Quality Assessment of Refuse Derived Fuel Produced from Municipal Solid Waste of Ravi Town, Lahore

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Abstract-The present study aims to convert municipal solid waste (MSW) reject into refuse derived fuel (RDF) and estimate its quality by physical and chemical analysis. A model was set for all four seasons of the year (spring, summer, autumn, winter). A sample of 30,000 kg of MSW was investigated to project combustibles (162.14 tons/day) used for RDF production. The samples were shopping bags (SB) (38.45 %), textiles (TX) (23.56 %), paper and cardboard (PC) (17.29 %), other combustibles (OC) (12.51 %), *polyethylene terephthalate* (PET) bottles (4.86 %), tetra-pack packaging (TP) (2.69 %) and other plastic (OP) (0.63 %). The results of the ultimate and proximate analysis of the RDF samples were in the favour of the RDF production with high volatiles and lower ash contents. Plastic polymers showed highest volatile matter (93.64±1.32 % to 81.61±8.06 %). C/H ratio was found maximum for PET (14.77±0.23) followed by TX (11.5±73.97). Chlorine content was negligible that also reduced the potential damage risk to the RDF processing equipment. Net calorific value, moisture content, ash content, chlorine content, sulphur content, mercury, arsenic, cadmium, nickel, lead, copper and chromium complied EURITS RDF standards. Through this study it is established that production of RDF addresses the MSW management problems sustainably.

Keywords-municipal solid waste, refuse derived fuel, RDF quality standard, major combustibles, RDF potential, RDF projection, RDF pellets, Ravi Town Lahore Pakistan.

I. INTRODUCTION

The population explosion, services to compete with the modern technology and the rapid trend towards urbanization have resulted in many environmental concerns. The current generation is deeply concerned about the constant depletion of natural resources to meet their needs and the rising trend in different types of the wastes. Solid waste (SW) is one of its kind, dealing mostly with wastes that are solid or semi-solid in nature. Municipal solid waste (MSW) is an important branch of SW that is produced from residential, commercial and institutional areas. This type of waste includes food waste, rubbish, ashes, construction and demolition waste and occasionally special waste. It is the integral part of any society [i]. Development of international markets for packaged goods and foods have also dramatically added to the global MSW problems in the past years.

In developing countries, MSW is increasing exponentially with the passage of time posing a huge threat to the environmental conditions. Ground and surface water contamination, outbreak of plagues, greenhouse effect, air and land contamination and many more related issues need to be addressed due to the improper municipal solid waste management (MSWM). Many human diseases like cholera, diarrhoea and lung infections are attributed to poor MSWM [ii, iii]. Contemporary, landfill gas is one of the key greenhouse gases (GHGs) resulting in atmospheric pollution and climate change [iv-vi].

One of an attractive option to deal with the ever increasing environmental pollution and MSW, is to transform this into refuse derived fuel (RDF). The waste derived fuels (WDF) are considered to be the resource drawn from solid waste that has potential to transform into energy without producing threat to the environment. The term RDF is mostly used for MSW that has undergone some kind of process resulting in increased calorific value. In many European countries RDF is used as an alternative fuel [vii].

Principally, RDF constitutes the combustible portion of MSW, e.g. paper and cardboard, different types of plastics, textiles, etc. The waste is shredded and transformed into pellets using a variety of pelletizing machines using heat, temperature or both. Since, there is a seasonal, spatial and temporal variation among the MSW statistics, it is very important to know the RDF quality of the region under consideration. The RDF quality is mainly dependent on the energy content of the feedstock and lesser the moisture content higher will be the derived energy [viii].

Thesaurus on resource recovery terminology explains, there are seven types of RDF according to ASTM STP 832-EB [ix] as given in Table I. Solid waste without any treatment is itself a fuel, but it has a higher energy value of about 4000 kcal/kg when processed into RDF [x, xi]. The most frequently used RDF type is RDF-5 that is in the form of pellets [xii]. In general, RDF is concocted from the combustible fraction of MSW that is capable of subjecting to thermal treatment and drawing energy from it.

TABLE I
RDF CLASSIFICATION ACCORDING TO ASTM STP832-EB

RDF-1	Wastes used in as discarded form.
RDF-2	Wastes processed to coarse particle size with or without ferrous metal separation such that 95% by weight passes through a 6 in square mesh screen, namely Coarse RDF.
RDF-3	Wastes processed to separate glass, metal and inorganic materials, shredded such that 95% by weight passes 2 in square mesh screen, namely Fluff RDF.
RDF-4	Combustible wastes processed into powder form, 95% by weight passes through a 10 mesh screen (0.035 in square), namely Powder RDF.
RDF-5	Combustible wastes densified (compressed) into the form of pellets, slugs, cubettes or briquettes, namely RDF slurry.
RDF-6	Combustible wastes processed into liquid fuels (Pyrolysis), namely RDF slurry.
RDF-7	Combustible wastes processed into gaseous fuels (Gasification), namely RDF syngas.

Source: [ix].

