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A Techno-Economic Analysis of Alternative Fuels in Cement Industry in Pakistan

Muhammad Umer Ali
Department of Energy Management and Sustainability, US-Pakistan Center for Advanace Studies in Energy (USPCAS-E), UET Peshawar
Umer.ali863@gmail.com
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***Abstract*—**Alternative fuel use in cement industry has seen a rise in the recent years in lieu of the growing concerns about the growing share of the industry in global green house emissions which stand at 8% of overall carbon dioxide emissions worldwide. Prominent amongst the reasons for this high emission is the use of conventional coal in providing heat requisite for processing in the cement industry. The use of alternative fuel, however, has started a positive downward trend in the emissions of the industry. The use of alternative fuel, most prevalent among which is Refuse Derived Fuel (RDF), has a twofold advantage: economic fuel for cement production, and a venue for disposing off the solid waste in the landfills around big cities. This experiment of alternative fuels use in cement industry is largely without any impact assessment on the economy and ecology of the cement manufacturing. Obviously the technical assessment has been performed by the industries themselves in terms of energy contents, the larger impact of these fuels on economy and environment is still unknown or not published. This research undertook the technical analysis of these alternative fuels used in three cement industries in Pakistan comprised of characteristics like calorific value, Sulphur and chlorine contents, carbon emissions accruing from the use of the these fuels. In addition the economics associated with the use of these fuels were also investigated through comparison with economy of the conventional fuels.

***Keywords*—** Techno-Economic, RFD, Fuel, Cement, Industry.

I. INTRODUCTION

Fossil fuel supply is depleting fast and is slated to run out in the third quarter of the current century [1]. The current rate of fossil fuel exploitation has raised alarms for the sustainability of the energy resources of the world. There in an acute instability in the prices which is fast forcing the world to look for alternative means of energy. Global warming has been treated with accentuated seriousness for the past thirty years starting with Kyoto protocol, where the consensus on the negative repercussions of the increased dependency on fossil fuels was realized and a plan to barricade against it was formulated. In the ensuing years, the need to keep up with global economic growth has forced individual countries to leave out the promises of environmental upkeep and focus more on their individual economic growth. This had resulted in the increased utilization of fossil fuels post Kyoto protocol as shown in the Figure 1.

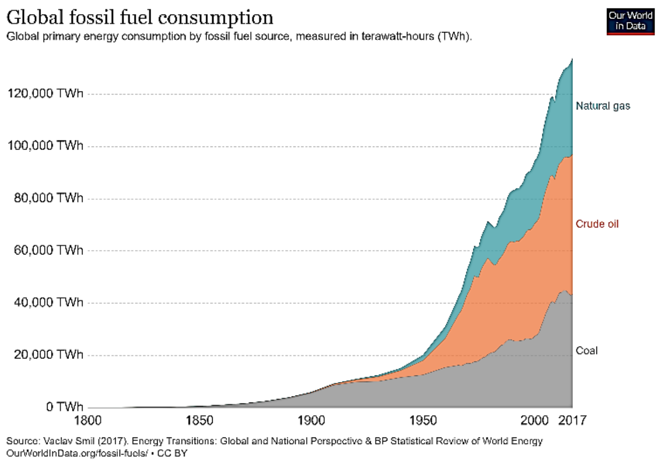

Figure 1. Fossil Fuel Consumption[2]

Refuse Derived Fuel is used in various cement industries in Pakistan. The fuels are made from the landfills and waste dumps in the vicinity of these industries. The RDF fuels, however, have not yet been analyzed through an independent research to form an all-encompassing view of the contents, economic impact, and emissions.

In addition to the differences in the chemical composition of the RDF fuels caused by the variation of landfill composition, the emissions resulting from the burning of these fuels also vary from site to site and day to day [3]. This research will also investigate the emissions level and composition of the emission in the product of combustion of the RDF fuels in various cement industries in Pakistan. The determination of the emissions, their impact on environment, and the comparison with the conventional fuels across the whole life cycle of these RDF fuel will establish convincing evidence for their large-scale acceptability in other industries across the country.

II. LITERATURE REVIEW

A. Cement Manufacturing Process

Cement manufacturing process is highly energy intensive consuming energy in the form of electrical and thermal energy at different stages of the process. Additionally, energy is also required for the transport of the raw material, mining of the raw materials, and the end product..

