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Chemical Analysis of DG Cement's Municipal Waste Used for Refuse Derived Fuel

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Abstract

Purpose: Rampant population growth particularly in South Asian region has turned solid waste management a challenging task. Huge resources are squandered for collection and disposal without considering the recyclable and energy potential. However, in Pakistan, some companies are utilizing waste as refuse derived fuel (RDF) – a process to separate combustibles from municipal waste in order to generate energy.

Methodology: For RDF analysis, DG cement RDF plant near Lakhodair landfill site Lahore was selected in order to collect RDF raw waste, which are then converted in to RDF pellets for further analysis. The chemical analysis consisted of proximate analysis (moisture content, volatile combustion matter, fixed carbon & ash content) and net calorific value (NCV) along with heavy metal analysis.

Findings: Upon analysis, percentage of volatile combustible matter (VCM) tetra pack and jute was about 84% followed by other waste and thermo-pole 78%. Fixed carbon (FC) of wrappers and paper waste was about 24 and 16% whereas Ash content (AC) was recorded highest in textile, shoppers, thermos-pole and foam with 14% while rest 10%. The moisture content (MC) of other waste type followed by shopping bags and jute was found highest among other component such as 3.5%, 24% and 20.9% respectively. Moreover, the highest calorific value was obtained in plastic wrappers (61.26 MJ/kg) whereas lowest was observed in jute (6.4 MJ/kg). For heavy metal analysis such as Chromium (Cr), Lead (Pb), Cadmium (Cd) and Copper (Cu), Atomic Absorption Spectrophotometry (AAS) was used; highest concentration of copper was observed in the foam waste (45.5 mg/kg) and the lowest value was observed in thermos-pole (8.5 mg/kg). All the results were in EURITS standards range.

Recommendation: Therefore, in the light of above analysis, it was confirmed that collected waste is highly feasible for RDF in DG cements.

Keywords: *Refuse derived fuel, atomic absorption spectrophotometry, calorific value, moisture content, heavy metals.*

1.0 Introduction

Over the decades, living pattern has drastically changed owing to technological advancement and population growth. The rapid population growth has already threatened the natural resources. All these parameters have made solid waste management a global issue across the world (Sharholy et al., 2007; (Ilaboya, 2011). Any useless or unwanted material obtained from households, industries and other commercial establishment and has ability to witness harmful impact on near surrounding and living organism is termed as solid waste (Wikener, 2009; Ali et al., 2015; Govindaraju, 2011). In developing countries particularly in Asia, its management is still neglected owing to lack of expertise (Berkun et al., 2015). Urbanization is in full swing and people prefer to move in cities and over half of population would be living in cities by 2050 and generating massive amount of waste and experience health hazards (United Nations, 2012). Similarly, insufficient capacity and resources turn in to serious health and environmental implication (Majid et al., 2012).

In the preceding years, there has been a growing social mindfulness in respect of environmental issue associated to the waste by tempting the rise of several proposal to threat the waste in a sustainable way (Cremiato et al., 2018).There is no doubt that converting the waste into energy is a sustainable approach that not only decreases the amount of waste generated but also reduces the harmful impacts on environment as well as on human health (Saeed et al., 2009; Yang et al., 2012 ; Akdag et al., 2016). It is pertinent to mention here that climatic conditions and seasonal changes play significant role in composition of solid waste and its properties in terms of incineration, biogas production and as alternative fuel (Gómez et al., 2009; Khajuria, 2010). Waste composition is also influenced by income level (Oyelola & Babatunde, 2013).

Moreover, apart from these methods, alternative fuel production is another way of managing solid waste. The most common among others is Refuse Derived Fuel (RDF), which is obtained from Municipal Solid Waste (MSW). It's being used for decades, which not only reduces the volume of land and waste but also reaping rational results for environment (Rotheut & Quicker, 2017). There is no doubt that high energy value of RDF makes it well-compatible with the fossil fuels (Gallarado et al., 2014). When compared to other natural fossil fuels, it is found that pellets of RDF samples contains high moisture, high ash content, high proportion of volatile matter but low fixed carbon (Akdag et al., 2016). In Portugal, as in other countries, it is estimated the use of RDF in direct combustion or co-combustion systems, namely in the cement manufacturing, paper and pulp mills or in thermoelectric power plants, keeping in mind the principle of proximity manufactures-users.