Recycling and composting activities divert the MSW from the landfill, but a huge amount of waste rejects end up there. It is very important to know the prospects of resource in the rejected waste. The MSW processing into RDF is most commonly used for waste to energy purposes. This process also helps to reduce the volume of waste and handling is made easy. The heating value of MSW is 6-14 MJ/kg and its global energy potential estimate is considered to be 13 to 30 EJ by 2025 and conversion of MSW to RDF increases the calorific value [xiii]. Since, it is heterogeneous in nature, it may be hazardous or non-hazardous, Thus, there exists a need to investigate the physical and chemical nature of the waste to seek its potential to be used as a resource. The RDF standards vary from country to country. Currently, the European standards (CEN 343) are considered to be the most relevant standards of the time [xiv].

The major utilization of RDF is in the industrial sector. The industrialized countries are mainly concerned about the quality of RDF that is produced from MSW or its reject. It needs to follow two basic rules: (1) ensure the protection of the processing equipment; and (2) the final product should be environmental friendly. To estimate the RDF potential, it is very essential to know its physical, chemical and thermal behaviour [xv]. These properties need to follow environmental specifications defined by some standards. Few industrialized countries like Finland, Germany and Italy have developed their own RDF standards. In Germany the RDF standards are governed by RAL-GZ [xvi]. Physical and chemical properties are categorized by medium and high quality RDF, in Italy and regulated under UNI 9903 [xvii]. SFS 15358 [xviii] is the governing technical standard in Finland that defines three levels of quality assessment for all parameters. Other European countries like UK, Spain and Switzerland give RDF standards specifically for combustion or co-combustion in cement kilns. These standards are administrated by the European Association of Waste Thermal Treatment Companies for Specialized Waste [xix]. It is to be noted that the RDF standards for the use in cement kilns are more stringent than the other ones [xx].

Cement Industry is one of the developed sectors in Pakistan. There are twenty nine cement plants producing a total of forty four tons of cement annually contributing significantly to the gross domestic product (GDP) [xxi]. Similar to the European countries, Pakistan has also developed guidelines for processing and using RDF in Cement Industry [xxii]. Millions of tons of MSW is dumped on the land as a reject. Somewhat, the energy generation through MSW fabricated RDF may be a better option than throwing into the dumps. Keeping in view, the energy crises in Pakistan, foreign investors have signed an agreement to invest 10 million Euros to build RDF plant in Rawalpindi [xxiii]. The Fauji Cement Company Ltd. (FCC), is the pioneer to set a RDF plant in Pakistan with a capacity of 10 tons/hr using MSW. Furthermore, Cherat Cement Company, DG Khan Cement Company Ltd. and Best Way Cement are next on using RDF as a resource. These studies indicate that there is a room for research to use RDF in other sectors of Pakistan for energy production.

The aim of this study was to develop an efficient and beneficial municipal solid waste management system for *The Ravi Town, Lahore, Pakistan,* as a case study. Explicitly, the conversion of combustible MSW components into RDF and its evaluation in compliance with the available RDF standards was also in focus.

II. MATERIALS AND METHODS

A. Study Area

Lahore is the second largest city of Pakistan. It is the capital city of the most populated province of Punjab. The Ravi Town is at the entrance of Lahore, situated in its North and subdivided into 19 Union Councils (UCs). It has a total population of 1156218 approximately, representing middle and lower income groups. The total area of Ravi Town is about 30828668 m^2 with almost 320000 households. A total quantity of 849 tons (approximately) of solid waste is being brought forth daily, dumped at the Saggian dump site. The 19 UCs are further divided into three administrative Zones; (1) Zone 1: Shahdrah and adjoining areas; (2) Zone 2: Badami Bagh and adjacent areas; and (3) Zone 3: Walled City of Lahore [xxiv]. The mentioned conditions indicate that the Ravi Town exhibit the lowest economic conditions with the highest population among the other towns in Lahore. Previous studies have clearly explained that the quantity and quality of the MSW increases with the income levels [iii, xxv]. Thus, if the results of this study prove to be significant, MSW statistics of the Ravi Town may be taken as an example. The models and examples are set for the worst of the conditions to optimize the best SWM technique available. The geographical information system (GIS) population map of the Ravi Town is given in Fig. 1.

