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Experimental Studies on Pellets Prepared from Different Proportions of Wastes

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Abstract: As per estimates more than 55 million tons of MSW is generated in India per year; the yearly increase is estimated to be about 5%. A number of widely referenced environmental advantages suggest municipal solid waste as an interesting feedstock to obtain energy in large quantities. Pelletization of municipal solid waste, with or without additional binder, is worthwhile consideration for energy utilization. Pelletization is one of the preferred options when compared to anaerobic digestion and biomass gasification to treat organic waste as this is easy to operate if the wastes are segregated. Pelletization enhances the bulk density of waste components used and hence, makes transfer of material easy and economical. The segregated waste is treated and transformed into pellets, which can be used as a fuel for burning purpose. Sixteen different municipal solid waste samples with different composition were considered for the study. The properties such as moisture content, ash content, volatile matter, fixed carbon, CHONS, and calorific value were evaluated for the pellets obtained from pelletization. SEM analysis was also carried out to obtain information about the surface morphology and composition.

1. Introduction

Across the globe, it is observed there is an increase in the rate of solid waste generated at least in the urban areas. Collection and disposal of MSW results in environmental challenges (Nordi et al., 2017). Hence, it is essential to explore how best these large amounts of solid waste generated can be utilized beneficially. Most of the waste generated in India and elsewhere is managed by the Urban Local Bodies (ULBs) and mostly disposed in open dumps. India generates approximately 133760 tonnes of MSW per day and about 91000 tonnes is collected while 26000 approximately treated (CPCB Report, 2020). MSW in general comprises of 19% recyclable waste, 40% inert or non-organic and 41% organic or biodegradable waste (Sharholy, 2008). In India, untreated MSW finds its way directly into landfills which are technically open dumps. In view of several environmental issues with landfills / open dumps, there is an urgent need to explore alternate ways to convert the wastes into useful products. In this context, conversion of segregated MSW to energy and compost are the options considered by ULBs.

To achieve sustainable solid waste management, waste-to-energy technologies play a special role in developing countries (Cucchiella et al., 2016; Shi et al., 2016). MSW is a precious renewable resource, and through the use of appropriate waste-to-energy technology, biogas can be produced for cogeneration. Suitability of appropriate technology depends on the physical and chemical properties of the MSW (Cheng and Hu, 2010). Choosing appropriate waste-to-energy technology is tough task, because the generation of solid waste involves seasonal changes in producers and socioeconomic levels. Pelletization is one of these processes which convert waste into pellets and subsequently to energy. Pelletizing includes the process of compressing a material into a definite shape of a pellet. Different types of materials are pelletized including animal compound feed, garden biomass, iron ore, plastics, and more. Pelletization of large quantities of segregated MSW results in alternative energy, thereby reducing dependence on fossil fuels (Stelte et al., 2012). The purpose of this study was to recover energy from MSW and to investigate properties of pellets prepared from different proportions of waste. This work focuses on the study of calorific value, moisture content, ash content and CHONS content for pellet samples prepared with waste components.

2. Materials and methods

2.1 Preparation of Waste Compositions

Pellets were prepared by using different proportions of garden biomass (GB), Municipal Solid Waste (MSW), Cow Dung (CD), Aerobic Sludge (AS), Anaerobic Sludge (ANS), Glycerol (GL) as indicated in Table 1. Waste samples were collected for seven days to take care of variations and appropriate samples from mixed waste is used for pelletization. All the waste components are oven dried individually at 50 ◦C, over a 24-h period and ground using pulvarizer. Aerobic and anaerobic sludge was collected from wastewater treatment plant. Cow dung and glycerol were used as binding material. The pictures of waste collected and pellets made are shown in Figure. 1 and 2 respectively.