The recovery of energy from these fuels is also possible through the syngas production by gasification, but even in this process, ways to reduce moisture and increase the heating value should be followed (Bras et al., 2017). Previous authors reported the use of waste separation and subsequent pyrolysis in order to produce pyrolysis liquids comprises of carbon dioxide (CO_2) hydrogen (H_2), carbon monoxide (CO) and methane (CH_4). Some of the researches showed that they removed the food waste fraction from the MSW and the quality of the RDF was improved (Lopes et al., 2018). Refuse derived fuel (RDF) is a treated form of MSW where noteworthy size reduction, screening, sorting, drying and glass separation. In some cases, pelletization is achieved to expand the handling characteristics and configuration of the material to be fed to a gasifier. Even though there is no standardized method with a required number of pre-processing steps, a selection of these processes alters the composition of the waste by reducing the metal, glass and moisture content of the discarded portion and enhancing the volatile content of the RDF, thus, making it more homogeneous feedstock in relative terms (Aluri et al., 2018). The RDF which is made up from municipal solid waste is termed as RDF-5 (Sharholy et al., 2008). During an experiment in Turkey, net potential values of RDF and petroleum coke were studied. It was noticed that carbon monoxide in coke was higher while RDF has less carbon and sulphur dioxide (Akdag et al., 2016).

The term RDF as a rule alludes to the isolated high calorific value of handled MSW. In the European Union, it is assessed that the aggregate sum of RDF created from MSW is around 45 million tons every year (Grau & Farre, 2011). The principle focal points of utilizing RDF as an alternative witnesses ecological advantages from strong waste pre-arranging, enhanced incinerator execution, and the immediate incomes from reused materials (Chen et al., 2015). The present research was done to observe the potential of pellets of RDF made from municipal solid waste in the Lahore City. The purpose is to optimize the use of conventional fossil fuels by utilizing waste as a source of energy. It can also help to cope with the energy crisis. Other techniques such as landfilling and incineration naming a few gave become outdated because they emanate NOx, SOx, ash, carbon dioxide, particulate matter and leachate as a product to environment. The objectives of the study were:

i. To assess the possibility to obtain RDF from the solid waste of Lahore.
ii. To analyze the calorific potential of waste being used as RDF.
iii. To quantify and characterize feedstock by estimating proximate analysis of each component.
iv. To evaluate quality of feedstock components through the heavy metal analysis respectively.

2.0 Materials and Methods

2.1 Study Area

The selected site was DG cement's RDF plant located near Lakhodair Landfill site, Lahore. Waste after passing through various stages transported to DG cement industry, Kalakahar where it is used as alternative fuel in cement rotary kilns.

2.2 Methodology

The RDF sample was collected from RDF plant and transported to College of Earth & Environmental Sciences (CEES) laboratory, University of the Punjab. Through segregation, the waste was divided into nine components i.e. papers, shoppers, tetra packs, thermos-pols, jute, textile, foam, wrappers and other organic waste. To find out the moisture content, each component was then oven dried and shredded in to pallets subsequently. For the Gross Calorific Value (GCV), bomb calorimeter was used heavy metal were analyzed through Atomic Absorption Spectrophotometer (AAS).

2.3 Sampling Instruments

The sampling instrument used throughout the research is weighing balance (Model No. GE 7101), Muffle Furnace (Model No. ECF2) for proximate analysis, Drying oven (Model No. ULE 400), local assembled shredder, local assembled lab scale pelletizer, Bomb calorimeter (Model No. LECO AC 500) and Atomic Absorption Spectrophotometer (AAS).

2.4 Chemical Analysis

i. To determine the chemical composition of the samples, Proximate Analysis **and** Gross Calorific Value (GCV) methods were used.

ii. For metal analysis, Atomic Absorption Spectrophotometer (AAS) was used.

2.4.1 Sample Preparation

The samples were prepared to carry out proximate analysis and gross calorific value according to the following procedures:

i. **Oven Drying:** The segregated components were oven dried at 1050C for 24 hours in drying oven (Model: ULE 400) to remove the moisture.

ii. **Cutting & shredding:** The components of waste which were large in size, like textile and few shopping bags were first manually cut with scissors before putting them into the local assembled shredder. The samples were shredded into small pieces and the samples were put into the air tight bags and converted into pallets.

