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Research Article

Study on the Use of Refuse Derived Fuel in Cement Industry as an Alternative to Coal

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KEYWORDS

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ABSTRACT

The focus of this study was on preparation of Refuse Derived Fuel (RDF) from Municipal Solid Waste (MSW) and its utilization in cement manufacturing process. The aim of this study was to evaluation of RDF as a fuel supplement in cement manufacturing. For this purpose, municipal solid waste composition and calorific values were calculated. To know about its impact on environment in terms of flue gases and particulate matters, the cement plant was kept under observation for three months. It was found that 69.6% of the municipal solid waste consists of combustible material with 3500 kcal/kg calorific value. It was estimated that 4 tons of RDF was equivalent to 1 ton of coal, already being, used in the cement plant. Emissions of various pollutants, CO, SO2 and ash were within the permissible limits set by National Environmental Protection Agency of Pakistan. Therefore, because of high prices of coal and associated atmospheric pollution, it is recommended to use RDF prepared from MSW, as an alternate of coal or as fuel supplement.

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1. Introduction

Both organic and inorganic materials found in municipal solid waste (MSW) and can be recycled or reused in one form or another [1,2]. Various techniques, such as composting, incineration, gasification and refused derived fuel (RDF) conversion are available to manage solid waste in environment friendly manner [1]. Recently, researchers presented an improved system for gasification with removal of tar and sulfur by 90% and the hot purification system demonstrated removal of tar and sulfur by 90% with syngas yield of 14% [3,4]. Due to high demand and price hike, the use of municipal and industrial waste for power/energy generation is valued worldwide. After proper evaluation, solid waste can become one of the new sources of energy [5]. Apart from the energy supply, municipal solid waste has many other benefits. It is worth mentioning that though the energy recovery from MSW is beneficial, there are by-products such as ashes remain after thermal treatment. Nevertheless, recent research are focusing on further re-utilize of these ashes and moving towards a circular economy: The use of solid waste as RDF not only reduces the environmental pollution but also saves on fuel cost in the manufacturing or processing in different industries [6].In this scenario, one of the options suggested by waste management planners and government authorities is the recovery of material and energy from municipal solid waste through RDF production [7]. Municipal solid waste composed of plastics and other combustible materials like textiles, and wood that can be used as RDF [8,9]. It can be very helpful in production of energy in various industrial sectors such as cement, brick kiln and small-scale steel industry [10].

In most of the cement plants, unsorted MSW is not burnt directly due to its heterogeneous nature and the potential to cause environmental problems, such as emission of Greenhouse gases and hydro carbons, an environmental problem. Various techniques for preparation and use of RDF have been developed in countries like Italy, Austria, Belgium, United States and Denmark. These countries mostly utilize the waste in cement production, which is proved to be a successful solution [11]. Use of RDF Pakistani cement industry is still in experimental stages. The cement factory under study has the leading role to convert solid waste, collected from Rawalpindi city, in to RDF and use it as a source of fuel supplement [12,13].

In Pakistan, the average solid waste generation rate is 0.61 kg per person per day [14]. Such an amount of solid waste has many disadvantages arose as a result of improper handling of solid waste and unscientific disposal. These factors pose potential risks to the environment and to the human health. The hazards associated with solid waste could be properly be minimized by applying solid waste management technologies. Pakistan is a developing country and has been passing through energy crises for last two decades. Utilization of municipal solid waste as an alternative energy resource is important and beneficial for the country

Total area of the city, under study is 5,286 km (2,041 sq. mi.) with 5.4 million populations (National population census 2017). Among various problems, solid waste is identified as one of the growing problem of the study area. The average solid waste production rate is 0.32 kg /capita per day in the city and was found less than the average generation rate of 0.45 to 0.61 kg /capita per day of the country [15,16]. In 2012, total solid waste production of the city was 90 thousand kg/day [17]. As per recent estimate of Dino and Mustrafa [16], solid waste production raised up to 1728 thousand tons per day. In this study an attempt has been made to study the present RDF preparation, composition and utilization in comparison with coal, with the aim to see either RDF is cost effective or not.