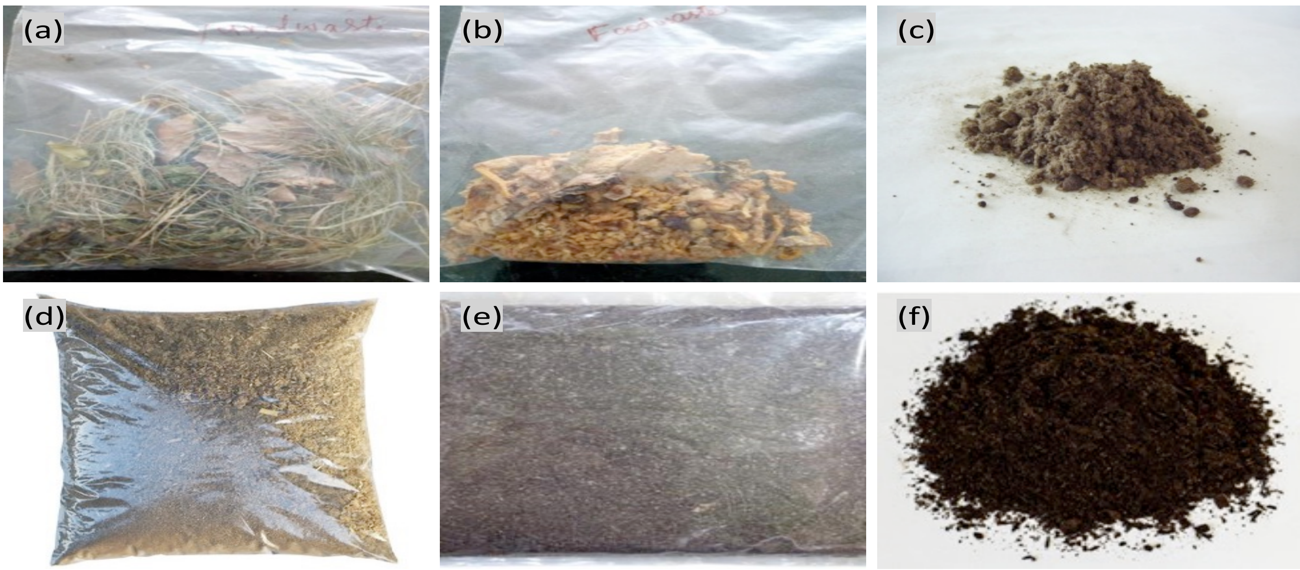

Figure 1. Waste samples used for making pellets: a Garden Biomass b Food Waste c Municipal Solid Waste d Cow Dung e Aerobic Sludge f Anaerobic Sludge

2.2 Pelletization

The wastes were mixed into sixteen combinations as indicated in Table 2. The wastes are moistened to 20±0.5% by spraying water and mixed thoroughly to make homogeneous material and stored in sealed glass jars at room temperature for 24 h. Initial and final moisture content of the material in glass jars is found using moisture analyzer. Pelletization involves several operations which include segregation, shredding, mixing, blending, solidification and drying. Pellets were prepared with different waste compositions using the flat die pelletizer shown in Figure 3.

Figure 2. Waste samples used for making pellets: a Garden Biomass b Food Waste c Municipal Solid Waste d Cow Dung e Aerobic Sludge f Anaerobic Sludge

The specifications of the pelletizer used during the study are presented in Table 2. Flat die pelletizer included a cylindrical die and piston unit. Standard procedures were used to determine ash content and calorific value of the pellets. Pellets with five highest calorific values were subjected to ultimate analysis (CHONS) and Proximate analysis. HCV was determined using Dulong's Formula and compared with the experimental Calorific value of pellets. Calorific value is a parameter that determines the energy potential of the waste materials (Harker and Backhurst, 1981). Calorific values are determined after drying the pellet samples for 24 hours. Measurement of calorific values within 6 hours of drying is reported to be influenced by fungus.

Table 1. Samples with different composition

Samples	Composition of pellets* (%)					
	GB	MSW	CD	AS	ANS	GL
1	80	0	10	10	0	0
2	70	0	15	15	0	0
3	60	0	20	20	0	0
4	50	0	25	25	0	0
5	75	0	10	10	0	5
6	60	0	15	15	0	10
7	45	0	20	20	0	15
8	0	75	10	10	0	5
9	0	60	15	15	0	10
10	0	45	20	20	0	15
11	0	75	10	0	10	5
12	0	60	15	0	15	10
13	0	45	20	0	20	15
14	0	75	10	10	5	5
15	0	60	15	15	7.5	10
16	0	45	20	20	10	15

*Note: GB-Garden Biomass, MSW-Municipal Solid Waste, CD-Cow Dunk, AS-Aerobic Sludge, ANS-Anaerobic Sludge, GL-Glycerol

Table 2. Detailed specifications of a flat die pelletizer

Particulars	Specifications
Rollers Diameter (mm)	10
Die specifications	
Channel length (mm)	40
Die hole diameter (mm)	12
Overall dimensions	
Length(mm)	200
Breadth (mm)	150
Height (mm)	300
Net machine weight (kg)	2.85