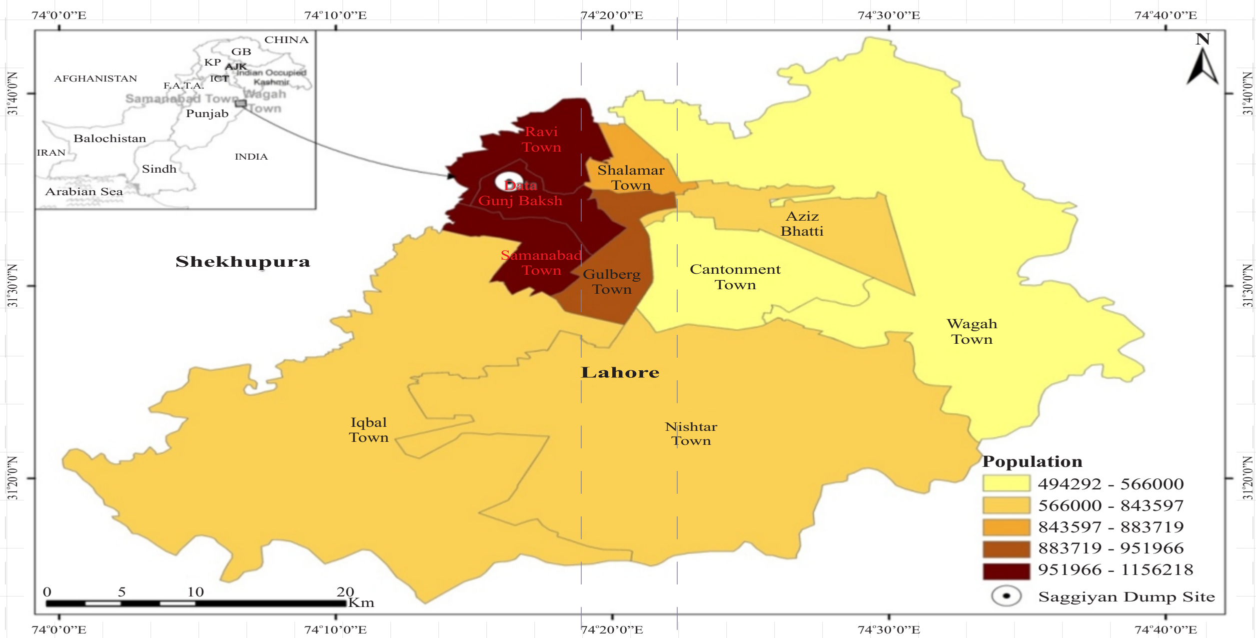


Fig. 1. GIS map of the sampling area

B. Compositional Analysis of MSW in the Study Area

1) Sampling Site Description

The sampling of the MSW was carried out at the Saggian dump site. It is situated in the suburbs of Lahore and the resting place of MSW reject collected from the Ravi town and a few other towns. The MSW reject include the final reject that has gone through every possible segregation carried out at different stages of the MSWM. Thus, it has no further use and official status. The LWMC and private contractors collection vehicles bring the waste to the dump site. This site, with an area of 25 ha has been in operation since 1995. Its exact location is pointed on the map given in Fig.1.

2) Sampling and Sampling Techniques

The field surveys for the characterization of MSW of Ravi Town were carried out periodically for four seasons, Spring, Summer, Autumn and Winter in the months of April (2011), July (2011), October (2012) and December (2012), respectively.

To increase the level of accuracy, the sampling was carried out according to the joint approach of *Stratified Random Sampling* (taking seasons of the year as strata) and *American Society for Testing Materials* international standard *ASTM D5231-92 (2003)*. According to the standard, a representative sample was drawn from each truck load approaching from Ravi Town, Lahore. The following formula was used to calculate the representative number of loads i.e. n:

$$n = -\frac{b\,R}{1.0516} \qquad (1)$$

Where, $t^* = 1.645$ (student t distribution statistic), against (1-α) = 90 % the desired level of confidence), $\alpha = e = 0.10$ (the desired level of precision), $s = 0.03$, and $\bar{x} = 0.10$ [xxvi]. Where, s (standard deviation) and $\bar{x}$ (mean) were selected on the basis of the governing component, i.e. food waste in the city of Lahore [iii, xxv]. The number of sample loads, $n = 5$ were calculated using equation (1) and validated according to *ASTM D5231-92 (2003)*. Thus, for component analysis, segregation of 5 truck loads was taken as statistically significant. Randomly, five truck loads were selected from those coming from the 19 UCs of the Ravi Town. They were unloaded, loosely mixed and a sample of about 200 lb or 100 kg was selected after coning and quartering. This process was repeated daily for fifteen days extended over four seasons. Thus, for physical characterization, approximately 100 x 5x15x4

=30,000 kg of MSW reject was segregated as a representative sample.

The segregation process was mainly based on the major combustibles and non-combustibles fractions of the MSW reject of Ravi Town, Lahore. The MSW reject may not have any other use than converting to RDF. Most of the components which have any other potential use as recycling or composting, they do not end up in the dump sites. Such components are segregated in the upper tiers of the MSWM hierarchy or picked up by the scavengers. Only the rejects fall to the dump sites. Thus, the MSW reject was segregated into two major categories with seven sub-categories each. The first category was major combustibles: paper and cardboard (PC), shopping bags (SB) that are made of *low density polyethylene* (LDPE), other plastic (OP), p*olyethylene terephthalate* bottles (PET), tetra-pack food and beverages packaging (TP) that is made up of three raw materials: cardboard (about 75%), aluminium foil (about 5%) and LDPE (about 20%) [xxvii], textiles (TX) and other combustibles (OC). The PET bottles included coke, sprite and mineral water bottles. Other plastic comprised of *polystyrene* and other combustibles included toffee, biscuit and potato chips wrappers (mixture of LDPE, *high density polyethylene* (HDPE) and aluminium foil). The second category was taken as others: e-waste, green waste, diapers, metals, hazardous waste, glass and miscellaneous. Seasonally, the weights of the segregated components (hand sorting) were averaged (using mean) and the variability among them was also calculated using standard deviation (SD). Finally, Combined average and combined standard deviation was calculated for all four seasons. The projection of combustible elements was estimated for the refuse derived fuel (RDF) potential.

C. *Laboratory Samples and RDF Production*

The laboratory samples for further analysis consisted of seven sub-samples of major combustibles labelled such as paper & cardboard (PC), shopping bags (SB), other plastic (OP), PET bottles (PET), tetra-pack (TP), textiles (TX) and other combustibles (OC). They were sorted and transported to the laboratory in sealed airtight plastic bags on the last day of each season. The samples were sorted by employing all the safety measure, i.e. use of safety goggles, gloves, masks and shoes.

