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Bangladesh J. Sci. Ind. Res. **57(2)**, 77-84, 2022

BANGLADESH JOURNAL OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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Impact of bulking agents on municipal solid waste refused derived fuel

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Abstract

The main objective of this study was to investigate how the bulking agents (BA) effect on municipal solid waste (MSW) moisture contents and refused derived fuel (RDF) pellets bulk density (BD), durability (DU) and hardness. In this experiment applied sugar cane trash, rice husk and cotton waste bulking agents each at 15%, 25%, 35% and 45% to reduce the moisture contents of MSW for RDF pellet development. Sugar cane trash was prominent in moisture reduction capability in 10 days than others BA. MSW and sugar cane trash mixture, RDF pellets pertained maximum BD (1.58 g/cm^3), DU (99%) and hardness (27kg) were developed with compaction process, die diameter 8inch and 120°C. It was also observed smoke appeared at 150°C during pelting process due to burning of biomass. Furthermore bulking agents had also revealed effectiveness in BD, DU, hardness results as the quantity of BA increased. It was concluded that BA are suitable for moisture reduction and RDF pellet development, can be sued as an alternative energy fuel.

Received: 04 November 2021
Revised: 13 March 2022
Accepted: 11 April 2022

DOI: https://doi.org/10.3329/bjsir.v57i2.60403

Keywords: Bulking agent; Bulk density; Durability; Hardness; Moisture

Introduction

Pakistan and other developing countries urbanization have increased massively in recent decades. It upsurge the quality of human life as well as rapid social economic development which leads to problems like housing, transportation, water and sanitation and solid waste generation in urban areas. Pakistan generates about 48.5 million tons of solid waste a year, which has been increasing more than 2 percent annually. The Government of Pakistan (GOP) estimates that 87,000 tons of solid waste is generated per day, mostly from major metropolitan areas. It becomes the most critical current environmental problem of Pakistan (Iqbal *et al*., 2020).

There are so many disposal techniques which can be applied on municipal solid waste (MSW) for instant thermo chemical treatment by using incineration, combination mechanical and biological treatment, bio-gasification and landfilling. Each disposal techniques has its own advantages and disadvantages (Dianda *et al*., 2017). Landfilling is a long standing disposal option, but not appropriate due to leachate contaminate the ground water. Composting is another approach, which is only suitable for bio-degradable material.

Incineration is to be an attractive and proven method for waste disposal used for many years. Incineration has been widely used because it reduce the quantity of waste up to 90% but the production of heavy metals in ash, hazardous air pollutants such as dioxin and furans not contemplate as disposal process. In addition Pakistan also face the lack of natural resources for energy production but refused derived fuel (RDF) is best option as an alternative energy source and waste management problem.

The quality of the RDF depends upon the feedstock composition, starch, protein, fiber, fat, lignin, feed moisture content; feed particle size and distribution; feed conditioning, temperature of feed; and binder's variable which significantly affect the strength and durability of RDF products.

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Mani *et al*. (2006) observed that initial moisture content of feed stock >15% and <5% has a negative effect on the final RDF quality; perceived the cracks on pellets and break down during storage and transportation. The moisture contents in MSW varied from 60-70% which affect the combustion characteristics and several researcher shifted their attention on RDF combustion. The excessive moisture content of MSW, results in significant poor palletization. Moisture contents between 8-12% in biomass act as binder during pelleting process. So bulking agents are lignocellulosic materials absorbed the moisture content and form van der Waals forces during compaction process (Tun *et al*., 2019). The bulking agents are the material that provides the optimum water contents to waste for palletization. These are commonly fibrous with carboneous material with low moisture contents to provide optimal moisture, lignin and strength to MSW for RDF pellet process. Mudassar *et al.* (2020) explored its generation, treatment, and characteristics of physical/chemical composition and assessed the potential of MSW as a renewable energy source in Lahore, the second largest city in Pakistan. Based on the average generation rate of MSW (i.e., 0.65 kg/capita/day), the daily production of MSW in this city would reach 7150 tons/day. Yousafzai *et al* (2020) demonstrated the self-organizing, low-tech, informal solutions as an alternative energy source which act as a foundation towards cleaner productions and environmental sustainability.