2.4.2 Proximate Analysis

In proximate analysis, moisture content, volatile combustion matter, fixed carbon and ash content of the waste was observed. The process was done using drying oven & muffle furnace. These analyses were done according to ASTM standard procedures. These standards include.

i. Moisture content: ASTM E 949-88 (Standard Test Method for Total Moisture in the Analyses Sample of Refuse Derived Fuel)

ii. Volatile Matter: ASTM E 897-88 (2004) (Standard Test Method for Volatile Matter in the Analysis of Refuse-Derived Fuel)

iii. Ash content: ASTM E 830-87 (2004) (Standard Test Method for Ash in the Analysis of Refuse-Derived Fuel)

Moisture Content: The moisture content of the samples was found according the Standard test Method "ASTM E 949-88". The following formula was used to determine the moisture content in percentage: **% moisture Content = [(Wet weight – Dry weight)/ Wet weight] × 100**

Volatile Matter Content: About 5g of the dried waste is kept in the muffle furnace at 950^{o}C for 30 minutes to find out the volatile matter content. The waste in crucible china dish, covered with the lid. After burning, waste turned in to ash. The following formula was used to determine the Volatile Matter Content in percentage: **% volatile matter = [(Dry sample weight – Ash weight)/ Dry sample weight] × 100**

Ash Fixed Carbon Content: The residue left after heating the dried samples in the muffle furnace represents the ash content. The following formula was used to determine the fixed carbon content in percentage: **% Fixed Carbon = 100- weight (% moisture content + % ash + % volatile matter)**

2.4.3 Gross Calorific Value (GCV):

The calorific Value of the RDF pellets was identified using Bomb Calorimeter (LECO AC 500). The process was done using the ASTM standard "ASTM-E 711-87 (2004).

2.4.4 Heavy Metal Analysis

To carry out heavy metal analysis, initially acid digestion of the samples was carried out by using nitric acid. EURITS Standard Limits were followed during the process.

3.0 Results and Discussion

This section includes the proximate analysis, heavy metal analysis and gross calorific values to analyze the potential of RDF Pellets from RDF samples of DG Cement, near Lakhodair Land fill, Lahore.

3.1 Composition of the MSW from the RDF Sample

The first step of the study was to identify the components of the waste and their quantity. The amount of each component including wet weight and percentage by weight is given in table 1.

Table 1: Percentage by weight of components

S. No.	Components	Wet weight	Percentage by weight
1	Thermo-pol	118.5	0.62
2	Hard plastic	739.7	3.9
3	Tetra pack Waste	956.5	4.89
4	Jute waste	762.9	3.97
5	Wrappers	1739	9.04
6	Diapers	3759.5	19.56
7	Foam	128	0.67
8	Paper	34.8	0.19
9	Ceramic	76.5	0.4
10	Textile	3024.4	15.7
11	Shopping bags	3826.8	19.9
12	Other organic waste	4057	21.1

3.2 RDF Pellets Formation

Before the proximate and heavy metal analysis the pellets from each component of MSW were formed. Hydraulic press, pelletizer was used for pellet formation. Among 12 components, some of the pellets pictures are shown below.

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(a) (b) (c)



(d) (e) (f)

(g)

3.3 Proximate Analysis

After segregation of sample in to nine components, the proximate analysis in the light of ASTM standards that includes moisture content (MC), volatile combustion matter (VCM), fixed carbon (FC) and ash content (AC) was carried out. The results are shown in table 2.

Table 2: Proximate analysis of components

S. No.	Components	%VCM	%F.C	%Ash Content	%M.C
1.	Paper Waste	75.4 ± 0. 54	15.9 ± 0.12	8.03 ± 0.25	10.7 ± 0.32
2.	Shoppers	76.8 ± 0.24	11.09 ± 0.9	9.67 ± 0.42	5.6 ± 1.14
3.	Tetra pack	83.4 ± 0.61	11.7 ± 0.32	3.67 ± 0.42	16.43 ±0.55
4.	Thermo-pol	77.5 ± 0.52	11.3 ± 0.71	10.43± 0.51	21.5 ± 0.55
5.	Jute	83.2 ± 0. 82	9.4 ± 0.62	5.77 ± 0.25	30.93 ± 0.4
6.	Textile	69.3 ± 0.74	15.8 ± 0.2	8.2 ± 0.26	17.88 ± 0.4
7.	Foam	71.09 ± 0.9	17.5 ± 0.52	10.4 ± 0.4	18.6 ± 0.44
8.	Wrappers	69.7 ± 0.32	23.4 ± 0.62	6.03 ± 0.15	26.9 ± 4.8
9.	Other waste	81.3 ± 0.71	9.2 ± 0.84	7.9 ± 0.3	14.8 ± 0.55