2. Material and Method

2.1. Material (Sampling and Preparation of RDF)

- **Waste Sampling:** For a representative sample, 40-50 kg sample was isolated from a randomly selected truck at two different dumping sites through quadratic composite sampling method. For this purpose, a truck was unloaded and was divided into four equal parts. Each part was sub-divided into four sections. One section was used as a sample for calculation of percent composition. After calculation of percent composition, isolated portion was sampled for further laboratory analysis. For this purpose, 0.5 kg sample of each individual component was collected. This whole sample was carefully collected and packed in labeled and airtight sacks.
- **RDF Preparation:** Once the ingredients for refuse-derived fuel were ready, the sorted material was fed into the secondary shredder. These were shredded into smaller pieces of size 15–30 mm.
- **Drying:** When the shredded mixture came out of the shredder, it was dried before powdering to enhance its burning efficiency for better heat generation. The mixture was kept in open air for one day, so that its moisture content was reduced to 10-15%.
- **Powdering and Briquette Formation:** The dried waste was powdered with the help of a machine equipped with stainless steel blades, capacity of one horse power and 800 RPM at 60Hz. Briquettes were formed from compression of the crushed waste by compressing the material in Universal Testing Machine, Model UH-200A, US made. The waste was squeezed through a die having holes of the size 2 inches. Pressure of 4 tons was applied to form a solid briquette.

2.2. Method (Characterization and Analysis)

- **Solid Waste Percentage Composition:** The isolated part, which was 12% of a truck, was sorted out to calculate percent composition. Different waste materials were separated and weighed. Large components, such as plastics, wood, and glass bottles were broken into small pieces. The collected materials were carefully divided and stored separately. These components were weighed through electronic balance on site.

The gross, sorted out components were divided into three major categories i.e., kitchen (putrescible) waste, recyclables (combustible) and inert materials (non-combustibles), to assess its potential use as an alternative fuel. The various components include paper, plastic, glass, wooden material, textile, leather and metals etc.

- **Metal separation:** All sorts of ferric and non-ferric metals were removed and weighed from the waste stream via manual sorting. Separated metals can be recycled and the non-ferrous metals were discarded or it can be sold to kabari (scrape dealer) for recycling. The reason is that even a very small quantity of metal could destroy the briquette mill equipment. In the end, all the combustible materials were stored separately. Putrescible and inert materials were discarded for composting and landfill respectively.
- **Analytical Test at the Plant:** Density, proximate analysis include percent moisture content, percentage ash content, percentage volatile matter content and the calculation of percentage fixed carbon [2]. Ash content was determined by using standard method ASTM code D3174 – 12 [18].
- **Gas Emissions Analysis:** For flue gas analysis three briquettes (25 g) of plain MSW, three of RDF and three mixed with 4 % $Ca(OH)_2$ were burnt in muffle furnace at 1000°C for 10 minutes. The flue gas analyzer model No. CAS 101P was fitted at the outlet nozzles of muffle furnace, to trap all the emitted gases for detailed analysis. Flue gas emissions were also noted from the installed flue gas analyzers LANCOM III (Combustion and Stack Emissions Monitoring Machine), pre-fitted at the kilns for environmental monitoring of the cement industry.
- **Particulate Matter Monitoring:** The cement industry is equipped with Iso-kinetic the Casella Particulate sampling system (Instrument) designed to comply with BS 3405 and ISO-9096 [19]. The total time of stack gas at inlet was noted with a stopwatch, which provides measurements in seconds with high precision and accuracy. To ensure maximum accuracy, time of all observations was kept fixed. Monitoring was carried out from the two monitoring holes already provided on cement kiln and coal mill stacks.

3. Results and Discussion

3.1.Municipal Solid Waste Characterization

Municipal solid waste of the study area consisted of 15 major components that could be grouped into three main categories i.e. kitchen, combustible and inert (Table1). Combustible materials were comparatively high with 69.6 %. Kitchen waste was only 20 % and inert substances were 10.4% of the total solid waste. Due to high moisture content, kitchen waste cannot be used directly as a fuel. As kitchen waste is high in organic content and can be used as a compost or soil conditioner. The inert waste includes glass particles, metal scrape, stone and dust.

