Utilization of Refuse-Derived Fuel (RDF) from Urban Waste as an Alternative Fuel for Cement Factory: a Case Study

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Abstract- The country's industrial development has led to increment in consumption of energy. Thus, energy saving is substantial in developed countries. Due to implement of cement in industry construction, authentic manufacturing method is essential. Cement is considered as high consumed source for industry which requires high productivity. On the other hand, imminent depletion of fossil resources, leads to utilization of alternative fuels. In this paper, we explore the possibility of alternative refuse-derived fuel (RDF) from Rasht city for Lowshan Cement Factory. The best choice of RDF for Lowshan cement factory is Fluff RDF. Considering the amount and the type of waste, 168 tons per day Fluff RDF has been calculated. Results represent that the use of RDF as an alternative fuel could raise heating value and lower production costs. 168 tons of RDF with heating value of 17790Kj/kg would be 21.2% of the energy needed to supply the cement factory. Furthermore, Exergy efficiency of the reaction is increased by applying RDF. By increasing the amount of paper in RDF, exergy efficiency increment rate is more than other material contained in RDF.

Keywords Cement, RDF, Alternative Fuel, Municipal Waste, Exergy

1. Introduction

Nowadays, lack of energy is a considerable issue globally and many developing countries meet their demanded fuel from other countries. Iran has one of the most energy consumptions between countries of the world, with per capita energy consumption of 10 times more than European Union [1]. Although, Iran is in top 3 countries in owning oil fields and second country for gas but with this high energy demand, in early next century, it will become an importing energy user [2]. The model modified in which the real energy price has used. In other hand, population rise and civilization development results in many problems is related to municipal solid waste bury. The place needed for burying residue is 1/3 m3 which this place produce 400 m3 greenhouse gas and 250 L fluid. The amount of investment to destroy municipal solid waste is very important to establish destroying residue factories. Today in addition to residue burners, residue pyrolysis and RDF–Refuse derived fuel has been used to produce energy from municipal residues. This technology has assisted by increasing energy price in industrial countries. Derived fuel from RDF has energy and organic materials that is useable by heating value adjustment for cement, wood and paper industries and thermal stations and residue burners.

MSW production is increasing notably in Europe, and MSW has become a common alternative fuel in the cement industry. However, most cement plants do not directly burn unsorted MSW due to the heterogeneous nature of the waste and the presence of components that could pose quality and environmental concerns. Instead they use RDFs like the ones mentioned above [3]. The RDFs from MSW have different physical and chemical properties depending on their sources, especially with respect to their ash, chlorine, sulphur, and water contents [4]. There are notable differences among RDFs, and certain physical and chemical properties can cause difficulties in the kiln combustion process in cases where the RDF is added directly [5-6].

Nomenclature

RDF	Refuse Derived Fuel	**LandGEM**	Landfill Gas Emissions Model
MSW	Municipal Solid Waste	**EUETS**	EU emissions trading system
IMGSR	Institution Manager & Guilan solid residues	**NG**	Natural Gas
EPA	United States Environmental Protection Agency	**ASTME**	American Society for Testing Materials

The cement industry is an energy-intensive industry with energy typically accounting for 30–40% of production costs. Fig. 1 presents the distribution of electricity demand in each stage of the cement production process. The energy consumption is estimated at approximately 2% of world's total, and 5% of industry total. The fuel mix in the industry is carbon intensive, and the calcination process itself produces CO2, so that in total the cement industry contributes 5% of the global CO2 emissions [7-8].

The 2008 production of cement in the European Union was 200 Mt, approximately 7% of the world production [7]. In Europe, 158 Mt of CO2 were emitted in 2008 from cement plants which corresponds to 38.5% of all industrial emissions in Europe or 3.2% of the total European CO2 emissions [8]. In a modern cement plant, 60% of the CO2 emitted by a cement plant results from the calcinations of limestone, 30% from combustion of fuels in the kiln and 10% from other downstream plant Energy efficiency improvements (use of energy efficient equipment, process modifications, etc.). Switching fuel to waste as an alternative fuel, and blending cement with industrial by-products have helped to decrease the CO2 emissions associated with energy conversion [9-10].