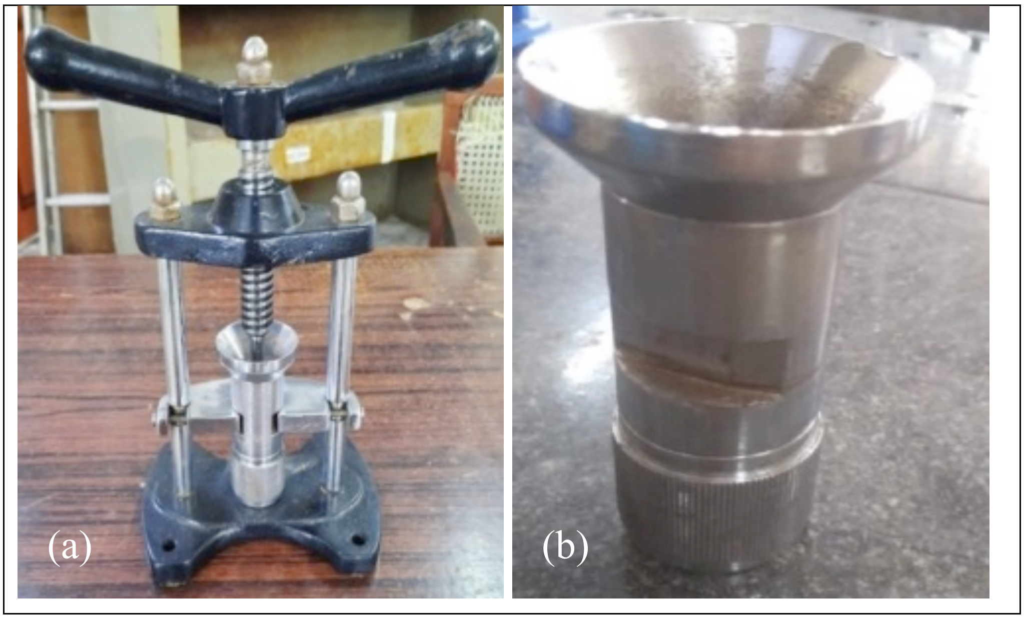

Figure 3. Flat die pelletizer with a piston unit and b cylindrical die

3. Results and Discussion

3.1 Moisture content

Moisture content is one of the important parameters for production of pellets as it influences the density of pellets. Initial and final moisture content of pellets is presented in Table 3 and Figure 4. To enable compaction of waste components, water and binders (cow dung and glycerol) are used during the study. Rise in temperature during compaction due to material friction decreases the moisture content and the balance during drying. The moisture content of pellets was in the range of 7 to 18%, with majority of the samples in the range of 10±2%. There is about 1 to 2% decrease in moisture content of the pellets after 24 hours drying. Minimum moisture content of 7% was observed for pellet sample 2 (combination of garden biomass, cow dung and aerobic sludge in 70, 15 and 15% respectively). Combination of MSW, cow dung, aerobic sludge, anaerobic sludge and glycerol in 75, 10, 5, 5 and 5% respectively resulted in about 9% moisture content where MSW was major component.

A moisture content of 5% to 25% is generally good for pelletization. As per the available literature, 10% to 20% moisture content will give good quality pellets. The moisture content of pellets reduced after drying, however lower moisture content offers safety in storage of pellets. Lower moisture content also reduces the risk of fungal contamination. Pellets with low moisture content offer safety in storage while higher moisture content reduces the intermolecular forces and results in biphasic mixture (liquid and solid phase). In order to reduce moisture content further, heat drying is also reported in literature. As reported in literature, standard moisture content for using pellets for deriving energy in Europe are Austria < 10%; Germany < 12%; Sweden <10% (Garcia-Maraver, 2011). In the present study, the moisture content of most of the pellets after 24 hr drying is in the range of 10±2% which indicates that the waste can be recommended for use as energy source. However, for those combinations of wastes with higher moisture content suitable methods are to be explored for reduction in moisture content. Pellets with low moisture content and dense will be burn with high efficiency of combustion.

Table 3. Moisture content of different samples

Samples	Composition of pellets* (%)						Initial moisture content	Final moisture content after 24 hours (%)
	GB	MSW	CD	AS	ANS	GL		
1	80	0	10	10	0	0	10.20	9.60
2	70	0	15	15	0	0	7.82	6.98
3	60	0	20	20	0	0	10.73	9.17
4	50	0	25	25	0	0	9.92	8.70
5	75	0	10	10	0	5	11.12	9.57
6	60	0	15	15	0	10	14.32	12.95
7	45	0	20	20	0	15	20.47	18.39
8	0	75	10	10	0	5	13.20	11.76
9	0	60	15	15	0	10	12.11	10.67
10	0	45	20	20	0	15	19.69	18.92
11	0	75	10	0	10	5	12.64	10.00
12	0	60	15	0	15	10	19.24	16.67
13	0	45	20	0	20	15	12.92	11.69
14	0	75	10	10	5	5	11.82	9.23
15	0	60	15	15	7.5	10	13.21	11.11
16	0	45	20	20	10	15	14.62	13.33

*Note: GB-Garden Biomass, MSW-Municipal Solid Waste, CD-Cow Dung, AS-Aerobic Sludge, ANS-Anaerobic Sludge, GL-Glycerol.