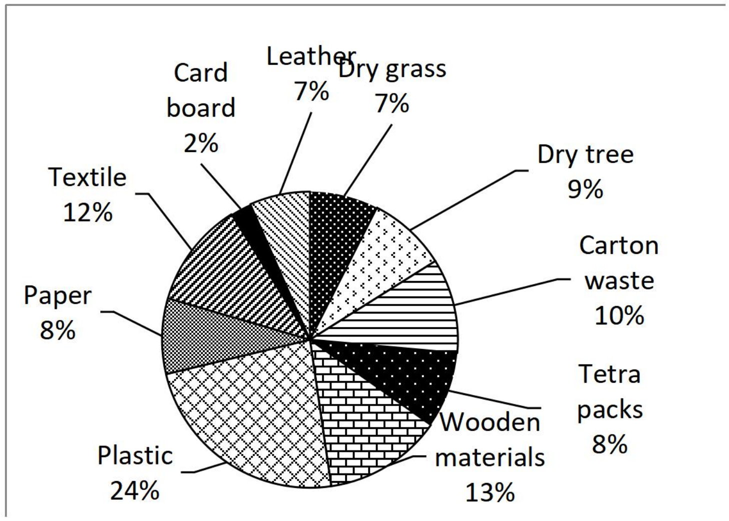
Table 1. Characteristics of Municipal soil waste of the study area

S NO	Components	Weight in kg	Percentage
1	Kitchen waste		
1.1	Vegetable peels etc.	800	8
1.2	Fruits peels etc.	720	7.2
1.3	Flowers/ twigs	220	2.2
1.4	Green grass	260	2.6
Sub total		2000	20
2	Combustibles		
2.1	Dry grass	520	5.2
2.2	Dry tree	600	6
2.3	Carton waste	720	7.2
2.4	Tetra packs	580	5.8
2.5	Wooden materials	900	9
2.6	Plastic	1640	16.4
2.7	Paper	574	5.74
2.8	Textile	806	8.06
2.9	Card board	160	1.6
2.10	Leather	460	4.6
Sub total		6960	69.6
3	Inert waste		
3.1	Inert materials (Stones, dirt, glass and metals)	1040	10.4
Sub total		1040	10.4
Grand Total		10000	100

3.2 RDF Composition

Combustible materials are separated manually from the main stream of the solid waste through a conveyer belt. The percentage components are given in Table 1. The 10 main components were used in RDF manufacturing Figure.1.

Figure 1. Composition of RDF



Plastic content was the highest with 24%, followed by wood with 13%. Paper and wood contain lignin, which not only produce high energy but also help to bind the MSW particles together into the briquette. Lignin also acts as stabilizer of cellulose molecules in the cell wall. The more lignin the material contains, the more of it can be released to produce briquettes with higher quality. Higher concentration of the lignin assures better briquette strength [20]. Most of the waste of the study area contains lignin containing material i.e. paper 5.74 %, textiles 8 %, grasses 11.2 %, cards boards and cottons 1.6 and 7.2 %, tetra packs 5.8 % and wooden material being 9 %.

Here, it is important to discuss that plastic (plastic materials, polythene bags etc.) comprises the major portion of the material to be used in RDF manufacturing process. On combustion at lower temperatures, they emit dioxins and furans, which pose high environmental and health risks [21]. This fuel is meant to be used in cement kilns or where temperature of the kiln is above 1400^{O}C. At this temperature dioxins and furans cannot be destructed, therefore, the RDF prepared from such waste can easily be used as a fuel in cement factories [22].

3.3. Characteristics of RDF

The major characteristics of RDF in comparison with Municipal solid waste are summarized in table 2. Fixed carbon was observed to be 8 % in municipal solid waste, 10 % in RDF briquettes and 12 % in RDF briquettes with lime. Fixed carbon indicates the proportion of char that is left after the de-vitalization. Low fixed carbon content and low ash content are good property of better fuel [23]. Ash left after combustion was recorded as to be 15 %, 9 % and 8 % for MSW, RDF and RDF with lime respectively (Table 2). However, standard value for ash content in RDF should be 8-12 % [24].