First, the RDF-fluff was produced from the combustible portion of MSW for all four seasons. The seven sub-samples of PC, SB, PET, OP, TP, TX and OC (each was mixed for four seasons) were converted into RDF using ASTM E829-16 [xxviii] by dehydrating, shredding and then sieving through sieve with a 1 inch square mesh screen. In the second step, the RDF-fluff of the seven sub-samples (representing four seasons) were transformed into pellets by using a laboratory scale hydraulic press.

D. *Quality Characterization of RDF*

The following tests were performed to optimize the pellets quality. This will ensure their acceptability as fuel.

1) Sample Preparation

Each RDF pellet (PC, SB, PET, OP, TP, TX and OC) was frozen in liquid nitrogen and grounded immediately using a mill. Seven homogeneous samples were prepared. They were labelled and stored in airtight glass vials for further analysis.

2) Proximate Analysis

The Proximate analysis was used to estimate (a) Moisture Content (MC %) using ASTM E 790-15 (2015); (b) Volatile Matter (VM %) using ASTM E 897-88 (2004); (c) Ash Content (AC %) using ASTM E 830-87 (2004); and (d) Fixed Carbon (FC %) by subtracting VM % and AC % from 100. They evaluate the combustible characteristics of these RDF samples.

3) Net Calorific Value

Net calorific value (NCV) or lower heating value (LHV) is the latent heat energy, mostly used to represent the energy balances of waste derived fuels. It is 5 % to 6 % lower than the gross calorific value for solid and liquid fuels [xxix]. The higher heating value (HHV) or gross calorific value (GCV) is the gross energy that can be released through complete combustion of fuel in MJ/kg. Digital Bomb Calorimeter of LECO Corporations AC 500 was used for GCV estimation in RDF samples. The NCV was estimated by subtracting 5 % of GCV from the original value.

4) Ultimate Analysis

Ultimate analysis provides the elemental composition of carbon (C %), hydrogen (H %), nitrogen (N %), oxygen (O %) and sulphur (S %), that gives a better understanding of fuel value and its characteristics. Elementar Analysensyteme GmbH-vario MICRO CHNS Elemental Analyzer (serial number: 15095076) was used for the estimation of the elements in RDF samples. Oxygen value was estimated by subtracting the sum of (C, H, N and AC) percentages from 100 [xxx].

5) Chlorine Estimation

Chloro content in the RDF samples was estimated using *Sintering* method [xxxi]. In this process the RDF samples clumped into larger particles. More importantly, the organic Cl converted to inorganic chloride, such as Sodium Chloride (NaCl) and Zinc Chloride ($ZnCl_2$), that is leached from the residues with water. Extraneous metal ions were removed from the samples by a cation exchange column, and then the purified eluent was analyzed for Cl using the Volhard titration methodology.

6) Heavy Metal Analysis

Since, MSW is heterogeneous in nature and it is commingled including both hazardous and non-hazardous materials. In the current study major combustibles were segregated, but the traces of heavy metals leached from other MSW components may be found. The microwave digestion method was used to estimate the metal concentration in the RDF samples. Europen standard EN 13656 [xxxii] was used: 1.0 gram of sample was mixed with concentrated 3 ml Hdrochloric acid (HCl), 1 ml of Nitric acid (HNO_3) and 5 ml of Hydrofluoric acid (HF); Then the sample was digested in the microwave under 70 watt power for 10 minutes; A 5 ml of concentrated HNO_3 was added in the hot solution and digestion process was repeated for 5 minutes; After that another 5 ml of concentrated HNO_3 was added in the hot solution and digestion process was repeated for 5 minutes; Then 5 ml of concentrated HCl was added in the hot solution and same process of digestion was repeated for 5 minutes; At the end 40 ml (4 % m/m) Boric acid (H_3BO_3) was added to reduce acidic conditions of the solution and microwave digestion was carried out for final 5 minutes. The hot solution was cooled down and filtered for further analysis. The whole process was repeated for all seven RDF samples, and each sample was triplicated to reduce variability. Afterwards, the samples were neutralized using Sodium hydroxide (NaOH) and PerkinElmer Analyst 800: Atomic Absorption Spectrophotometer was used for estimation of Mercury (Hg), Arsenic (As), Cadmium (Cd), Nickel (Ni), Lead (Pb), Copper (Cu) and Chromium (Cr).

All the above mentioned parameters were compared with EURITS RDF Standards given in Table II.

E. Graphical Presentation and Statistical Analysis

TABLE II
RDF STANDARD LIMITS

Parameters*	EURITS Limits
NCV (MJ/kg)	>15
MC (%)	< 25
AC (%)	< 5
Cl (%)	< 0.5
S (%)	< 0.4
Hg (mg/kg)	< 2
As (mg/kg)	< 10
Cd (mg/kg)	< 10
Ni (mg/kg)	< 200
Pb (mg/kg)	< 200
Cu (mg/kg)	< 200
Cr (mg/kg)	< 200

**Parameters: Net Calorific Value (NCV), Moisture Content (MC), Ash Content (AC), Chlorine Content (Cl), Sulphur Content (S), Murcury (Hg), Arsenic (As), Cadmium (Cd), Nickel (Ni), Lead (Pb), Copper (Cu), and Chromium (Cr)*

Source: [xix]

The OriginPro 2016 ® software was used to estimate average (mean) values and their corresponding standard deviations (SD). Pie Graph and Bar graphs were also constructed through this software. The parameters with higher and lower concentration levels were grouped separately for better understanding and resolution. All numerical values were rounded off to two decimal places.