Pelleting is the utmost common and widely spread technology, which compressed the biomass into compact shape without using the binder or any additive under high pressure. These biomass undergoes the process of pelleting when the temperature and pressure simultaneously act upon the material, the cellular structures within the material release lignin, which binds individual particles into a compact unit RDF (Kers *et al*., 2010). However there is little literature available regarding the impact of bulking agents on properties of MSW-RDF because each bulking agent has unique characteristics.

The objective of this study is to determine the effect of bulking agents in the production of high quality MSW-RDF pellets and to investigate the pelleting process parameter effect on bulking agents RDF.

Materials and methods

Feed stock

Lahore metropolitan is the leading city in Punjab, generate a large amount of MSW from urban and industrial areas of city every year. The physical composition of MSW was as Food Waste 45.52 ± 5.47; Wood, Grass and Leaves 15.02±2.11; Paper (Include Tetra Pack) 3.5±1.02; Leather and Rubber 1.05 ± 0.02; Cloth 15.8 ± 3.02; Plastic (Polyethene) 8.69 ± 1.74; Dust, Stone and Ceramics 1.9 ± 0.01; Metals 0.17 ± 0.01; Glass 2.58 ±0.2; Others 5.77 ± 0.7 (Table-I).

The MSW was classified into combustible including wood, fruit and vegetable waste, hotels waste, paper, plastic, textile, synthetic resin and non-combustible waste including metals, stones and glass The MSW (fruit and vegetable waste, hotels waste, paper and wood) has moisture contents 65% and average bulk density 76.4 kg/m^3. The MSW moisture content was not suitable for RDF pellet formation therefore bulking agents (sugar cane trash, rice husk and cotton waste) were used for the reduction of moisture from MSW. Bulking agents were collected from different location, crushed and grinded with biomass grinder. Each material was ground and screen the size less than 1.5 mm. Karpana *et al* (2021) also sued such raw material for energy production.

The moisture reduction level of all bulking agents in different percentages (15%, 25%, 35%, 45%) was determined by adding each bulking agent separately with MSW in plastic container to note the absorption capacity under laboratory conditions for seven days as per guidelines of Iqbal *et al*. (2010).

Description of drawing and pellet development

The Fig. 1 illustrates the execution of the process according to present research. It depicts the passage of raw material; sugar cane trash and other feedstock to make pellets through various steps. The pellet machine of 30 x 30 x 48 inch is mounted on cemented platform with iron stand (9) and iron spacer (8) contains hopper, barrel, screw, die, electric motor (5Hp) and electric heater. The hopper (3) of GI is fixed vertically on the barrel mouth (8 inch) to receive the mixture of composition. The end mouth of hopper (3) opened at the top of barrel. The barrel is a hallow M.S cylinder of 30 inch length and diameter 10 inch retained the stainless steel screw (4) length of 20 inch. The one end of screw is coupled with gearbox (1) and electric motor (2) to control the variables or RPM, whereas on the other end the die (7) of six holes is screwed. The electric heater (6) is coupled on the body of die to heat or dissolved the lignin of biomass and other materials. In addition the water body (5) was used to reduce the temperature of barrel whereas the heater was used to raise the temperature of die for lignin dissolution. The temperature of electric heaters and machine operation was controlled by control panel. It helps to make coherent bonding between particles and reduces the quantity of binder. The mixture of feedstock was charged in the hoper, traveled directly to barrel and pellet machine screw push towards the die with 4000psi pressure produce by gearbox electric motor, eventually RDF pellet of diameter 8 mm was produced. The pellets were produced by applying different temperature 60ºC, 90°C,120ºC and 150ºC on optimized sugar cane trash (45%) best moisture absorption bulking agent and other parameters pressure and die diameter were not changed. Furthermore sugar cane trash 15% and 45% mixture (MSW and BA) were also used for pellet formation and observed bulk density, durability and hardness characteristics of RDF pellets.