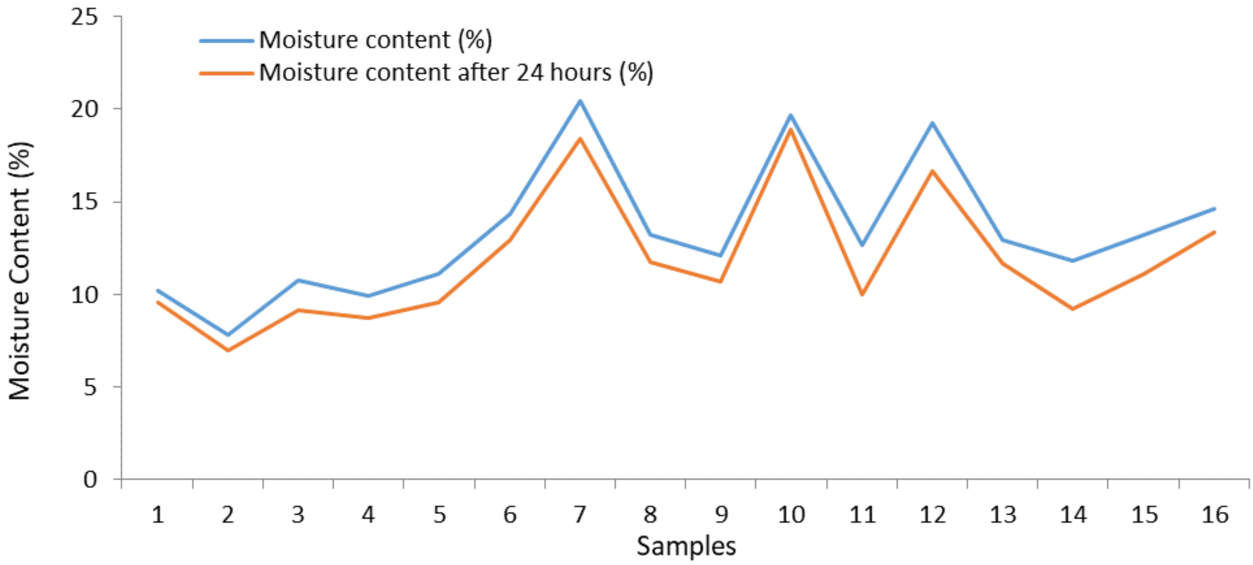

Figure 4. Flat die pelletizer with a piston unit and b cylindrical die

3.2 Calorific value

Calorific values for the pellets prepared using different proportions of MSW are presented in Table 4 and Fig. 5. All the calorific values of the pellet samples were in the range of 2750 to 5750 cal/gm. Calorific value of traditional fuel, i.e., wood varies from 3500 to 4600 cal/gm (approximately). Calorific value of refuse in general is about 800 – 2000 kcal/kg (CPHEEO Manual, 2016) and that of fuel pellets derived from MSW will be around 4000 kcal/kg (Uson et al., 2013). The calorific value increase by 3-5 times by conversion of wastes to pellets. The calorific values obtained for pellets produced using different combination of solid wastes are in agreement with values reported in literature. Samples 5, 6, 7, 14 and 16 results in good calorific value in the range of 3682 to 5747 kcal/kg indicating good energy potential for pellets produced.

Table 4. Calorific Value of Different Samples

Samples	Composition of pellets* (%)						Calorific value (Cal/gm)	Residue (gm)
	GB	MSW	CD	AS	ANS	GL		
1	80	0	10	10	0	0	2753	0.262
2	70	0	15	15	0	0	3049	0.254
3	60	0	20	20	0	0	2772	0.312
4	50	0	25	25	0	0	2754	0.300
5	75	0	10	10	0	5	3682	0.248
6	60	0	15	15	0	10	4674	0.238
7	45	0	20	20	0	15	4433	0.225
8	0	75	10	10	0	5	3290	0.210
9	0	60	15	15	0	10	2807	0.172
10	0	45	20	20	0	15	2782	0.196
11	0	75	10	0	10	5	2957	0.194
12	0	60	15	0	15	10	2850	0.212
13	0	45	20	0	20	15	3286	0.253
14	0	75	10	10	5	5	5747	0.171
15	0	60	15	15	7.5	10	3735	0.219
16	0	45	20	20	10	15	4670	0.210

*Note: GB-Garden Biomass, MSW-Municipal Solid Waste, CD-Cow Dung, AS-Aerobic Sludge, ANS-Anaerobic Sludge, GL-Glycerol.