There are many advantages in using RDF such as minimizing CO2 emission and ash residue, producing more homogeneous fuel, having higher calorific value content and a lower moisture content. It is reported that for a net carbon offset through the replacement of coal with RDF, water content must be less than 15% and in this case net reduction in emissions is obtained as 0.4 tons CO2/ton coal [11]. RDF production and use in cement kilns can be environmentally and economically viable solution for Metro Vancouver [12].

The basic issue regarding the use of RDF instead of cement kilns is the chlorine content, since chlorine weakens the cement and increase the risk of corrosion of steel bars in reinforced concrete structures. Alternative fuels that have high amount of chloride like PVC should be used in limited amounts and fuel mix optimization is very critical in terms of sufficient heat value in kiln and cement quality [13-14].

The utilization of RDF in cement industry is common since 1993 in EU while in Austria, Belgium, Denmark, Italy and Netherlands are some of the indicative countries. Around 115,000 ton of MSW were co-incinerated in cement kilns in Europe in 1997 and more than 300,000 ton of RDF in 2003 [6]. Also in Turkey the target for a single cement plant is 35000t/y the usage of RDF [15].

The scope of this study was to evaluate the use of waste as an alternative fuel in cement factory. The amount of energy saving is calculated and the influence of component of waste on chemical exergy of the fuels is shown. It has been shown that by increasing the amount of plastic exergy increase rate reduced and can be seen that by increasing the amount of paper, exergy increase rate is higher.

2. Solid Waste Situation in Rasht

Since 1984, Rasht residues is transferred to Saravan jungle. This place is in 20 km south of Rasht (Latitude: N 37° 4' and Longitude: E 37° 49'). It is 2 km far away Rasht – Qazvin road, its sea level is 200 m that more than 850 tons residue in day bury in it. For 29 years it accepts Rasht, Fouman, Shaft, Somaesara, Khoskebijar, Kochesfahan and Lashtenesha residue that Rasht share is up to 680 tons in day. 90 % of total residue is for Rasht. Their latex enters Anzali lagoon through Zarjoob and Pirbazar rivers. This place is not healthy. Production rates in Rasht are collected house and commercial residues.

2.1. Percentage of waste

Rasht wastes were transferred to Saravan forest park in 1984. This stockpiled place is located in a valley with natural vegetation, and due to the expansion of Saravan forest in the south-easte, Rasht is surrounded by forest like all the northern regions of Iran. It is not designed on the principles of landfill engineering and there are lacks of the necessary components such as liner, cover soil, gas and leachate collection and treatment systems and other systems for the sanitary landfill. The most important environmental issues identified in this landfill is the surface water pollution by leachate emissions, leachate infiltration into the underlying layers and the possibility of groundwater pollution, gas emissions in the atmosphere, native animal feeding of wastes and damage to vegetation and wildlife. The percentage of municipal waste of Rasht shown in Table 1 [16].

Table 1. Appearance properties of accepted manuscripts

Percentage of municipal waste	Municipal waste of Rasht
Organics	67.5%
Metals	1.5%
Glasses	3%
Papers	10.6%
Plastics	11.9%
Textiles	2%
Rubbers	2.5%
Wood	1%

2.2. The amount and waste generation rate

Institution manager and Guilan solid residues management (IMGSM) reported that Rasht capita residue product range is 900 to 1000 kg per day. Regarding to present population of Rasht (almost 700000 according to 90 statistic) and capita residue production (900 – 1000 g / each one) Municipal waste rate in day is 630 to 700 tons per day. Regarding to increasing population during spring to summer due to tourists in area, residue production rate receive to 800 – 850 tons per day.

2.3. Special heating value of waste

The residues heating value in Rasht has determined to be 5968 (Kj/kg). If this value is less than 6000 (Kj/kg), thus it is not suitable for residue burner stations. Rasht low heating value of residues is unacceptable. We should help fuel or RDF to solve this problem.