VCM= Volatile Combustion Materials

F.C= Fixed Carbon

M.C = Moisture Content

The analysis of the waste sample has shown that the major portion MSW is other waste i.e 21.1% which includes yard waste, dust, sand and stones, also have lower moisture content up to 14.8%. However, among other components, the highest value of moisture content was found in jute i.e. 30.93 ± 0.4. The moisture content values of other organic waste (14.8 ± 0.55), tetra pack (16.43 ± 0.55), textile (17.88 ± 0.4) and foam (18.6 ± 0.44) were relatively close to each other. The lowest value 5.6 ± 1.14 was found in the shopper waste. While Kalanatarifard & Vang, (2012) showed percentage of moisture content similar to the current study for most of the components.

The highest volatile combustion matter was found in tetra pack (83.4 ± 0.61) and jute (83.2 ± 0. 82). Both had the same values. While, the paper waste (75.4 ± 0. 54) shopper waste (76.8 ± 0.24) and Thermo-pol (77.5 ± 0.52) had the similar values. According to Manya et al (2011), the moisture content and ash content of thermos-pol is 7% and 2.35% respectively, which is lower than the percentages observed in current study i.e. 21.47% and 10.43% respectively. The textile (69.3 ± 0.74) and wrapper (69.7 ±0.32) waste had shown comparatively lowest VCM values. The wrapper waste showed the highest amount of fixed carbon i.e. 23.4 ± 0.62. Shopper, tetra pack and Thermo-pol waste showed 11.09 ± 0.9, 11.7 ± 0.32 and 11.3 ± 0.71 of fixed carbon respectively. The lowest amount of fixed carbon was found in jute i.e. 9.4 ± 0.62. The ash content was found more in textile waste i.e. 8.2 ± 0.26. Shopper, Thermo-pol and foam waste showed same amount of ash content i.e. 9.67 ± 0.42, 10.43 ± 0.51 and 10.4 ± 0.4 respectively. Lowest ash content was showed by tetra pack waste i.e. 3.67 ± 0.42. It's obvious that Higher the amount of the VCM, higher will be the production of gas and better it can be used as an alternative fuel (Sarc & Lober, 2013).

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3.4 Heavy Metal Analysis

Heavy metals get through municipal solid waste stream remain unchanged which may harm the environment and human health in many ways. Heavy metals are emitted into the environment due to the burning of MSW. So, there should be proper controlled emission conditions. Many physical; and chemical methods can be adopted to reduce the mobility of heavy metals in the environment. Heavy metal analysis of the samples was carried out by using Atomic Absorption Spectrophotometry. Four metals were analyzed i.e. Chromium (Cr), Lead (Pb), Cadmium (Cd) and Copper (Cu). The results of the analysis are given in figure 1.