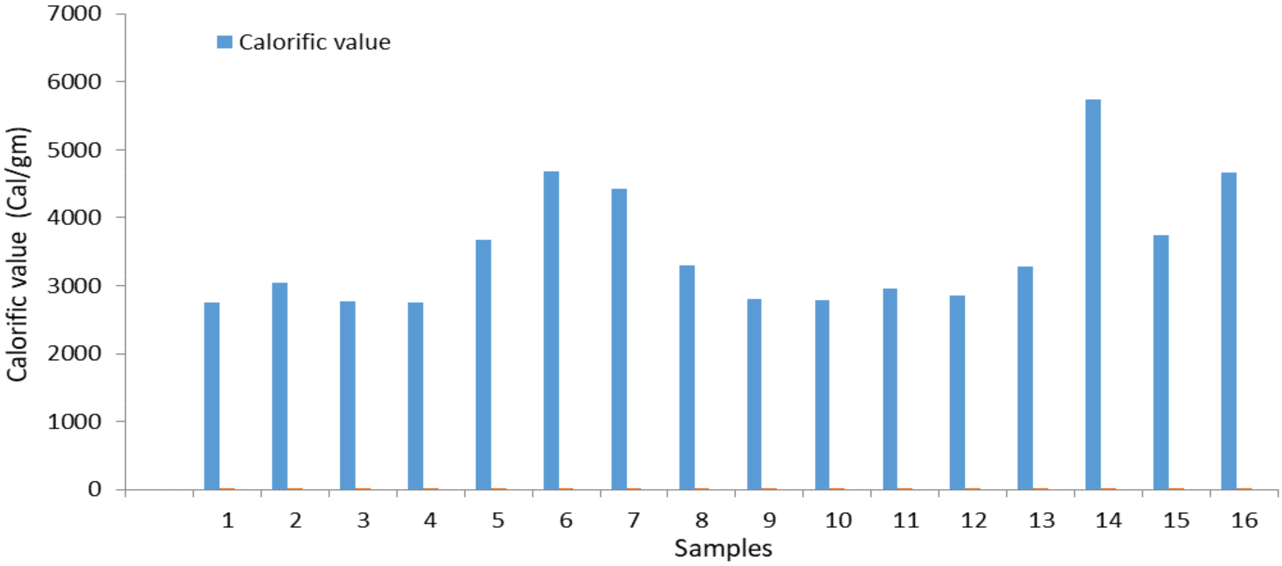

Figure 5. Calorific value of pellet samples

As per European standards, the calorific values of pellets in Austria > 4302 kcal/kg; Germany >3705-4661; Sweden > 4039 (Garcia-Maraver, 2011). In fact, as on today, there are no prescribed standards for calorific value of pellets in India. Binders are used to increase the calorific values of solid wastes with low calorific values. Wherever standards are prescribed for caloric values, pellets are produced by addition appropriate % of binder to enhance the calorific value (Nursani et al., 2020). It is to be noted that the type of binder (organic and inorganic) also influences the calorific value of pellets. Common inorganic binders used are clay, lime, cement, plaster and sodium silicate. Similarly, the popular organic binders are biomass binders (cassava paste, wastepaper pulp, molasses, cow dung, and starch), tar, bitumen, polymers, plastics, etc,. In the present work cow dung and glycerol are used as binder material. Garden biomass with cow dung and glycerol as binders resulted in maximum calorific value. Two samples of MSW with cow dung and glycerol as binders and equal quantities of aerobic and anaerobic sludge yielded maximum calorific value. The influence of aerobic and anaerobic sludge on calorific value is not attempted in this study.

Calorie meter gives ash as a residue after combustion of pellets. The residue of different pellets presented in Table 4, varies from 0.171 to 0.312 grams which is negligible as the weight of pellets was in the range of 0.8 to 1.8 grams. If the above wastes are properly segregated at source and used for preparation of pellets, the energy can be recovered and hence revenue for the local bodies handling the MSW. Conversion of MSW into pellets is a sustainable alternative for safe disposal of MSW which otherwise is disposed in open dumps or sanitary landfills. Furthermore, production of pellets from MSW results in renewable energy similar to that of biomass, solar and wind energy.

3.3 Elemental composition of pellets.

Ultimate analysis of solid wastes gives the elemental composition of pellets in percentages of CHONS. Elemental composition is required to estimate the amount of air required for combustion and volume of emissions released. Ultimate analysis and higher calorific value (HCV) of pellets gives broad information of the combustion and emissions. Based on the calorific values presented in the Table 4 for different solid waste samples, the 5 best pellet samples with high calorific values were further subjected to ultimate analysis to determine elemental composition. The results of the CHONS analysis are presented in Table 5 and Figure 6. The C, H, O, N, and S content in these pellets is similar to the RDF derived from MSW.

Table 5. Results of Ultimate Analysis

Samples	Composition of pellets* (%)						C	H	N	S	O	HCV
	GB	MSW	CD	AS	ANS	GL	(%)	(%)	(%)	(%)	(%)	(Cal/gm)
5	75	0	10	10	0	5	41.83	6.34	1.80	0.83	89.77	3724
6	60	0	15	15	0	10	28.75	4.24	1.04	0.34	60.45	4698
7	45	0	20	20	0	15	32.75	5.67	1.16	0.28	75.80	4457
14	0	75	10	5	5	5	31.07	5.03	1.62	0.42	68.84	5773
16	0	45	20	10	10	15	29.79	5.49	0.96	0.27	71.41	4693

*Note: GB-Garden Biomass, MSW-Municipal Solid Waste, CD-Cow Dung, AS-Aerobic Sludge, ANS-Anaerobic Sludge, GL-Glycerol.