Characteristics of RDF Pellets

Size of RDF Pellets

Five RDF pellets were selected from different moisture reduction percentage to determine the length and diameter by using the Vernier Caliper and their average results were reported with S.D.

Proximate ultimate and chlorine contents analysis

The samples of feedstock and RDF were milled, homogenize and determined the moisture (104ºC), ash (550ºC) and volatile matter (950ºC) as per prescribed method of ASTM-2007.

The CHNS (Elementar) was used to determine carbon, hydrogen, nitrogen and sulpher by using the oxidation reduction tubes of CHNS and chlorine contents were determined during gross calorific value (Parr-6200) estimation by adding the 10% solution of $Ca(OH)_2$ for dissolving the soluble chlorine contents and proceeded further as per ASTM-2007. The same procedure was adopted for feed stock and other materials.

Metal analysis

The metal analysis (Si, Al, Fe, Na, K, SO_3 and P_2O_5) of sugar cane trash, rice husk, cotton waste, MSW and RDF pellets was conducted through high tech instrument ICP by acid digestion.

Low and higher heating value

The calorific value or higher heating values of feed stock and pellets were determined by using the Bomb Calorimeter (Parr-6200) three times and average results were reported with standard deviation. The lower heating value was also determined as per ASTM-2007, the hydrogen contents were taken from ultimate analysis.

Bulk density

The bulk density was determined by measuring the volume, mass and dimension according to ASTM-2007 procedures respectively. The pellets were randomly selected from each bulking agent moisture reduction percentage and reported the average results with standard deviation.

Durability

The pellet samples were sieved to remove the fines before analysis of durability. The pellets were (500g) subjected separately in perforated tumbler for the period of 5 minutes to collide at 50 rpm with each other and with hard surface of the tumbler. After completing the cycle of 5 min the pellets were collected separately; reweight and calculate the difference in percentage that depict the durability of pellets (ASABE, 2007).

$$Durability = \frac{mass\ of\ pellet\ after\ tumbling}{mass\ of\ pellet\ before\ tumbling}\ X\ 100$$

Hardness

The hardness of RDF pellets was analyzed with single press unit with hemisphere end rods. The compressive force was applied to the center of cylindrical pellets after placing horizontal on steel plate. The tester speed was 2 mm/min and recorded the maximum force when the pellet break/fracture. The Meyer hardness was calculated by following equation (Lam *et al*., 2011).

$$Hm=F/3.14(Dh-h2)$$

Where h is the indentation depth (mm); F is fracturing force in "N" and D is the diameter of rod in mm.

Statistical analysis

Each physico-chemical characteristics of feed stock and RDF pellets of various trials were analyzed three times and their results were reported as an average along with standard deviation.

Results and discussion

The information collected from the place beneath jurisdiction to determine the proportion (by means of weight) composition of solid waste in summer and winter season. The percent composition of solid waste as food waste, wood, grass and leaves, paper (Include tetra %), leather and rubber, cloth, plastic (polythene), dust, stone and ceramics, metals, glass, others of summer time and winter season common effects has been given in Table I. The percentage of food