Special heating residual value specified in Table 2:

Table 2. Typical wet heating value of waste components

Waste components	Special heating value (Kj/kg)
Plastic	25000
Glass	-290
Cloth	13000
Metals	-290
Paper	12000
Paperboard	12000
Hazardous waste	1500
Organic matter and vegetables	3000
Wood and branches of trees	15000
Rubber and leather	16000

3. RDF Production

RDF is a kind of energy recovery that after different processes produces as residues fuel. After separating and selecting suitable residues, for to produce RDF production, the residues are dried by sun or hot air passing. Then screening is done to separate residues in different sizes. Next steps are size reduction and magnetic separation. Final RDF produces by 3 methods that include bricks, pellets and fluff.

- Materials in large size which are separated by screening including plastic bags and etc. produce Bricks.
- Materials that becomes small by size reduction and screening, produce Fluff.
- Finally small residues such as plants mix produce Pellets

Another kind of RDF fuel consists of municipal solid residues burning after separating materials such as glass which they don't burn. This fuel uses as a solid fuel in RDF boilers beside oil. At present RDF enters in cement oven as fossil fuel replacement.

RDF has classified according to ASTME 828 – 81 in 7 groups and has shown in Table 3.

Table 3. RDF types

types RDF	**Specifications**
RDF_1	Raw waste or with minimal processing
RDF_2 (Coarse – RDF or C –RDF)	Waste processed into coarse particles with no Separation metals in a way that 95% by weight of 6-inch square mesh sieve pass
RDF_3 (fluff RDF)	Processed fuel derived from waste by separating the metals, glass, and other inorganic materials. The material in a way that a 2 inch square mesh sieve passes.
RDF_4 (Power_RDF or dust_RDF)	Combustible waste components in powder form and 95% by weight of 0.035 inch square mesh sieve pass.
RDF_5 (densified–RDF or d – RDF)	Flammable waste extruded sections (compressed) in the form of pellets, cubes, briquettes, or similar forms. Due to the numerous advantages of portability and storage, and the ability to coordinate with a variety of combustion systems in developing
RDF_6	The combustible waste in liquid form is processed
RDF_7	The combustible waste gas is processed to form

4. The Use of RDF in Lowshan Cement Factory

Lowshan cement factory has founded in 1956 and first oven had 300 tons capacity in 1956 which ran Sefidrood dam in Lowshan. Second oven ran in 300 tons in 1993 and this factory received 600 tons production in day. Rasht residue derived RDF uses in Lowshan cement factory. RDF production includes 2 units and a pre–calciner according to dry process. Each unit has 2000 tons calciner in day. Gasoline and natural gas is used for production in pre–calciner and main oven flare. Different feed points to feed RDF in cement factory pre–calciner are:

- through main flare in oven and exit (powder fuel)
- through feed shooter in transfer chamber in oven end entrance (piece fuel)
- through pre–calciner to pre–calciner flares (powder fuel)
- through feed shooter to pre–calciner (piece fuel)

This means RDF feeding makes possible to use powder RDF (RDF–5 according to ASTM) and piece RDF (fluff RDF and RDF–3). Cement factory Azarab firm experts accepted RDF conditionally, if the factory did not need main changes or modification in facility quality and their productivity position. Feeding by pre–calciner and main flare will need considerable changes. While feeding facility in stalls is easy through transfer chamber. Another advantage of transfer chamber feeding is that air running and temperature help RDF quick burn. In other hand EPA studies shows that to ensure Fluff RDF burn completely in cement oven reactors, this RDF size should be less than 25mm.. Regarding previous researches and mentioned facts, it is necessary to produce fluff RDF for Lowshan cement factory.

To produce Fluff RDF one should place RDF in large size in next processes. After separating by magnet the RDFs lead to breaker and material larger than 80 mm including 80% of materials with high heating value (suitable to burn) select directly as large RDF and after adding by recovery material from composite factory its size decreases. Material severity in this direction is 350 tons in day. Then, broken materials, transfer to separating units by passing air. Air passing separates heavy materials such as metals, glass and organic from light ones. Light materials severity is 168 tons/day (which is suitable for RDF). Such materials lead to second breaker to decrease size in 25 mm. According to table 1 thermal value is 17790Kj/kg.