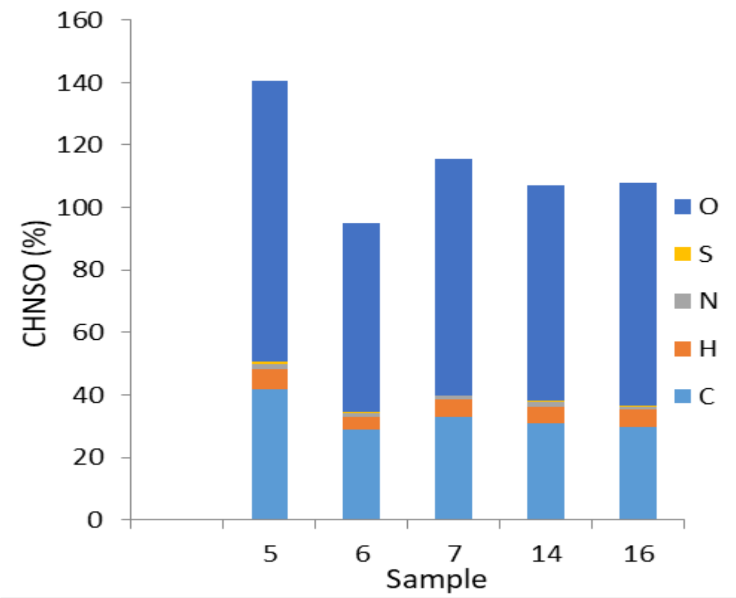

Figure 6. Elemental composition of pellet samples

The hydrogen content of the pellets varies from 4.24 to 6.34%. The percentage of oxygen ranges between 60.45 to 89.77%. Nitrogen content in the pellets is observed to be in the range of 0.96 to 1.80%. Nitrogen in pellets leads to harmful emission as it takes part in combustion. The sulfur content in pellets was found to vary between 0.27 and 0.83%. Sulfur content of < 1% is acceptable as lower sulfur content results in lower SOx emissions during burning process. Carbon in pellets ranged between 28.75% to 41.83%. Higher percentage of carbon in pellets improves the combustibility of the pellet when used as fuel. Heating value or gross heating value, lower calorific value and high heating value are used to give an idea of energy content in pellets. These terms depend on the elemental composition and proximate analysis. Higher calorific value is determined by using Dulong's Formula given in Eq. 1.

$$\text{H.C.V.} = (33800C+144000(H_2-O_2/8)+9270S)\ \text{KJ/KG} \quad \text{(Eq. 1)}$$

where, H.C.V. = Higher Calorific Value, C = Carbon, H = Hydrogen, O = Oxygen, S = Sulphur

Using Dulong's Formula, higher calorific value for pellets is determined as 15590, 19670, 18660, 24170 and 19650 KJ/KG respectively. This is nearly same with the calorific value obtained using Bomb calorimeter. The calorific values obtained for pellets produced with different proportions of solid wastes in the present study are in the range of about 16 to 20 MJ/kg which is in agreement with the calorific value 19.87 MJ/kg reported in literature (Safwat et al., 2019).

3.4 Proximate analysis of pellets

Proximate analysis of solid wastes gives the ash content, volatile matter, fixed carbon and moisture content of pellets in percentages. Moisture refers to water discharged from pellet by specified method without causing any chemical reaction. Volatile matter is the loss in weight minus the moisture when the pellet is heated without contact with air to a sufficiently high temperature under specified conditions. Ash is the inorganic residue left when the pellet is completely burnt in air under specified conditions. Fixed carbon is the residue obtained by subtracting the sum of the percentages by weight of moisture content, volatile matter and ash from 100. It is essentially carbon containing minor amounts of nitrogen, sulphur, oxygen and hydrogen. Five pellet samples with highest calorific values were subjected to proximate analysis to determine percentages of volatile matter, moisture content, ash content and fixed carbon. The results of the proximate analysis are presented in Table 6.

Table 6. Results of Proximate Analysis

Samples	Composition of pellets* (%)						Volatile matter (%)	Moisture content (%)	Ash content (%)	Fixed Carbon (%)
	GB	MSW	CD	AS	ANS	GL				
5	75	0	10	10	0	5	23.64	9.57	23.63	43.16
6	60	0	15	15	0	10	33.15	12.95	33.14	20.76
7	45	0	20	20	0	15	36.42	18.39	36.41	8.78
14	0	75	10	5	5	5	31.69	9.23	31.67	27.41
16	0	45	20	10	10	15	35.61	13.33	35.60	15.46

*Note: GB-Garden Biomass, MSW-Municipal Solid Waste, CD-Cow Dung, AS-Aerobic Sludge, ANS-Anaerobic Sludge, GL-Glycerol.