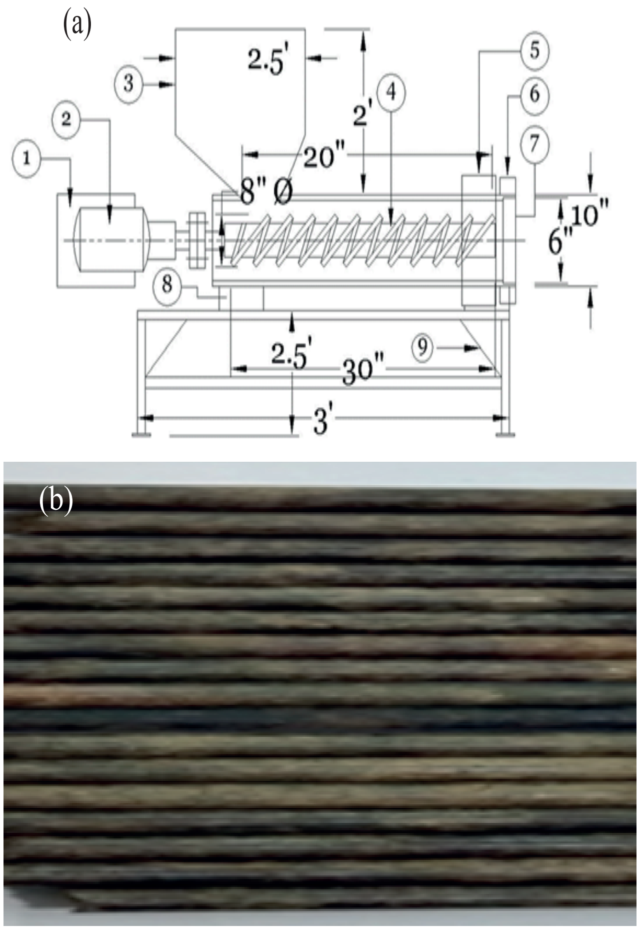

Fig. 1. Diagram of pellet machine and RDF pellets

waste (OW) has now not proven any massive difference in summer, wherein as its average proportion was 45.52% of the overall common waste.

The MSW contained paper (3.5%), leather and rubber (1.05%), cloth (15.8%) and plastic (8.69%). The moisture of MSW (15%) changed into decreased by means of the addition of bulking agent (BA) like rice husk, cotton waste and sugar cane trash. Its elemental composition has effect on physical and chemical characteristics of RDF due to ash produced during its combustion. The mineral fractions contained normally the factors Si, Al, Fe, Na, K, S and P. These elemental compositions vary in quality with the nature of waste (Table. II). It effects on sintering softening and melting temperature of RDF.

MSW contained 65% moisture, which turned into optimized upto 15% through the addition of different BA with various ratios in winter and summer time. Each BA showed the increasing trend in the moisture absorption from the waste, as percentage of BA increases, the DM also increases in both season. Different percentages of BA had proven version in their moisture absorption with the time, but all BA showed the most absorption at 45% addition. Sugar cane trash absorbs greater moisture than rice husk and cotton waste. The contrast of all BA of different ratios in moisture reduction is in Fig 2 a-d. Analysis of variance test additionally summarized the outcomes obtained for all of the experiments. Addition of 15% BA cotton stick, rice husk and sugar cane trash have now not any extensive difference within the moisture reduction results (P-cost 0.230) in summer time while in winter season a minor difference had been discovered. Maximum addition 45% of all BA confirmed the vast distinction within the absorption of moisture (P – 0.001 and 0.021) in each seasons. The addition of 25% BA show the significant distinction in their results in both season (P – 0.5, 0.001) in which as in 35% BA addition confirmed the distinction in summer time but in winter have the equal effect in its, moisture absorption from the waste. As the BA sugar cane trash and rice husk had been observed to offer best with excessive water absorption ability. The optimization time of moisture reduction of sugar cane trash become fourteen days in study time. Cotton sticks had been observed to have lower water absorption capability. Thus restricting their capacity to take in the leachate by the MSW at some stage in moisture absorption. The same observation had been found by Iqbal *et al.* (2010) during the absorption of moisture from solid waste in two different seasons and found the moisture absorption was maximum in summer days.

RDF Pellets durability, hardness, density and calorific values depends upon chemistry of feed stock and process parameters. These process parameters temperature, pressure, retention time, die geometry and speed play an imperative part in the distinctive and quality of RDF pellets. The feed stock moisture expedites the fiber solubilization, starch gelatinization, protein denaturation during the pellet extraction process. The moisture in biomass densification or pelleting act as a binder which increase the contact area between particles and develop the Vander Waals forces and moisture contents between 5-15% produced good quality RDF pellets for long term storage (Iqbal *et al*., 2020; Rezaei *et al.,* 2020).