Cement production cycle is described in Fig.1. The raw materials for cement production are quarried using powerful excavators or explosives and the limestone is crushed by special machinery into pieces usually smaller than 30 millimeters in size. The raw materials (crushed limestone, quartzite, bauxite, iron oxide, gypsum, etc.,) are stored separately by category, and then conveyed to the mill in carefully set and controlled proportions for mixing. The mills are metal cylinders with a powerful internal metal shielding that contain tons of spherical steel milling parts. As the mill rotates, these steel spheres crush the raw materials into granules, which form what is called raw meal. The raw metal is conveyed to special silos where the homogenization process is completed. After homogenization, the raw metal moves through a system of cyclones called a preheater, undergoing gradual heat treatment at temperatures up to 900 oC. Next, rotary kilns are used to roast the material. The kilns are metal cylinders with a length of 50±150 meters and diameter of 3±5 meters, lined with refractory bricks. The rotary action of the kiln and its angle drive the raw meal towards the exit. The temperature rises as high as 1400 oC. Due to processes within the kiln; the raw meal is transformed into a granular hard substance called clinker. Natural gas and Rasht residue derived RDF uses in Lowshan cement factory.

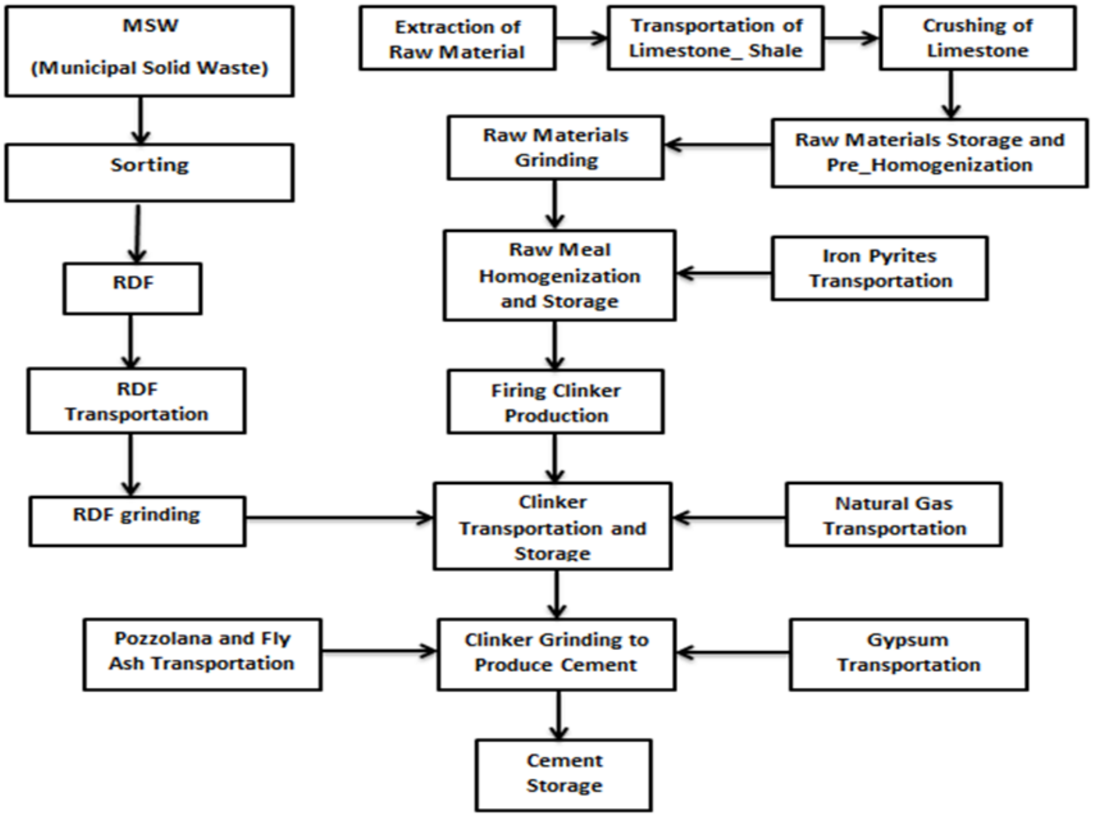

Fig. 1. Cement production cycle

5. Result and Discussion

5.1. Environmental assessment result

Cement plant creates environmental impacts to the surrounding area. CO, CO2, NOX, SO2, PM and PM10 are the emissions in the manufacture of cement and small amounts NH3, chlorine, and HCl spread [17]. CO2 produced by the combustion of fossil fuels and the calcined ore is the raw material mixture. CO2 content in cement production due to energy consumption is about 0.85 to 1.35 ton of CO2 per ton of clinker [18]. In general, the amount of 900 kg CO2 produced per tons of cement [19]. CO2 produced by the calcination of raw material is represented by equation (1):