B. RDF Production Process

The steps involved in the RDF production are given one by one in the following and schematically illustrated in Figure 2

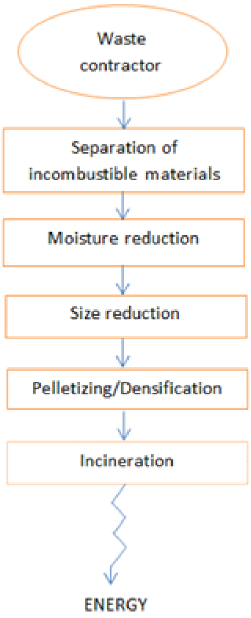

Figure 2. RDF pellet production process

C. Municipal Solid Waste for Energy Applications

MSW has been commonly used for electricity generation all over the world and has resulted in significant GHG mitigation [4]. In developed world particularly this technology has seen the greatest growth to the point where Sweden, for the first time, had to import MSW from neighboring countries in 2018 for electricity generation [5].

Current state of the MSW based electricity generation generally involves the conventional techniques such as direct incineration, pyrolysis, and biogas gasification [6]. Even in these conventional techniques there is a net positive impact on the environment for providing an avenue for disposal of non-disposable waste such as plastic waste [7].

Incineration, in the initial years, was solely used for reducing the solid waste volume, however in the recent years has found more and more use in electricity generation in co-processing with other conventional fuels [8]. The average energy contents in the various components of MSW is given in the Figure 3 below which would paint a clear picture for drawing the calorific value of MSW given the component percentage [9].

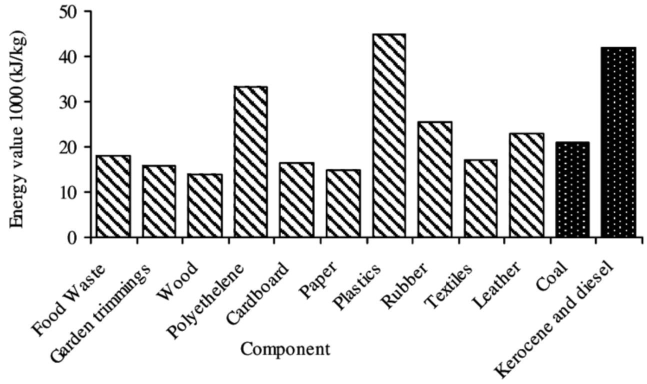

Figure 3. Energy Content of various components present in MSW

D. RDF in Pakistan

In Pakistan, as in most of the developing world the landfills are a big source of methane production, where extended stay leads to ever greater methane generation. Uncontrolled landfills contribute one third of global methane production, which can be significantly reduced by handling the MSW in a more productive way like converting them to RDF [10]. In Pakistan per capita waste generated ranks 135th amongst the world contributing 0.8% of global methane production [11]. The municipal waste in Pakistan consist of the common components in the proportions indicated in the Figure 4 below [12].

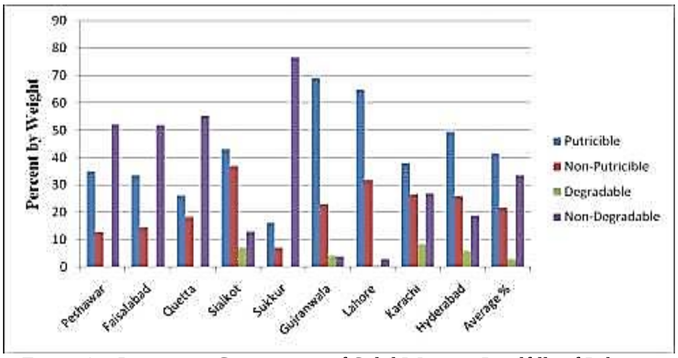

Figure 4. Percentage Composition of Solid Waste in Landfills of Pakistan

III. METHODOLOGY

A. Sample Collection

The Refuse Derived Fuel (RDF) samples from the three cement manufacturers were acquired along with a sample of the coal used in the respective facilities for cement manufacturing. The samples were coded as RDF 1, RDF 2 and RDF 3 for masking the names of the industry from where the sample were taken.