Table I. Physical characterization of MSW

Type of Waste	Percentage Composition	Units
Food Waste	45.52 ± 5.47	%
Wood, Grass and Leaves	15.02±2.11	%
Paper (Include Tetra Pack)	3.5± 1.02	%
Leather and Rubber	1.05± 0.02	%
Cloth	15.8 ± 5.02	%
Plastic (Polythene)	8.69± 1.74	%
Dust, Stone and Ceramics	1.9 ± 0.01	%
Metals	0.17± 0.01	%
Glass	2.58 ± 0.20	%
Others	5.77 ± 0.7	%

±: S.D of three replicate

Table II. Proximate, ultimate and metal analysis of feed stock and RDF

Parameters	ASTM Method #	MSW	Cotton Waste	Sugar Cane Trash	Rice Husk	RDF
Air Dry Moisture (%)	E-949	9.35±2.68	1.02±0.1	2.23±1.01	4.97±0.01	1.20±0.05
Inherent Moisture (%)	E-949	55.65±3.24	6.42±0.14	7.03±0.29	15.54±2.01	7.25±0.12
Total Moisture (%)	E-949	65.02±2.98	7.56±1.36	9.26±0.9	17.65±1.04	8.49±1.1
Ash contents (%)	E-830	7.68±2.41	2.74±1.02	12.84±1.58	65.01±2.04	16.25±1.21
Volatile Matter (%)	E-897	23.21±1.91	86.66±2.36	65.00±3.58	12.37±1.11	62.12±2.01
Fixed Carbon (%)	--	4.09±0.3	5.18±1.05	15.13±1.05	15.54±1.01	14.38±1.01
HHV (Btu/lb)	E-711	2389.11±5.11	77426.6±3.6	3966.54±3.9	6 399.10±3.25	3325.10±3.65
LHV (Btu/lb)	E-711	1817.09±1.32	7154.16±3.6	3864.56±3.8	5838.10±3.25	3250.93±2.11
Hydrogen (%)	D-5373	7.2±0.01	6.35±0.2	1.03±0.01	5.41±0.02	0.94±0.02
Carbon (%)	D-5373	50.44±3.6	47.26±1.25	47.63±2.05	39.84±1.25	47.76±1.26
Sulpher (%)	D-5373	0.11±0.01	0.28±0.01	0.02±0.01	0.5±0.05	0.11±0.01
Nitrogen (%)	D-5373	0.09±0.01	0.45±0.01	0.12±0.01	0.44±1.05	0.15±0.01
Oxygen (%)	D-5373	42.16±0.01	0.14±0.01	51.2±0.01	36.1 ±1.02	51.04±0.01
SiO_2 (Wt. %)	D-6349	25.11±1.01	82.815 ±6.58	47.11±3.5	92.169 ±1.07	32..11±1.11
Al_2O_3 (Wt. %)	D-6349	6.01±1.58	0.102±0.21	1.65±0.04	0.840±1.03	1.11±0.01
Fe_2O_3 (Wt. %)	D-6349	13.05±0.8	0.704±1.01	0.52±0.01	1.109±1.02	0.68±0.01
Na_2O (Wt. %)	D-6349	13.25±0.03	1.152±0.01	7.74±1.10	0.863±1.04	7.44±0.12
K_2O (Wt. %)	D-6349	0.54±0.00	3.445±1.01	1.01±0.01	2.137±1.02	1.02±0.02
SO_3 (Wt. %)	D-6349	0.0±0.0	7.734±1.01	0.10±0.01	0.561±1.02	0.10±0.01
P_2O_5 (Wt. %)	D-6349	1.11±0.04	3.161±1.05	0.09±0.01	0.324±1.03	0.09±0.01
Chlorine (total) (%)	E-776	0.02±0.01	0.008±0.01	0.05±0.01	92.169 ±0.02	0.02±0.01