Volatile matter in biomass generally is in the range of 70 to 85% and it is proportional to biomass reactivity and efficiency of conversion (Wang, 2014). The volatile matter of the pellets indicated in Figure 7, varies from 23.64 to 36.42%. Volatile matter influences the duration of fuel burnout: pellets with higher volatile matter require longer duration to burnout.

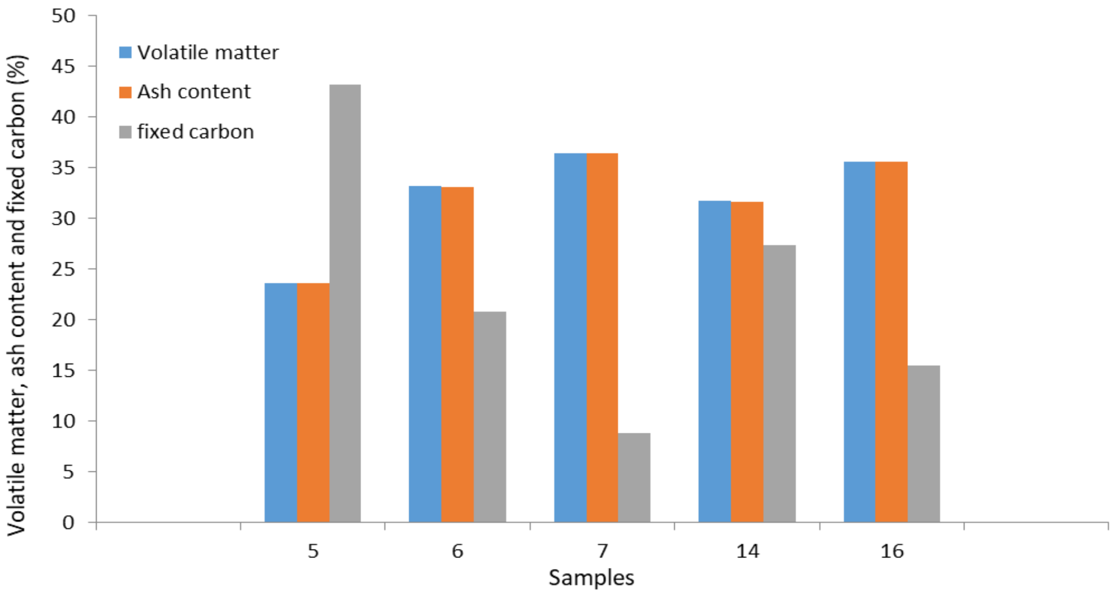

Figure 7. Elemental composition of pellet samples

High volatile matter (%) in pellets indicates higher concentrations of useful gases like methane. The percentage of moisture content ranges between 9.23 to 18.39%. Pellet samples with about 15% moisture content are considered to be suitable for efficient energy conversion process (Wang, 2014).

Higher moisture content is not favorable for combustion process as it demands for higher ignition temperature and decreases the calorific value of pellets (Mariasamy et al., 2010). However, pellets with higher moisture content lead to syngas but are not highly preferred due to lower performance of gasifier and poor quality of syngas (Wang, 2014). Ash content in the pellets is observed to be in the range of 23.63 to 36.41. Ash content values are higher indicating the possibility of salts, heavy metals and organics which are subsequently released into the environment (Lam et al., 2010). Pellets with lower ash content are referred over the pellets with higher ash content. Ash can be converted to clinker at higher temperatures. Fixed carbon is the solid residue minus the ash remaining. Higher fixed Carbon in pellet samples reflects higher energy in the conversion process. Fixed Carbon in pellets ranged between 8.78 to 43.16% similar to those reported in literature (Jones, 2010; Kalanatarifard, 2012).

3.5 SEM (Scanning Electron Microscope) Studies (Figure 8)

Pellets were subjected to SEM analysis to study the surface morphology and composition of the samples. The results indicated that the surface of the selected pellet samples is smooth and the mixture inside the particle is uniform. The binding of the different solid waste components used for making the pellets is important and it can be visualized in SEM studies.