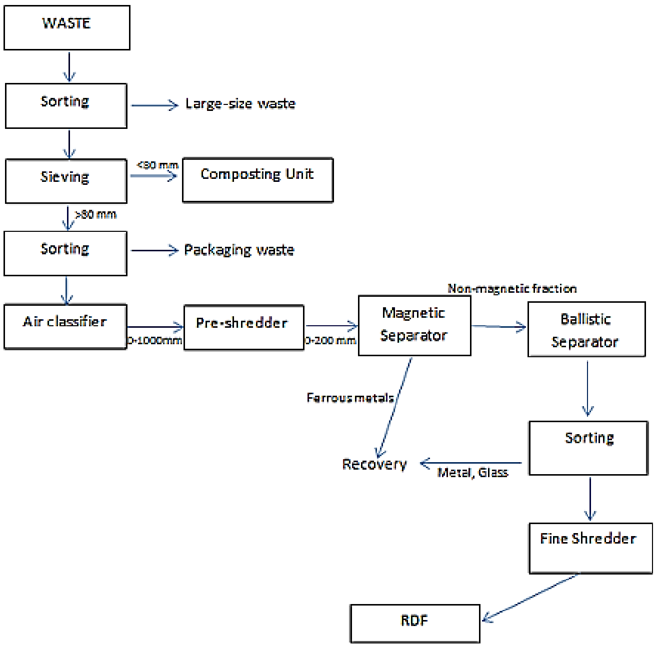

Figure 5. RDF Manufacture Process

B. *Proximate and elemental analysis*

The proximate and elemental analysis of the all the samples was conducted. The standard ASTM D5142 was followed for conducting this analysis. The standard is specially purposed for determination of coal, and coke quality parameters such as moisture content, ash, and volatile matter content. This standard will also be used for determination of these parameters for the RDF samples [13].For carrying out proximate analysis, the fuel was assumed to contain two kinds of portions: volatile matter and fixed carbon content. Accordingly, the moisture content of the samples were found out by placing the sample (1g each) at 105ºC for approximately 2 hrs. The weight loss accruing thus is a good indicator of the moisture content of the samples. For volatile matter and ash content the weight loss resulting from oxidation at temperatures of 550ºC and 750ºC respectively for 2 hrs. was measured. The fixed carbon contents are the difference of the volatile and ash content from the whole dry sample.

C. *Calorific value determination*

Calorific value of the RDF and coal samples from all the industries was conducted. For this purpose, bomb calorimeter was used [14]. A bomb calorimeter, as shown in the Figure 6, consists of a constant volume container, hence the process is isochoric. The heat contents of the sample are determined using the change in internal energy, obtained from temperature change inside the container and the heat capacity of the calorimeter. For finding calorific value of a sample a known weight was placed inside the steel ball and combusted. Subsequently pressurized oxygen is provided and the steel ball is kept in adiabatic water bath, connected to electric current. The spark from electrical energy combusts the sample, heating the water, and the change in the temperature is measured by electronic thermocouple. The change in mass vs the change in temperature gives an idea of the calorific value per kg of the sample.

Figure 6. Bomb Calorimeter for CV determination

D. *Carbon dioxide emission analysis*

The emissions, mainly Carbon Dioxide, determination in the samples will be carried out. For this purpose, The International Standards Organization's ISO 16948 standard was used. The standard presents the instrumental arrangement, calibrations, and precautions for determination of the carbon, hydrogen, and nitrogen contents of solid fuels [4].The equipment used for this purpose is called flue gas analyzer.

E. *Flue Gas Analyzer*

This analyzer consists of two separate units called conditioning and photon unit. Moisture in the flue gas is blocked in the conditioning unit, thus filtering out the solid particles in the flue gas. Consequently, what is reported is usually the emissions on dry basis. The conditioned flue gas is analyzed in photon unit. The flue gas analyzer gives out the percentage of CO_2, CO, NO, NO_2 and SO_2. Figure 7 shows a flue gas analyzer in the Laboratory of Department of Inorganic Chemistry at University of Peshawar.

Figure 7. Flue gas analyzer at UOP Laboratory

F. Comparison of Economy

For comparing the cost components of various RDF samples, the data from the sources to manufacture 1 Kg of RDF and the corresponding heating values in MJ was deduced from the CV and compared with the conventional fuel i.e. coal. The fuel cost per ton of cement manufacture for each of the alternative fuel samples and coal will be determined to give a Birdseye view of the economics of the RDF fuels in cement industry. The comparison of economy will also incorporate the long-term economic benefits and impact in terms of energy price, environmental impact, and the savings accruing thereof. The following formula was utilized to compute the net savings, both to environment and in direct benefits from Petcoke replacement.