±: SD of three replicates (SD: Standard Deviation)

Bulk density had a common role viewed in delivery and storage performance. In addition, bulk density supplied a healthy affect in the form of shipping system, storage and conversion procedure. Among the bulking agent, moisture content at 45% had the lowest value at the same time as moisture content at 15% had the best value of bulk density (Fig. 3 a-c). The bulk density of the pellets became significantly growth with the growth in moisture content materi-al. Similarly, other authors also stated a lower bulk density of 103 -160 and 181-220 kg m^{-3}, respectively, for corn stover and switchgrass. So pellets from sugar cane trash confirmed better bulk density, durability and hardness, which caused reduced transportation prices and enabled simpler coping with proper storage. Adequate storage space is necessary which will preserve massive deliver of RDF suitably in hand.

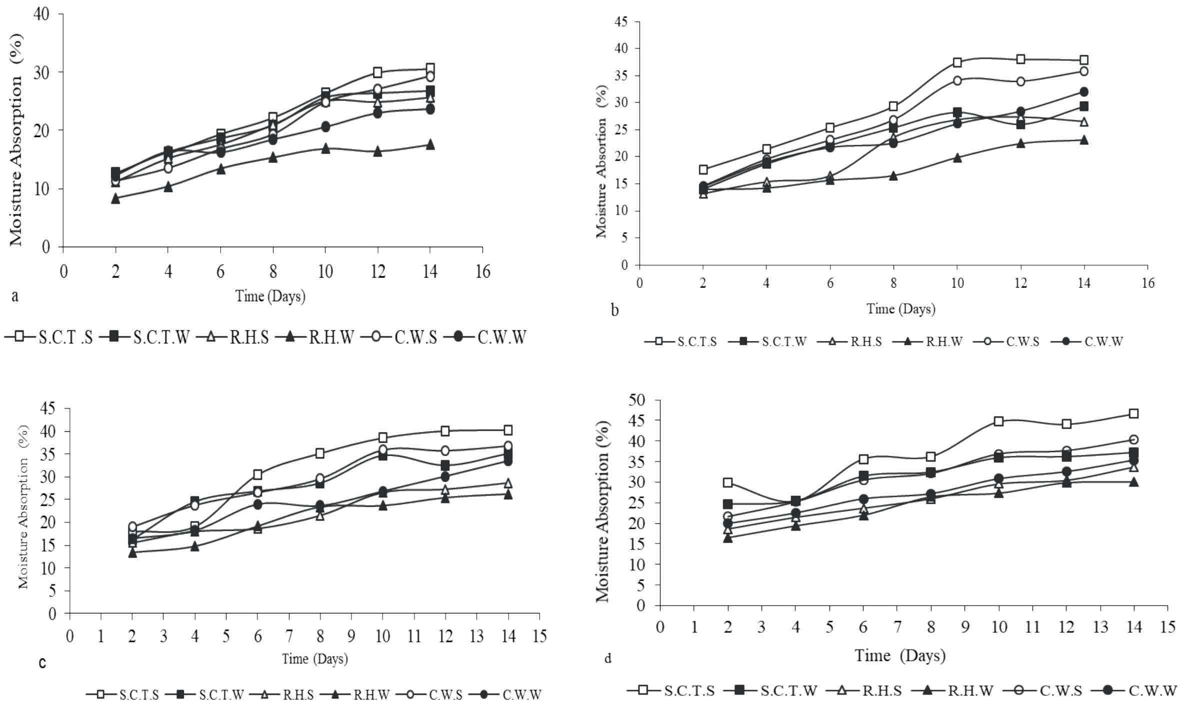

Fig. 2. Effect of bulking agents on reduction of moisture from MSW (a) 15% (b) 25% (c) 35% (d) 45% Sugar Cane Trash (S.C.T), Rice Husk (R.H), Cotton waste (C.W) Summer (S) and Winter (W)