Table 2. Proximate analysis of MSW and RDF

Parameters	Analyzed Values (%)											
	MSW				RDF				RDF Briquettes with Lime			
	Min	Max	Ave	St. dev	Min	Max	Ave	St. dev	Min	Max	Ave	St. dev
Moisture	50	54	52	2.98	29.8	31	30	0.89	15	20	17	1.06
Volatile Content	24	27	25	2.04	49	52	51	1.09	60	65	63	1.07
Fixed Carbon	7	9	8	1.46	8.5	12	10	1.5	12	15	12	0.81
Ash	14	18	15	1.6	8.5	10	9	0.61	7	9	8	0.82

3.4 Calorific Content

Calorific values are affected by moisture. For efficient RDF production, removal of moisture is mandatory. As RDF is prepared from selective components, therefore, MSW has very low calorific content compared to RDF.

The results in table 3 shows, that raw MSW has very low calorific value as compared to RDF briquettes i.e. 2000 and 4537 kcal/kg respectively. The calorific or heat value is a considerable aspect of RDF as also studied by [25]. The calorific value calculated for RDF briquettes with $Ca(OH)_2$ was 4540 kcal/kg, slightly high from a plain RDF (Table 3).

3.5 Flue Gas Emissions

At cement factory flue gas emissions were recorded at both exits, where coal was used as kiln feed, i.e. kiln stack and coal mill stack. Flue gas emissions from RDF briquettes were recorded in incinerator (muffle furnace) in the laboratory. An effort was made to compare the emissions from coal and RDF briquettes flue gases. It was noted that cement industry has in-built scrubbers and electrostatic precipitators installed in order to meet the limits set by environmental legislations.

Table 3. Calorific Value of MSW and RDF

Samples	Calorific value dry basis kcal/kg				Calorific value ash free dry basis kcal/kg			
	Min	Max	Average	St. Dev	Min	Max	Average	St. Dev
MSW	1990	2010	2000	6.14	1078	1090	1080	4.24
RDF briquettes	4530	4550	4537	6.41	4641	4662	4650	4.31
RDF briquettes with Ca $(OH)_2$	4510	4531	4540	6.61	4879	4892	4886	4.26

Carbon Monoxide (CO) from the cement kiln stack (Table 4) was at the average of 328 mg/Nm^3±1.4. It was at the average of 320 mg/Nm^3±1.2 from coal mill stack. CO from incinerator for RDF briquettes was recorded at the average of 505 mg/Nm^3 ±1.02 and from incinerator for RDF briquettes with lime was recorded at the average of 500 mg/Nm^3 ±0.6. The emission was less than the limit of 800 mg/Nm^3, set by the Federal Environmental Protection Agency (EPA) for RDF guidelines in the form of National Environment Quality Standards (NEQS).

Table 4 indicates that carbon monoxide emissions from stacks are lower than the incinerator emissions, because at the exit points in the cement-manufacturing unit, there are scrubbers and electrostatic precipitators (ESP) are installed which stops the emissions from going into atmosphere. No such facility was available in the laboratory, therefore, CO emissions are higher for the RDF briquettes but it comply the NEQS (800 mg/Nm^3) set by Federal EPA. These low values indicate the good combustion practices and fuel quality of RDF.

Sulfur Dioxide (SO_2) from the cement kiln stack was at the average of 165 mg/Nm^3±1.6. It was at the average of 224 mg/Nm^3±1.4 from coal mill stack. SO_2 from incinerator with RDF briquettes was recorded at the average of 552 mg/Nm^3 ±1.03and from incinerator with RDF briquettes with lime was recorded (Table 4) at the average of 513 mg/Nm^3 ±0.04. These values were within the permissible limits of 1700mg/Nm^{3}set by the Federal Environmental Protection Agency (EPA) for RDF guidelines in the form of National Environment Quality Standards (NEQS).