Net Savings = ((Traditional Fuel Cost Savings + CO2 Emissions Cost Saving − RDF Production Cost) × (100 − Energy Loss))/100

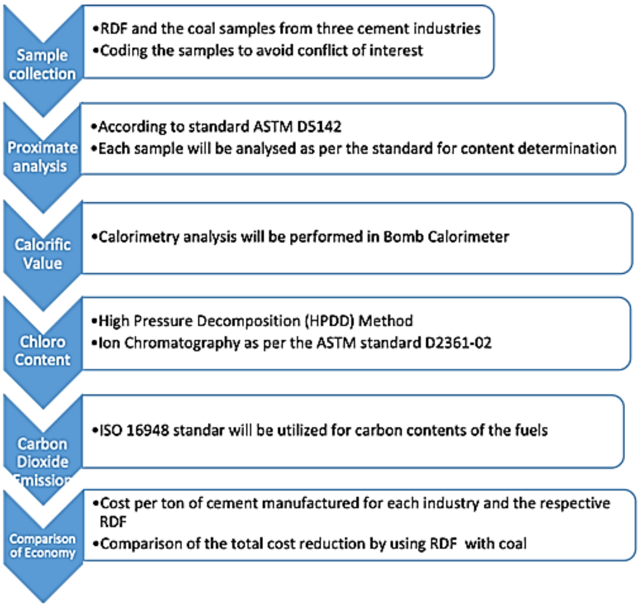

Figure 8. Overview of Methodology

IV. RESULTS AND DISCUSSIONS

A. Proximate analysis of RDF

The combustion properties of any fuel largely depend on the moisture content, ash and volatile matter in the solid fuel. Unless these properties are known it is not possible to get an idea of the nature of combustion the fuel undergoes [15].

The proximate analysis of a solid fuel sample usually yields four results namely: moisture content of the sample, volatile matter contained in the sample, fixed carbon i.e. nonvolatile content of sample, and inorganic byproduct in combustion process.In the current research the proximate analysis of the three available samples of RDF obtained from three different cement manufacturing plants in Pakistan was carried out. The results are given in the Table-1 in the form of the abovementioned four parameters.

TABLE I. PROXIMATE ANALYSIS

Samples used	Percentage moisture (%)	Percent Volatile Matter (%)	Fixed carbon content (%)	Ash content (%)
Sample-A	1.6	80.3	5.2	12.9
Sample-B	4.8	68.5	11.8	14.9
Sample C	5.2	74	10.6	10.2
Coal*	4.3	29.3	51.2	15.2
Petroleum coke**	6	12.1	81.2	0.7

The main portion of RDF is usually volatile matter which is also the case n the curent research. It should be noted that the volatile fraction is greater in case of the sample A in comparison with the rest. Also noticeable is the fact that the volatile matter in Coal and petcoke is usually smaller at the expense of higher carbon content. The moisture content of sample A is significantly lower than the other samples and coal and petcoke. This is due to long drying periods in the facility where the samples were produced. Large drying time leads to lower moisture content which inevitably manifests in desirable calorific values. Another factor which is significant in the Table-1 is the low carbon contents of sample A in comparison to the other samples and conventional fuels. This will give the RDF greater desirability in environmental protection. To categorically establish the credibiity of the results obtained here, a comparison was made with literature survey data [16]

B. Ultimate analysis of the samples and Calorific Value

The chemical composition of the fuel samples is significant to determining the combustion behavior of fuels. The exact carbon, oxygen, and hydrogen contents are important to the current study as they form the crux of the waste. In addition, nitrogen contents are also important aspect of fuels as they give an idea of the NOx gases released as a result of the burning of the fuels. Furthermore, Sulphur contents, due to their impact on the kiln and chimney and the formation of SO2 and SO3 is also important parameter in the viability of a fuel. For these reasons the ultimate analysis of the RDF samples was carried out. The results of the ultimate analysis are given in the Table II. The composition is compared with coal and petcoke chemical composition to give a clear idea of the viability of RDF as an alternative to conventional fuels.

TABLE II. ULTIMATE ANALYSIS

Samples	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulfur (%)	Oxygen (%)	Calorific Value (cal/g)
Sample –A	43.24	5.55	0.95	-	35.37	5262.63
Sample –B	56.76	8.67	1.65	0.47	17.45	4596.56
Sample -C	50.56	6.9	1.43	0.33	23.44	4958.34
Coal	63.76	3.65	1.75	0.55	12.94	6127.32
Petcoke	68.35	3.53	1.96	4.73	20.51	8217.53

The ultimate analysis of the samples under study suggest N, H composition under 9% albeit higher than the coal and petcoke samples suggesting presence of greater quantity of organic matter in the MSW. The samples are predominantly made up of carbon and oxygen. The higher CV of sample A than the others may be due to organic content in the samples. The coal under study is high cost and high CV so it may not come as a surprise that the CV of coal exceeds that of the RDF samples.

The CV values of the RDF samples are still closer to that of coal as compared with the other alternative fuels used in literature as shown in the Figure 9.