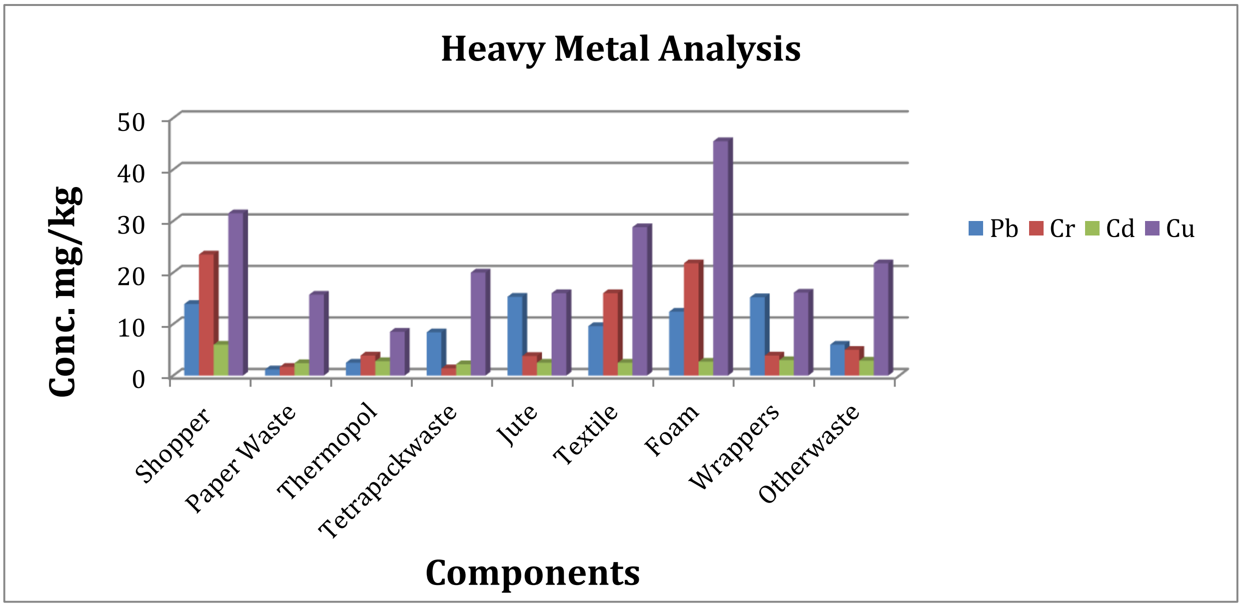

Figure 1: Heavy metal analysis

It was observed that the concentration of copper, as compared to the other heavy metals, was higher in all components of the waste sample. But these exceeded values were below the standard limits. The highest concentration of copper was observed in the foam waste i.e.45.5 mg/kg and the lowest value was observed in Thermo-pol i.e. 8.5 mg/kg. A very small amount of cadmium was detected in the components of the waste. The highest concentration of cadmium among all was found in shopping bags that was 6 mg/kg. The other components like paper waste, Thermo-pol, tetra pack, jute, textile, foam, wrappers and other waste had values that were very close to each other i.e. 2.4 mg/kg, 2.8 mg/kg, 2.2 mg/kg, 2.5 mg/kg, 2.5 mg/kg, 2.7 mg/kg, 3 mg/kg and 2.9 mg/kg respectively. Shopper waste had showed highest concentrations of chromium among all i.e. 23.5 mg/kg. The concentration of chromium in foam is 21.8 mg/kg. The lowest concentration was observed in tetra pack waste i.e. 1.4 mg/kg. The values of chromium heavy metal in the waste were also below the standard limits.

3.5 Net Calorific Value

Each component has different energy content due to the change in properties. The highest calorific value was showed in plastic wrappers i.e. 61.26 MJ/kg while the lowest calorific value was observed in jute i.e. 6.4 MJ/kg. Thermo-pol showed the value which was close to the plastic wrappers i.e. 57.1 MJ/kg whereas the NCV of other components are shown in figure 2.