$$(CaCO_3)_{1kg} \leftrightarrow CaO_{0.56kg} + (CO_2)_{0.44kg} \quad (1)$$

As it becomes noticeable calcination for 1 kg CaCO3 amount of 0.44 kg CO2 produced. The amount of CO2 produced per unit of fossil fuel consumption will be 0.46 per kg cement content.

With regard to the production of 4000 tons of cement in cement plant Lowshan, the amount of 3600 ton per day CO2 is produced. The 1840 ton per day CO2 value is derived from fossil fuels.

RDF consists of 37.86% paper, 42.5% plastic, 7.14% textile, 8.92% rubber and 3.56% wood. The amount of CO2 emissions produced by the use of RDF compared to coal, about 0.4 tons CO2/ton coal of reduced [13]. Unreported emissions from incineration of waste in cement pose a methodological gap in the international emissions accounting and in particular the EU ETS, which is currently overestimating the emission reductions in the cement sector [20].

The amount of CO2 produced by the landfill from 1984 to 2015 using the software LandGEM (Landfill Gas Emissions Model) shown in Fig.2 [21]. LandGEM (The US EPA Model) is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste landfills. The software provides a relatively simple approach for estimating landfill gas emissions. Model defaults are based on empirical data from U.S. landfills. Field test data can also be used in place of model defaults when available. The amount in 2015 is 54440 m3/ year. By using waste paper and wood production RDF this amount could reduce. The amount of buried waste is in Appendix 1 and the amount of CO2 produced by the landfill from 1984 to 2015 specified in figure 2.