Table 4. Flue Gas Emissions from Kiln and Coal Mill

Reference Point	Fuel Specification		CO (mg/Nm3)	SO2 (mg/Nm3)	NOx (mg/Nm3)
Kiln	Coal	Min	325	161	563
		Max	331	167	567
		Average	328	165	567
		St. Dev.	1.4	1.6	1.67
Coal Mill	Coal	Min	317	223	630
		Max	323	225	637
		Average	320	224	633
		St. Dev.	1.2	1.4	1.04
Incinerator (Muffle Furnace)	RDF briquettes	Min	500	550	780
		Max	506	553	784
		Average	505	552	784
		St. Dev.	1.02	1.03	1.08
	RDF briquettes with Ca $(OH)_2$	Min	499	513	732
		Max	502	517	735
		Average	500	513	734
		St. Dev.	0.6	0.04	0.5
NEQS Limits	Coal		800	1700	1200

As shown in Table 4 the SO_2emissions from the stacks were approximately 4 times less than the emissions from the incinerator in the laboratory. The reduced SO_2emission rates can again be explained by the presence of scrubbers and ESP in the cement unit. It is important to note that, the SO_2 emission rate was lower in the RDF briquettes with lime. The reason could be the heterogeneous reaction of SO_2, with the calcium hydroxide $Ca(OH)_2$ of lime to form calcium sulfate ($CaSO_4$).

Nitrogen Oxides (NO_x) from the cement kiln stack at the average of 567 mg/Nm^3±1.67 and from coal mill stack was at the average of 633 mg/Nm^3±1.04. It was recorded at the average of 784 mg/Nm^3 ±1.08from incinerator with RDF briquettes and from incinerator with RDF briquettes with lime was recorded at the average of 734 mg/Nm^3 ±0.5 (Table 4). These emissions are in compliance with the limits (1200mg/Nm^3) set by the Federal Environmental Protection Agency (EPA).

Table 4, shows that there is difference among the NO_x emissions that seems to vary due to fuel properties, or the temperature in the kilns or the incinerator. NO_x emissions by the RDF briquettes with lime are lower than the RDF briquettes in the incinerator. This can be attributed to the possible reaction with water droplets in the stack to forms nitric acid (HNO_3). Formation of NOx in the combustion process either comes from thermal fixation of nitrogen in the air at high combustion temperatures or through conversion of chemically bound nitrogen contained in the fuel.

3.6 Particulate Matter Monitoring

From the monitored and processed data (Table 5), it is clear that the average emission values of Particulate Matter (PM) from the cement kiln and coal mill were 134.27 mg/Nm3 ± 0.6 and 145.36 mg/Nm3 ± 1.0 respectively. Emission values recorded at incinerator with RDF and RDF amended with lime were 305.25 mg/Nm3 ± 1.5 and

290.45 mg/Nm3 ± 1.4 respectively. It is clear from table 5 that the emission values of particulate matter are higher for incinerators than the kilns due to absence of ESP.

Table 5. Particulate Matter Present in the Emissions

Reference point	Particulate matter (mg/Nm^3)			
	Min	Max	Average	St. Dev.
Cement Kiln	133.3	135.6	134.27	0.6
Coal Mill	142.8	145.9	145.36	1.0
Incinerator with RDF Briquettes	302.1	304.4	305.24	1.5
Incinerator with RDF Briquettes with $Ca(OH)_2$	279.4	281.7	290.45	1.4

Particulate emissions are influenced by a number of factors, the most important being the fuel composition, the method of firing i.e., excess air, under fire and over fire. The cement industry under study is well equipped and leading industry of the country. It tends to adopt sophisticated technologies to earn its customers trust. It uses export quality fuel and sophisticated machinery where there are less chances of production of particulate matter in large amounts.

4. Conclusion

With the average calorific value of 4540 kcal/kg, and low emission of flue gases with less particulate matter, the RDF briquette with mixture of Ca(OH)2 was a suitable most option to be used in cement industry.

It is recommended to use RDF, prepared from Municipal solid waste in cement industry after proper segregation. If it is used as a supplement with coal, amendment with lime is important to capture SO2 emission.

Author's Contributions

Mohammad Nafees
Principal investigator: Help in proposal, field work and laboratory work and report writing
Nazish Huma Khan
Co-investigator: Proposal review, Laboratory supervision, data analysis And field arrangements.
Saira Batool was M.Phil Student and was responsible for data collection in the field and Lab. Work.

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Data Availability

Data supporting reported results can be found in the links to publicly archived datasets analyzed.

Conflicts of Interest

The author has no conflict of interest

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