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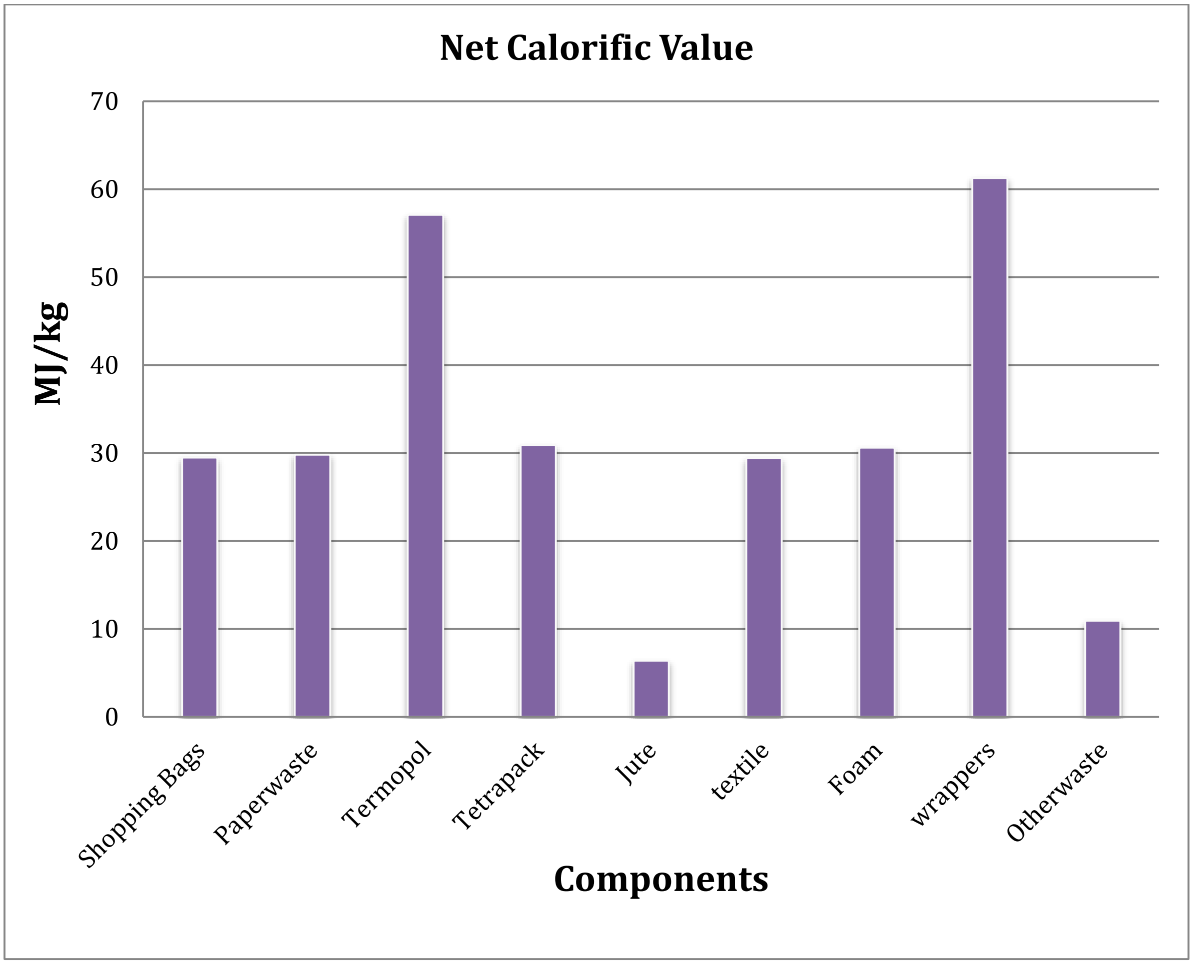
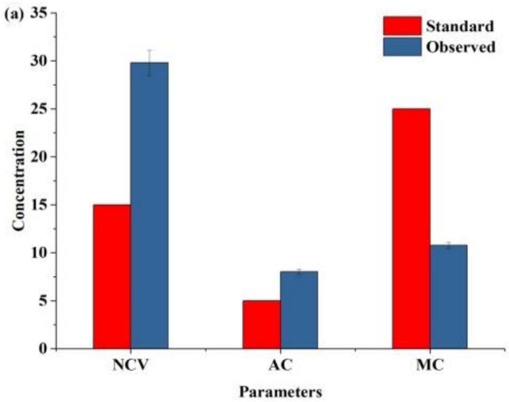