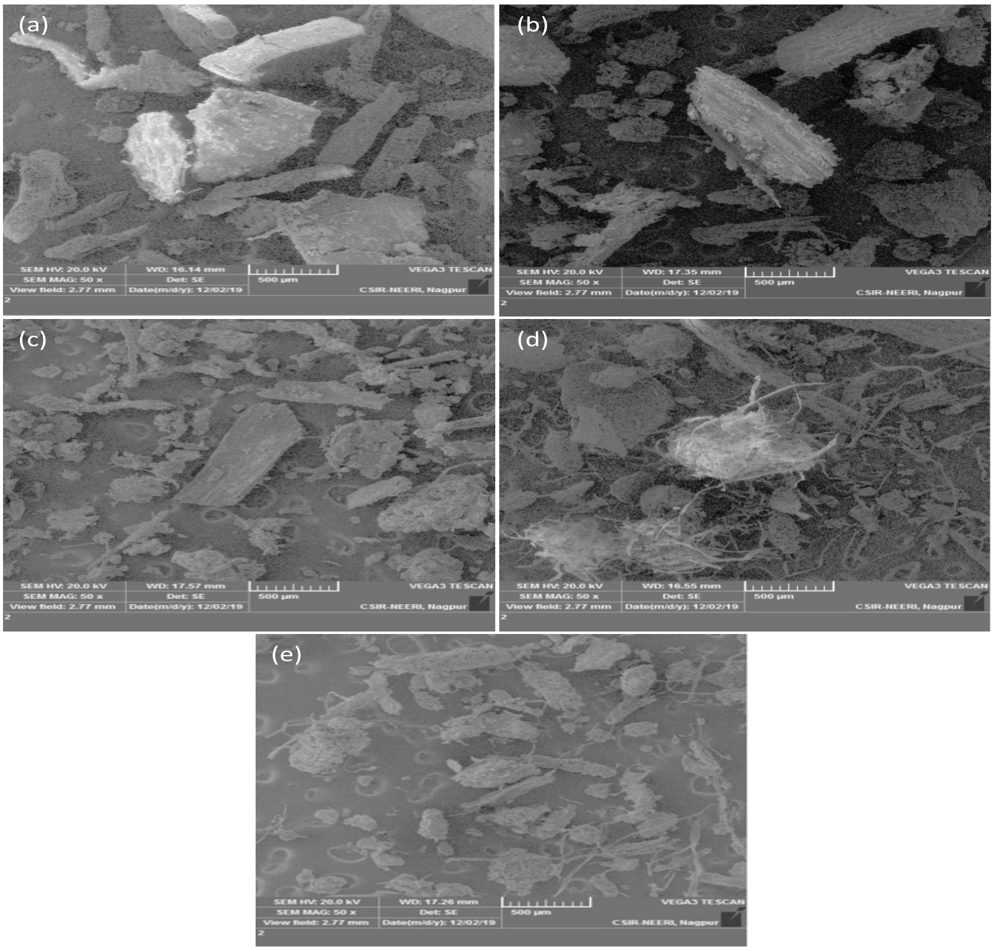

Figure 8. SEM images of a sample no. 5 b sample no. 6 c sample no. 7 d sample no. 14 and e sample no. 16.

In addition to visualizing binding mechanism, SEM images can be used for identifying the morphological characteristics of the pellets. The voids and gaps in images describe lack of binding among particles and hence lower density. In such case efficient binders are to be recommended to reduce the voids and increase the density of pellets. From SEM images (Figure 8) it was found that the particle bonding in sample no. 5 (Figure 8a) was not very efficient when compared with others. The bonding happens by solid bridges and the binders used play an important role in bridging. Cross linking and agglomeration of particles is better observed in Figure 8c, 8d and 8e. Significant fiber strands were also observed in these samples (Figure 8c, 8d and 8e) indicating better inter particle bridging.

Conclusions

MSW disposal in open dumps and sanitary landfills is resulting in numerous problems in urban areas due to ever increasing rate of solid waste generation. Alternative solutions like composting, incineration are implemented by ULBs in spite of challenges in operation and maintenance of these facilities. In this context, the present study focuses on pelletization technology for deriving renewable energy from MSW. In general, MSW has poor fuel value, however, if pellets are produced in combination with other wastes and binders, it is possible to achieve better fuel value. Production of pellets with different proportions of solid wastes suggests an alternative solution to derive energy from waste and hence, wastes are sources of renewable energy. The calorific value of pellets made with MSW and other wastes is comparable to that of wood and other fuels and pellets can be used in co-firing. Pellets with lower moisture content are to be preferred over the other pellet samples. The elemental composition indicates lower amounts of nitrogen and sulfur and hence less emissions during burning. 30 – 40 % Carbon and about 5% Hydrogen contribute to high heating value and hence pellets can be recommended for co-firing and firing depending on the temperatures required. SEM studies indicated inter particle bridging due to binders used in the study. The presence of voids and gaps in the pellets is visualized in SEM studies. Various types of pellets can be produced depending on the requirement by varying the proportions of wastes. Good quality pellets with high heating value and low moisture and ash content are generally preferred in industries like cement kilns, power plants, and other industries which involve steam generation. However, pellets have limited application in industries like metal fabrication, metal plating, iron and steel, ceramics, glass, etc, as they require maintaining high temperatures which cannot be achieved with these pellets. Though the technology used for production of pellets is simple, there are several barriers and challenges. Some of them include emissions from burning the pellets, financial barriers for municipalities, segregation of wastes, lethargy in changing from open dumping practice, lack of public awareness and involvement.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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