III. RESULTS AND DISCUSSION

A. Compositional Analysis of MSW for RDF Yield

The first step of this research was to investigate the quantity of different components present in the MSW reject collected from Ravi Town, Lahore. The RDF projection of this reject was estimated at the Saggian dump site where the waste is dumped after collection. Table III reveals the MSW reject compositional trend envisaging the RDF yield.

Table III shows that there was a total of 19.09 % of major combustibles present in the MSW reject of Ravi Town, Lahore. A similar study was conducted at Data Gunj Baksh Town, Lahore and the results are comparable to the current study as paper (5.04 %), film plastic (12.94 %), rigid plastic (5.55 %), textiles (1.00 %), glass (2.10 %), ferrous metal (0.02 %), non-ferrous metal (0.47 %), organics (67.02 %) and others (5.77 %) [iii]. A matching trend was observed in a review article on MSW management of Indian cities. Calcutta is a metropolitan city of India with MSW composition detected as: paper (10 %), textile (3 %), leather (1 %), plastic (8 %), glass (3 %), organic matter (40 %) and others (35 %) [xii].

TABLE III
MSW (REJECT) PHYSICAL COMPOSITION OF RAVI TOWN, LAHORE

Sr. No.		Components	% by wt*
1	Major Combustibles	Paper & Cardboard	3.30±2.04
2		Shopping Bags	7.34±2.09
3		Other Plastics	0.93±0.26
4		PET bottles	0.12±0.08
5		Tetra-pack	0.51±0.13
6		Textile	4.50±1.76
7		Other Combustibles	2.39±0.86
	Others	E-Waste	0.15±0.10
8		Green Waste	66.40±6.33
9		Diapers	6.87±2.01
10		Metals	0.18±0.67
11		Hazardous Waste	0.81±0.44
12		Glass	4.29±3.71
13		Misc.	2.27±1.82
14		E-Waste	0.15±0.10

* values are expressed in mean±standard deviation

Table III clearly explained that major combustibles can further be elaborated. Their individual percentages may be calculated with reference to 19.09 % of total combustibles shown in Fig. 2.

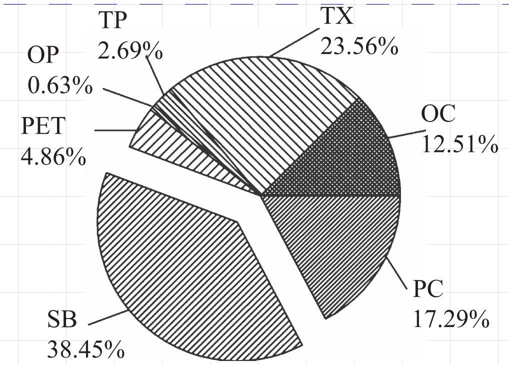


Fig. 2. Combustible raw material for RDF production

From Fig. 2. it is very clear that shopping bags were found in abundance (38.45 %) followed by textiles (23.56 %), paper & cardboard (17.29 %), other combustibles (12.51 %), PET bottles (4.86 %), tetra-pack (2.69 %) and other plastic were in the least amount (0.63 %). In a similar study carried out in a developed city of Vancouver, the RDF raw material was projected to be 52.8 % and the individual percentages were calculated as paper (49.24 %), plastics (36.33 %), leather (4.36 %), wood (1.89 %), textiles (5.49 %), rubber (0.38 %) and fines (2.46 %). Surprisingly, it can be observed that plastics and textiles RDF potential is very much the same. That portrays, the plastic consumption follow the same trend world wide.

The quantity of fresh garbage coming from Ravi Town is 849.32 tons/day [xxiv]. The daily raw material projection for RDF production is calculated below:

Total MSW reject generated = 849.32 tons/day
Combustible percentage = 19.09 %

$$\text{Combustibles per day} = \frac{849.32}{100} \times 19.09$$

$$= 162.14 \text{ tons/day} \quad (2)$$

Fauji Cement RDF plant is the first of its kind that was set in Pakistan in 2008. It has a capacity of processing 12 tons of raw material per hour [33]. If it works for the whole day, for 8 working hours it may process 96 tons/day. Thus, equation (2) projects a feasible amount of raw material for RDF processing.

B. RDF Production

The process for the production of RDF-fluff for each seven sub-samples of PC, SB, PET, OP, TP, TX and OC was followed as explained in materials and methods section. Using RDF-fluff samples, pellets were produced using a laboratory scale hydraulic press. The pellets of each sample are shown in Fig. 3.