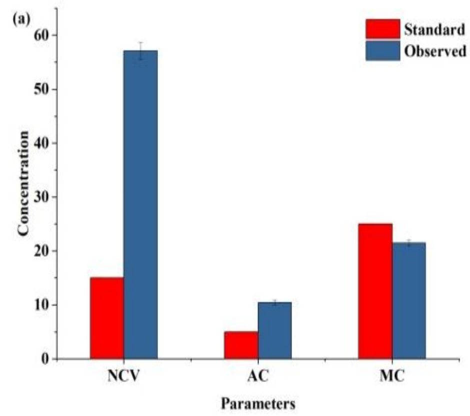
Figure 2: Net calorific value

3.6 Quality Characterization of RDF

The quality analysis of the RDF pellets was carried out graphically. The observed values were compared with EURITS standards. The comparisons done through graphs reveal that the RDF quality parameters of Shopper waste: NCV (29.5±1.33 MJ/kg), AC (9.67±0.42%) and MC were in accordance with the EURITS standards. Similarly, Paper waste, quality contrasts of the NCV (29.8±1.31 MJ/kg), AC (8.03 ±0.25%), MC (10.77±0.32%) also complied with the EURITS standards. The values of NCV (57.1±1.58 MJ/kg), AC (10.43±0.51%) and MC of Thermo-pol waste, all found within the acceptable limits of EURITS Standards. The characteristics of the tetra pack were observed as NCV (30.9±1.75 MJ/kg), AC (3.67±0.42%) and MC (16.43±0.55%) respectively. The Jute gave slightly greater moisture content (30.93±0.4%) value when compared with the EURITS standards while; the remaining results gave suitable values. The observed values of NCV and AC are (6.4±1.32 MJ/kg) and (5.77±0.25%) respectively. The concentration of NCV (29.4±0.25 MJ/kg), AC (8.2±0.26%) and MC (17.88±0.4%) in textile waste were within the allowed limits of EURITS standards. Foam waste gave the values as NCV (30.6±1.7 MJ/kg), AC (10.4±0.4%) and MC (18.4±0.7%) respectively while wrappers gave NCV (61.26±0.34 MJ/kg), AC (6.03±0.15%) and MC (26.93±4.82%). All the results were in range of EURITS standards.


(a)
Standard
Observed
Concentration
Parameters
NCV
AC
MC

(a)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Standard
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Concentration
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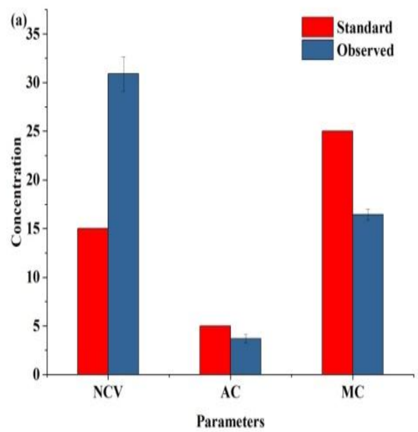
NCV
AC
MC

(b)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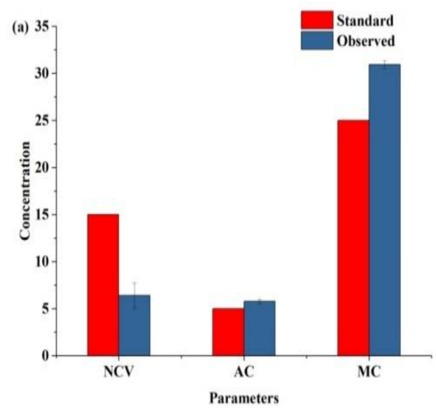
AC
MC

(c)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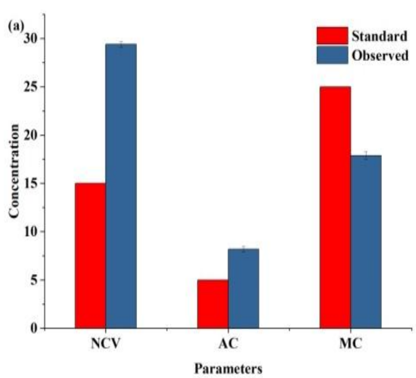
NCV
AC
MC

(d)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Concentration
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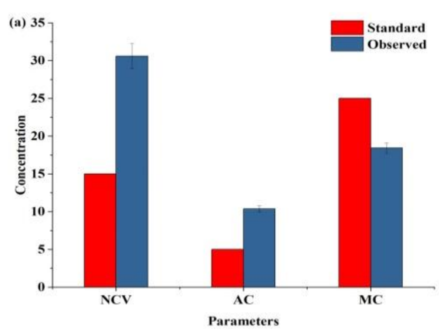
NCV
AC
MC

(e)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Concentration
Parameters
NCV
AC
MC

(f)

4.0 Conclusion

In the light of study and different methods, it's concluded that MSW sample collected from D.G cement RDF plant was suitable enough to produce fine quality RDF. Among nine components of MSW, Jute and Tetra pack showed greater VCM whereas wrappers showed the highest calorific values. Moreover, heavy metal analysis manifests that concentration of all the metals is within EURITS standards range. The RDF produced by the DG cement is not much harmful to environment but it saves landfill, health and environmental cost. However, it's highly recommended to transport waste in closed container. While handling waste at RDF plant, workers must wear appropriate personal protective equipment (PPE). Frequent training and monitoring would surely reap long term fruitful outcomes.

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