In terms of CV we can see that petcoke performs better than coal and RDF samples. This is largely due to the higher carbon contents, hence higher combustible material of the petcoke samples as indicated in the ultimate analysis. The petcoke sample has a higher C/H ratio when contrasted with that of the coal sample while lower C/O ratio than coal. The same ratios are in completely different range for the RDF samples providing a key distinction amongst the samples.

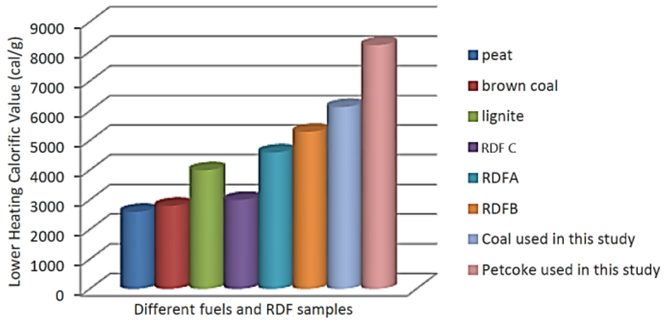

Figure 9. Comparison of RDF samples and coal and petcoke samples Calorific value with other fuels

C. Carbon Dioxide Emissions Determination

For the purpose of carbon dioxide emission determination flue gas analyzer was used on the RDF to give an idea of the percentage CO_2 emissions from the samples. The results are shown in form of the graph shown in the Figure 10 below.

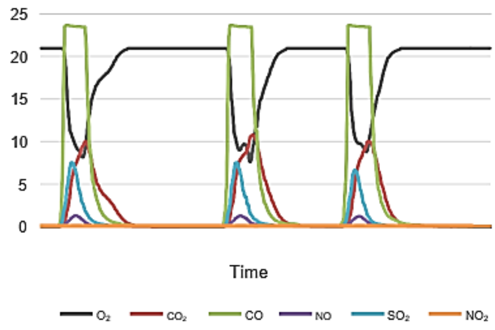

Figure 10. Flue gas analyzer results of RDF sample A

D. Economic comparison of RDF use with Coal

For assessment of the economic impact of using RDF instead of petcoke in the cement industry kiln an economic analysis was carried out. The analysis was based on the following assumptions:

- 4000 tons /day kiln production limit for 24 hours operation
- 24 hrs. operation implies 7200 hrs./year operation
- 381 tons/day petcoke consumption or 15.8 kg/hr.
- 715 kcal/kg.cl energy consumed in total
- Clinker production energy required 45.6 kWh/t
- Petcoke calorific value 8000 kcal/kg
- RDF calorific value 3500 -4000 kcal/kg (current research)
- Petcoke CO2 emissions: 70% of mass
- Cost of 1 kg emissions: 15 USD
- 1-ton RDF production cost 24 USD

Literature suggest the most optimum levels of RDF in cement production to be 15% in co-processing with petcoke or coal. Therefore, the current economic analysis takes this percentage in consideration for mathematical computation. Petcoke provides approximately 286x 107 kcal/kg.cl energy for producing 4000 tons of cement. Substituting 15% of this petcoke with RDF would suggest that 429 × 106 kcal/kg.cl of energy will be provide by RDF. Calculating the dollar cost of this mixture for energy generation results in total financial savings of 2,640,522 USD/year.This saving does not yet contain the savings accruing from CO2 mitigation. This saving is for scenario with adding 15% RDF with petcoke in co-processing for a plant with capacity of 4000 tons/day production.

CONCUSLION

The research endeavored to analyze the potential of Refuse Derived Fuel vis-à-vis the conventional fuels as an alternative. To this end RDF samples used in three Cement industries in Pakistan were collected and passed through a series of tests in laboratory and then economic comparison to figure out the most optimum performing RDF which could give us an insight in to the best practices regarding their production and use. The Calorific values of the three RDF samples, and a coal and petcoke samples from one of the industries were also carried out. The CV values of RDF samples, albeit lower than the coal and petcoke samples, showed a considerable disparity amongst themselves. This was also in agreement with literature data where the CV value ranged through a big margin. Upon deeper analysis through proximate and ultimate analysis it was found that the CV performance of the RDF samples was dependent on the dryness, C/H, and C/O ratios, however their exact correlation could not be determined. It was discovered that all the RDF samples possessed lower carbon and nitrogen and Sulphur contents as compared with the coal and coke samples. This is particularly desirable for alleviating the overarching impact of cement industry on environment and could mitigate the emissions.

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