C. Quality Characterization of RDF

The results of ultimate analysis and proximate analysis of PC, SB, PET, OP, TP, TX and OC are given in Table IV. Table IV shows that the results are in the favour of using these samples as RDF. They have higher volatiles, followed by fixed carbon and lower values of the AC [xxxiv-xxxv]. Textiles have highest value of volatile matter, i.e. 91.98 %. Fixed carbon is highest in paper and cardboard, i.e. 21.97 % and shopping bags have the least ash content, i.e. 0.01 %. Paper and cardboard have a high cellulose content and it can be realized from the basic elemental values given in Table 4. The estimated amount of carbon (38.84 %), hydrogen (5.49 %), nitrogen (4.66 %), oxygen (43.60 %) and sulphur (0.15 %) are comparable to the ones estimated in a similar study as 35.5 %, 4.6 %, 0.45 %, 35.96 % and not detected respectively [xxxiv].

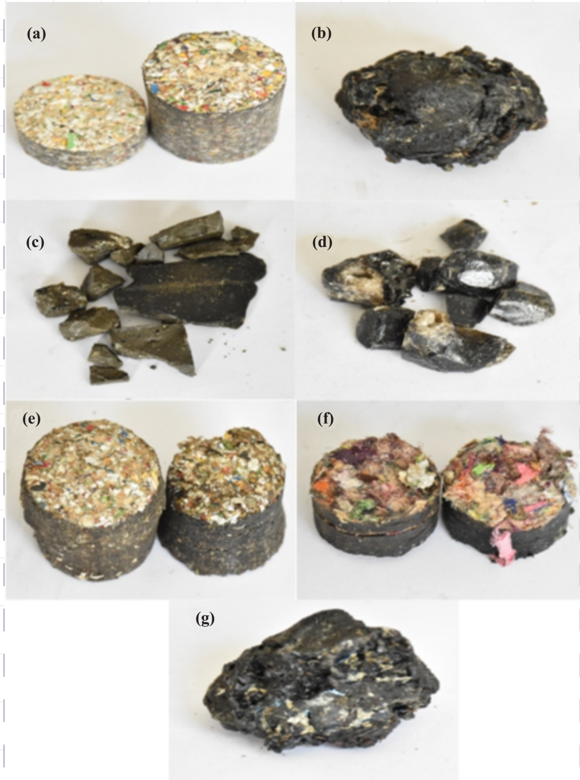


Fig. 3. RDF Pellets of (a) paper and cardboard, (b) shopping bags, (c) PET bottle, (d) other plastic, (e) tetra-pack, (f) textiles and (g) other combustibles

Synthetic polymers (SB, PET, OP) have carbon content (61.13 % to 78.57 %), hydrogen content (4.14 % to 12.98 %), nitrogen content (2.41% to 5.36%), Oxygen content (3.08 % to 31. 90 %) and negligible content of Sulphur. These values are quite similar to other research with related approaches to investigate the thermal behavior of combustible municipal solid waste [xxxv].

The elemental characteristic of textiles waste given in Table IV exhibited values as good as a study on the pyrolysis of textiles waste, i.e. carbon content (53.60 %), hydrogen content (7.28 %), nitrogen content (0.30 %), oxygen content (38.80 %) and sulphur content (0.005 %) respectively [xxxvi].

Table IV also displays tetra-pack carton elemental characteristics in the favour of a study on pyrolysis of tetra-pack carton packaging with carbon content (48.17 %), hydrogen content (7.54 %), nitrogen content (<0.01 %) [xxxvii], oxygen content (39.04 %) and sulphur content (not detected) [xxxiv]. Other combustibles are the mixture of remains with interesting results and promising RDF characteristics.

The quality check of the RDF produced was carried out by comparing the key parameters with the EURITS standard [xix] given in Table II. The graphical comparison in Fig. 4. reveals that all the RDF quality parameters (mean±SD) of (a) paper & cardboard: NCV (29.97±1.77 MJ/kg), AC (7.42±0.81 %), MC (17.01±11.99 %), Cl (0.02±0.01 %), S (0.15±0.11 %), Hg (0.29±0.07 mg/kg), As (3.84±1.45 mg/kg), Cd (6.11±0.07 mg/kg), Ni (31.23±1.47 mg/kg), Pb (0±0 mg/kg), Cu (47.47±2.55 mg/kg) and Cr (65.48±2.95 mg/kg); (b) shopping bags: NCV (29.57±0.89 MJ/kg), AC (0.01±0.02 %), MC (6.38±4.01 %), Cl (0.43±0.02 %), S (0.15±0.11 %), Hg (0.34±0.03 mg/kg), As (4.30±1.38 mg/kg), Cd (5.65±0.16 mg/kg), Ni (29.63±0.93 mg/kg), Pb (0±0 mg/kg), Cu (38.27±3.52 mg/kg) and Cr (64.00±1.22 mg/kg); (c) PET bottles: NCV (31.14±0.97 MJ/kg), AC (0.42±0.39 %), MC (2.14±1.54 %), Cl (0.17±0.04 %), S (0.02±0.03 %), Hg (0.43±0.07 mg/kg), As (4.81±0.62 mg/kg), Cd (7.33±0.59 mg/kg), Ni (41.07±2.12 mg/kg), Pb (0±0 mg/kg), Cu (40.05±2.10 mg/kg) and Cr (75.33±0.73 mg/kg); (d) other plastics: NCV (56.90±0.46 MJ/kg), AC (1.95±0.15 %), MC (5.05±2.27 %), Cl (0.39±0.16 %), S (0.11±0.05 %), Hg (0.29±0.03 mg/kg), As (3.60±1.20 mg/kg), Cd (6.00±0.51 mg/kg), Ni (31.15±4.80 mg/kg), Pb (0±0 mg/kg), Cu (41.94±4.17 mg/kg) and Cr (66.75±3.1 mg/kg); (e) tetra-pack: NCV (29.95±1.03 MJ/kg), AC (2.18±1.28 %), MC (10.303±7.83 %), Cl (0.04±0.02 %), S (0.01±0.01 %), Hg (0.32±0.04 mg/kg), As (3.68±1.55 mg/kg), Cd (5.84±0.59 mg/kg), Ni (33.81±1.79 mg/kg), Pb (0±0 mg/kg), Cu (42.27±2.53 mg/kg) and Cr (71.00±4.12 mg/kg); (f) textiles: NCV (29.4±0.44 MJ/kg), AC (0.93±0.3 %), MC (25.18±24.81 %), Cl (0.04±0.04 %), S (0.53±0.19 %), Hg (0.28±0.02 mg/kg), As (5.03±1.25 mg/kg), Cd (3.59±0.27 mg/kg), Ni (37.02±1.05 mg/kg), Pb (0±0 mg/kg), Cu (43.12±4.50 mg/kg) and Cr (69.42±4.48 mg/kg); and (g) other combustibles: NCV (58.53±1.37 MJ/kg), AC (1.94±0.99 %), MC (11.29±3.51 %), Cl (0.02±0.01 %), S (0.15±0.14 %), Hg (0.35±0.03 mg/kg), As (4.78±0.05 mg/kg), Cd (4.21±3.42 mg/kg), Ni (47.29±3.14 mg/kg), Pb (0±0 mg/kg), Cu (64.71±5.44 mg/kg) and Cr (78.73±6.27 mg/kg).