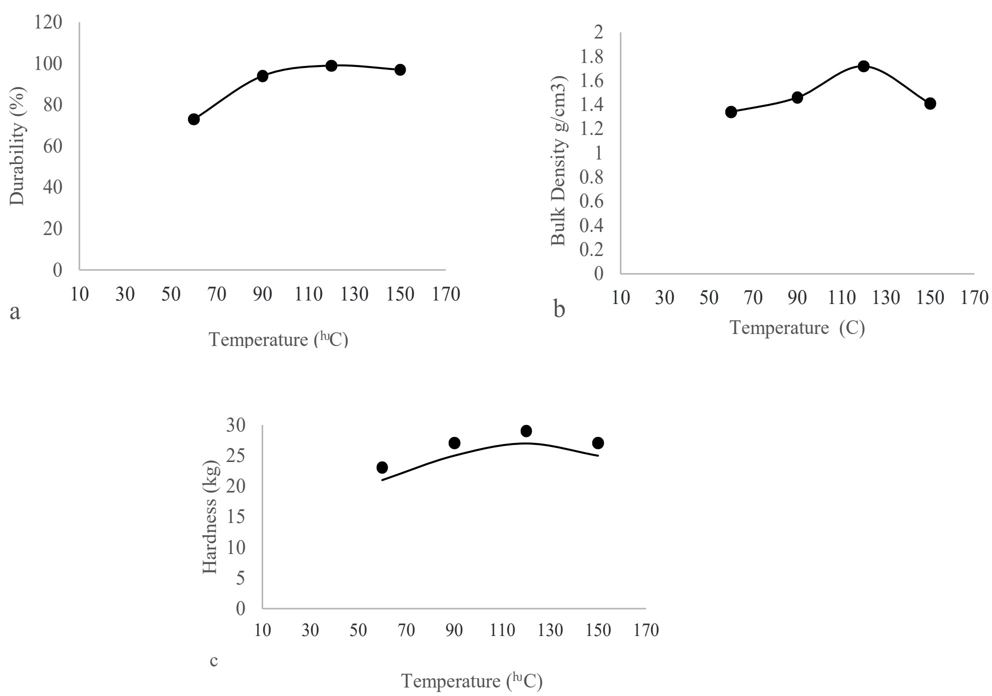

Fig. 3. Effect of temperature on characteristics of RDF pellets (a) durability (b) bulk density (c) hardness

Temperature also impacts on the physical characteristics of RDF pellets because when the temperature increased the material resistance tends to decrease and compaction of material increased. When die temperature 70-120^{o}C raised the water contents of bulking agent and MSW mixture evaporate and lignin contents act as binder for RDF pellet development. In present study DU, BD and hardness increased with temperature increased but bulking agent addition had also showed same results because the highest concentration of water produced the air spaces in material, which was the main hurdle in pellet formation. Moreover the addition of bulking agent reduced the moisture and increase the lignin contents. The lignin contents build a linkage between particles and developed RDF pellets of best quality having DU (99%) and hardness 27 kg (Fig.4 a-c).

Mani *et al*. (2006) observed a similar effect in terms of temperature, where higher temperatures resulted in reduced resistance of the material against an applied load for densification and resulted in better quality of pellets. Smith *et al*. (1977) in their article on briquetting of wheat straw, found that for a given pressure at temperatures between 60–140°C, the degree of compaction and dimensional stability were higher. They also concluded that the expansion of the briquettes was less when the die temperature was between 90 and 140°C. The same authors observed that briquettes were surface charred and slightly discolored at temperatures above 110°C due to chemical degradation.

It was also observed in study when the temperature of die increased up to 150^{o}C the product showed the soot during pelleting process. It impacts on the RDF physical characteristics like hardness, bulk density, durability and GCV. The same observation has been found by Rhen *et al.* (2005).

