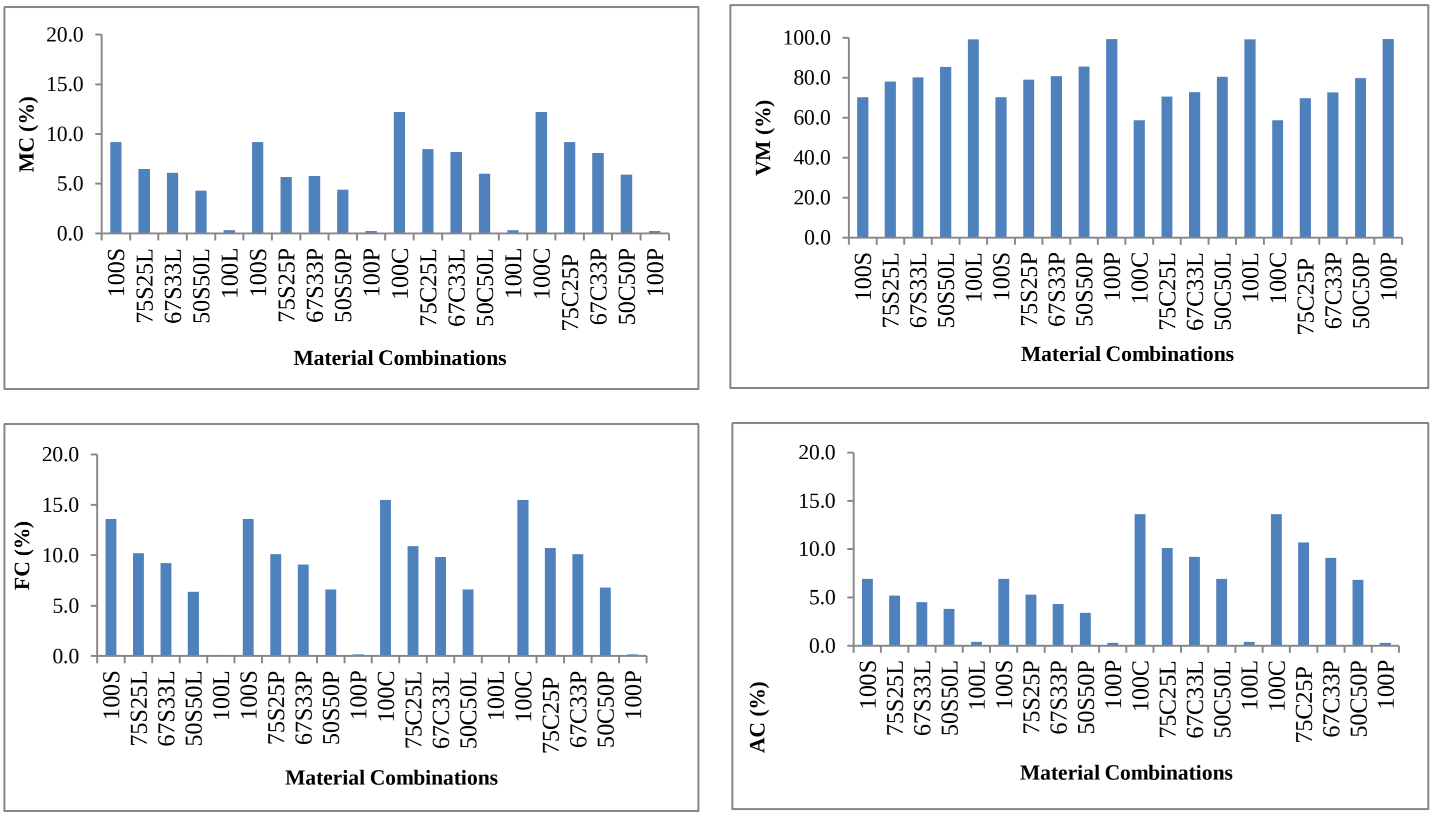

Figure 2: *Proximate analysis of individual and biomass-plastic blended pellets*

Broadly it is observed that, the volatile matter (VM) content of Ashoka leaves is around 70% and that for Cow dung is around 58%. On mixing this biomass based materials with plastics, the VM for Ashoka leaves increase up to 85% and that of Cow dung may reach a level of 80%. Such increases in volatile matters content result in increase in energy value of mix from around 16.2 MJ/kg for Ashoka leaves to 29.3 MJ/kg in mixed products, and from 16.8 MJ/kg to 29.1 MJ/kg for Cow dung and its mixed product with plastics. These higher heating values (HHVs) of blended products are greater than that of class C coal (HHV= 23.4-25.3 MJ/kg).

4. Conclusions

Based on the results of experimental study conducted during the present work, following conclusions may be drawn:

- Ashoka (Saraca Asoca) tree leaves and Cow dung cakes, under naturally dried conditions have fuel values of 16.2 MJ/kg and 16.8 MJ/kg and are comparable to G and F grades of non-coking thermal coal respectively. García, Pizarro, Lavín & Bueno (2014) reported HHVs of some of the tree leaves in the range of 17 – 19 MJ/kg. The observed values in the present study are very close to these reported values.
- LDPE and PS which are common components of municipal solid waste, have calorific values in the range of 40 – 45 MJ/kg, which much higher than the thermal coals in domestic uses. Subramanian (2000) reported HHV of plastic materials in the range of 41-46 MJ/kg.
- A 2:1 proportional mix by weight of dried Ashoka leaves as well as Cow dung with either of LDPE or PS increase the thermal values of product materials (HHV= 24 – 25 MJ/kg) comparable to grade C thermal coal (HHV= 23.4 – 25.3 MJ/kg)
- A 1:1 proportion of dried Ashoka leaves or Cow dung with LDPE or PS by weight increase the thermal value of mixed materials (HHV= 27 – 29 MJ/kg) comparable to grade A non-coking coal (HHV>.26.98 MJ/kg).

Thus, the dry leaves and plastic materials, which are the common components of municipal solid waste can serve as complementary ingredients to prepare a solid fuel, which give energy values comparable to domestic coal used in India.

5. Research Limitation & Scope of Future Research

Bomb calorimeter was used for measuring the HHVs of materials. The amount of sample for measuring heating value is limited to 1 g only. Thus, only small pellets up to 1 g can be measured precisely. The exact heating value of large sized samples, such as briquettes is difficult to assess.

The potential of Cow dung as a practical binding material to prepare solid fuel cakes or pellets need to be fully examined. Also, the composition of gaseous emissions from burning of these materials and their effects on human health have to be understood with due details.

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