TABLE IV
PROXIMATE AND ULTIMATE ANALYSIS OF THE RDF SAMPLES

RDF Sample[a]	Vm[b]	Fc[c]	Ac[d]	S	C	H	N	O
PC	70.62±2.51	21.97±1.84	7.42±0.81	0.15±0.11	38.84±5.04	5.49±0.56	4.66±2.39	43.60±5.63
SB	81.61±8.06	18.37±8.06	0.01±0.02	0.15±0.11	78.57±2.7	12.98±0.55	5.36±4.37	3.08±2.94
PET	91.82±3.64	7.76±3.59	0.42±0.39	0.02±0.03	61.13±0.16	4.14±0.06	2.41±0.28	31.90±0.24
OP	93.64±1.32	4.41±1.24	1.95±0.15	0.11±0.05	74.49±1.84	11.81±1.55	4.45±1.32	7.31±4.20
TP	66.76±3.94	31.05±3.16	2.18±1.28	0.01±0.01	47.32±0.78	7.14±0.19	2.6533±0.81	40.70±1.56
TX	91.98±1.82	7.10±1.60	0.93±0.30	0.53±0.19	53.42±8.68	4.88±1.15	3.78±1.42	37.00±6.37
OC	80.25±11.84	17.82±11.07	1.94±0.99	0.15±0.14	77.40±0.41	12.41±0.16	3.93±0.57	4.99±0.94

[a] *PC=paper & cardboard: SB=shopping bags: OP=other plastic: PET=PET bottles: TP=tetra-pack; TX=textile: OC=other combustibles*
[b, c, d] VM=volatile matter %, FC=fixed carbon %, AC=ash content %

The above mentioned results were observed in accordance with the EURITS standard given in Table II. The standard deviation values of moisture content, detect that there is a large variation among MC of all the RDF samples but still, they are within the standard limit of < 25 %. Previously, a study carried out to estimate the potential of refuse derived fuel production from Bangkok municipal solid waste showed parallel results [xxxviii].

Similar studies on rejected fraction of Purtoguese municipal solid waste and energy potential from Saudi Arabia also gave similar trends in their results [xxxix-xl].