Tang and Lee (2009) used the glass transition temperature behavior of the biomass to understand the densification behavior. Glass transition temperature was found to be inversely related to moisture content. Their studies included three different temperatures: two within the glass transition temperature (75 and 100°C) and one outside (150°C). The durability values of the densified biomass outside the glass transition temperature were lower compared to ones within the range.

Conclusion

The experimental work conducted to reconnoiter the efficacy of bulking agents for the development of RDF pellets from MSW. It was found that as the quantity of bulking agent

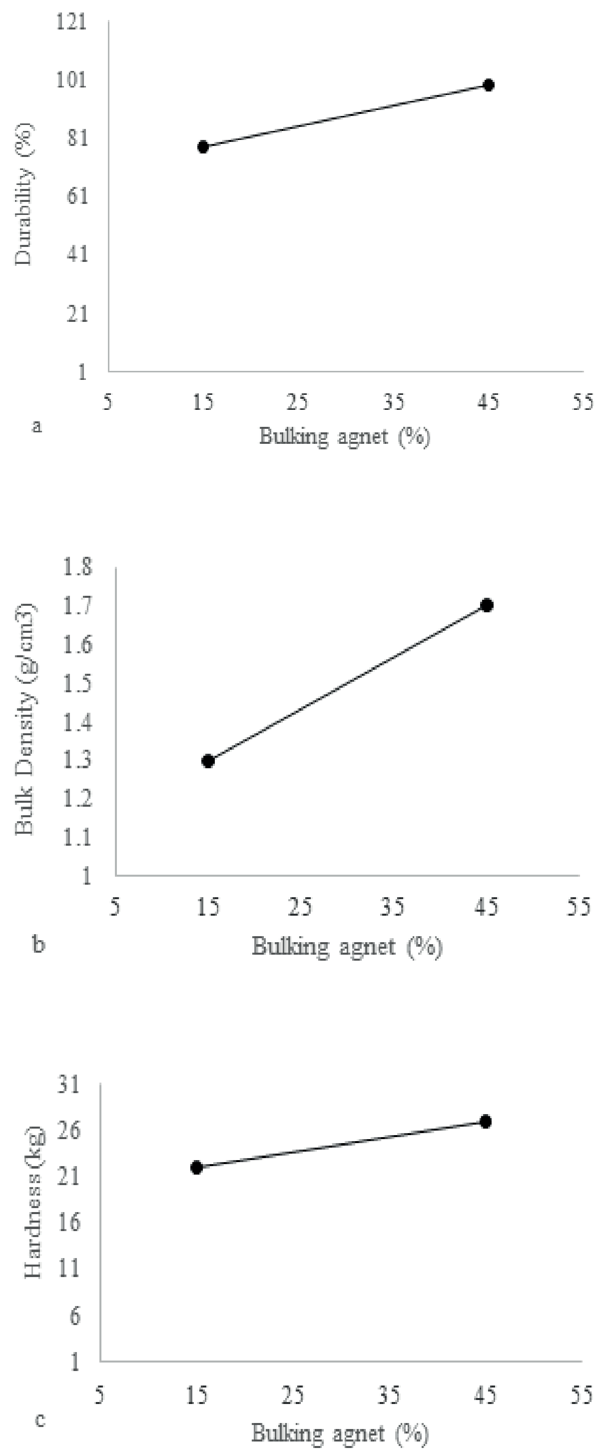

Fig. 4. Effect of bulking agent on characteristics of RDF pellets (a) durability (b) bulk density (c) hardness

increased the moisture concentration of MSW decreased (15%) whereas BD, DU, hardness values increased and significant correlation also inspected between these physical properties. Furthermore die 120°C temperature is optimum for pellet formation but as temperature increased between 140-150°C during pelleting process, the biomass exhibited smoke, which deceased the BTU of RDF pellets. The results of present study are useful to optimize conditions for development of RDF pellets from different waste in future. This technology is applicable to remote areas of under developed countries for use as an alternative energy source.

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