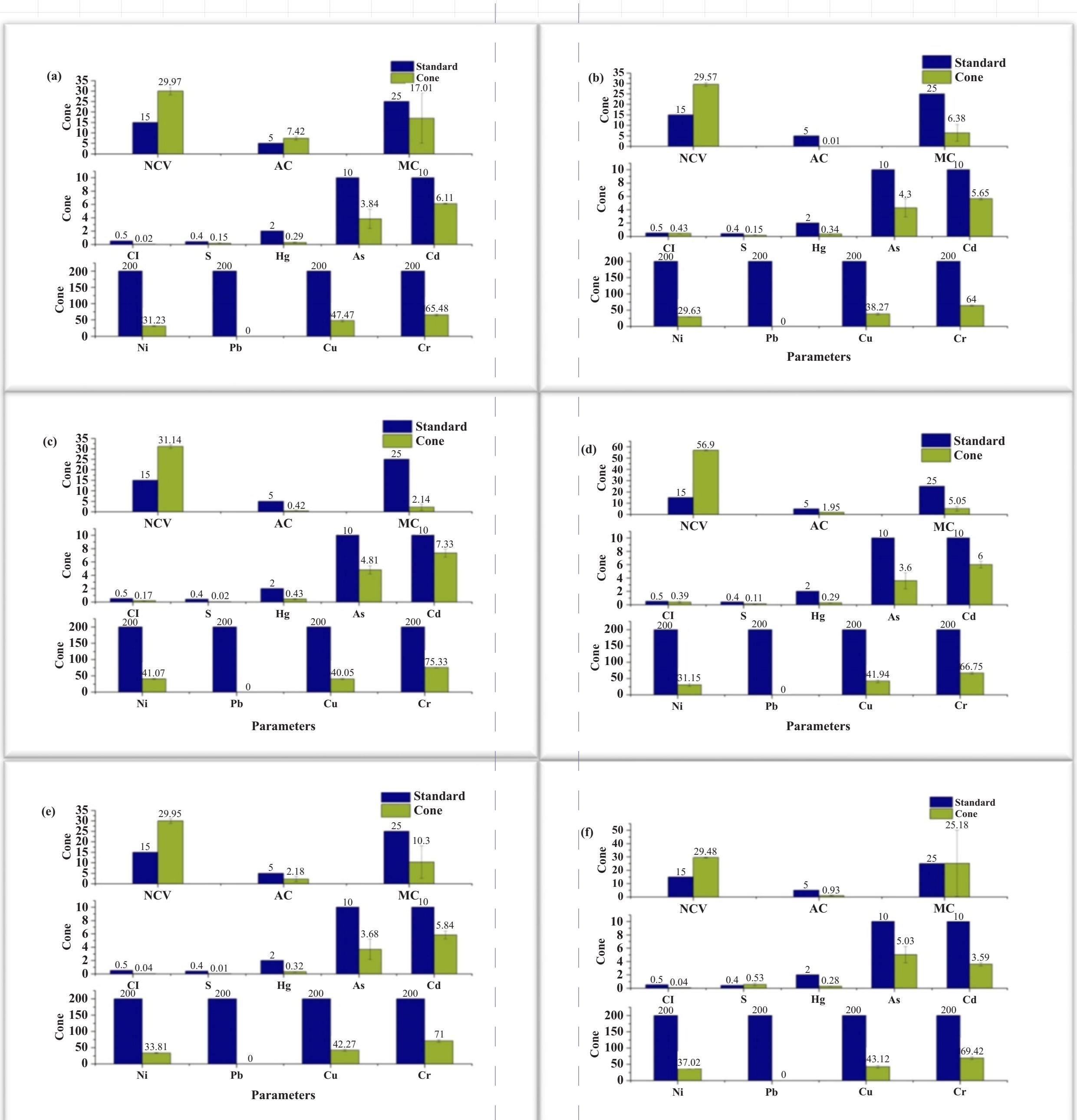
IV. CONCLUSIONS

In this study the waste was collected from Saggian dump site that is the resting place of MSW reject coming from different parts of Lahore, Pakistan, including Ravi Town.

A representative sample of 30,000 kg of MSW was evaluated for this study. It was segregated into two categories as (1) major combustibles and (2) others. These categories were further elaborated to seven sub-samples each. This study was based on the major combustibles (PC, SB, PET, OP, TP, TX and OC) found in the MSW reject of Ravi Town Lahore as a case study. The RDF projection from this kind of MSW was estimated to be 162.14 tons/day. When compared to Fuji Cement RDF plant feedstock capacity, it was found feasible for further processing. Higher percentage (on combustible basis) of shopping bags (38.45 %), textiles (23.56 %) and paper and cardboard (17.29 %) in the municipal waste stream makes RDF production as an appealing integrated municipal solid waste management (IWM) strategy and reducing burden on the land dumping. Moreover, these samples were dried and shredded to pass 1 inch square mesh size sieve. Seven RDF pallets were produced for each combustible component.

After quantifying and RDF production, it was important to know if these pellets have any qualitative potential to be used as RDF. The EURITS RDF standards were used to assess chemical characteristics of these samples. The results were dynamic and in the favour of RDF production.

The findings of this study can be a reliable database for the policy makers to design an integrated MSWM approach for the city of Lahore and other parts of Pakistan. The city district government and federal government of Pakistan can plan ahead to use MSW as resource, transform into RDF and use for energy production. Since, the present study is modelled for the worst conditions as a case study, the results may be useful for other countries too.



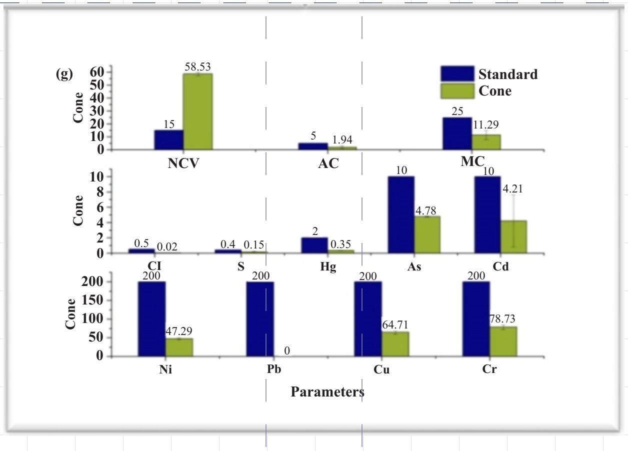


Fig. 4. Concentration of NCV (MJ/kg), AC (%), MC (%), Cl (%), S (%), Hg (%), As (mg/kg), Cd (mg/kg), Ni (mg/kg), Pb (mg/kg) Cu (mg/kg) and Cr (mg/kg).

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