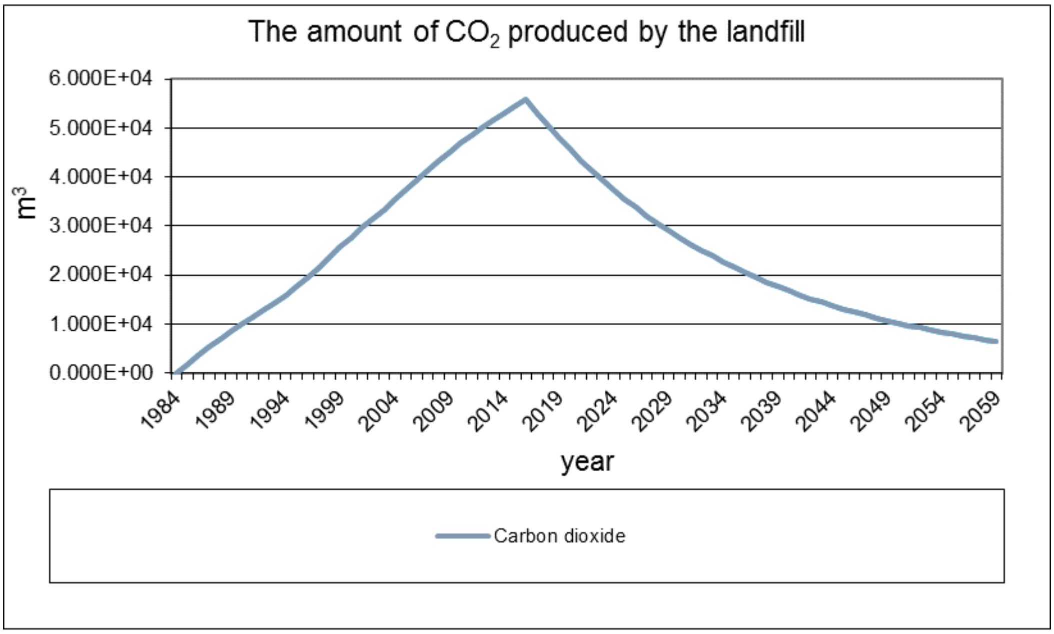

Fig. 2. The amount of CO2 produced by the landfill from 1984 to 2015

Use of alternative fuels (RDF) reduced the societal emission burned and converses fossil fuels. All remaining solids of the waste are used as raw materials in the cement itself; no landfilling of ash or slag is needed. Emissions from cement kilns remain essentially unchanged [22]. Air emissions, as heavy metals, are quite relevant when assessing waste co-incineration, as the amount of pollutants in the input are increased [23]. In Fig.3 the emissions produced in cement plants and incinerators can be seen.

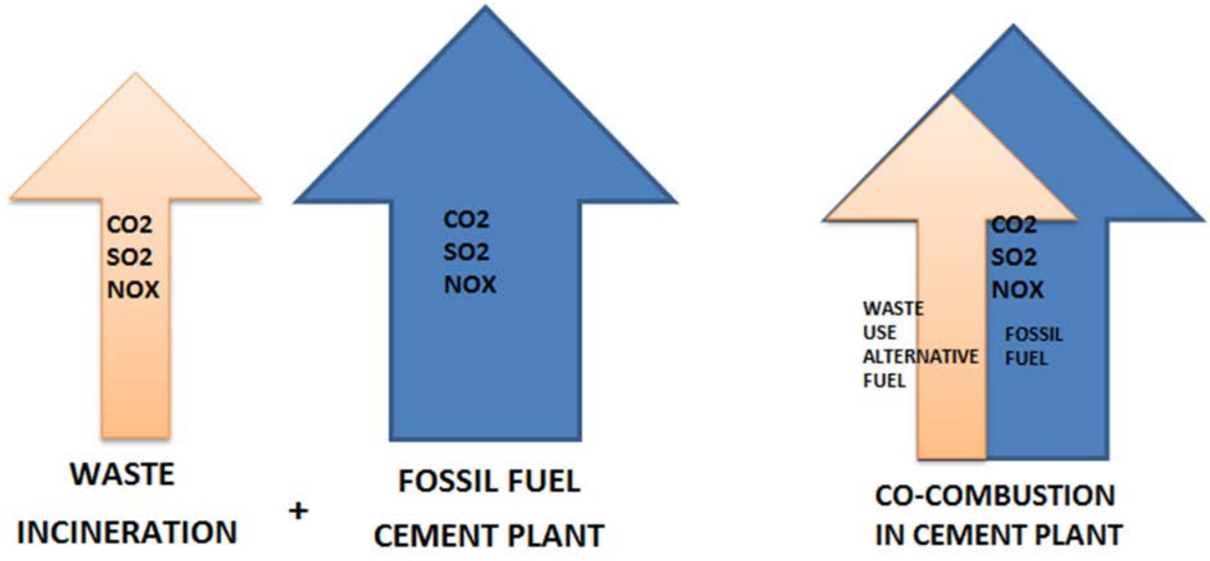

Fig. 3. The emissions produced in cement plants and incinerator

5.2. Energy assessment

RDF heating value is 17790 KJ/kg. If natural gas is used in the cement plant the amount will be 99.6 m^3/ ton clinker. Heating value of fuel is 3521662.7 KJ/ton. 168 tons of RDF with heating value of 17790 KJ/kg would be 21.2% of the energy needed to supply the cement factory. Information relating to the fuel consumption is given in Table 4.

Table 4. Fuel consumption of different fuel

The amount of natural gas consumed in the furnace	**99.6 m^3/ton clinker**
Heating value of natural gas	3521662.7KJ/ton clinker
Heating value of RDF	17790KJ/kg
Amount of RDF	168 ton
The amount of RDF is equivalent to natural gas	791829.72 kg
The amount of fuel saved	21.2%

The energy needed to produce one ton of cement is approximately equal to 3.5 GJ, which corresponds to about 120 kg of coal. 30-40% of total costs of cement plant included energy. The use of fuels made from waste in cement plants results not only in financial benefits for the industry, but also for society. Owing to such waste management, smaller quantities of waste will be disposed or directed to incineration plants. This will lead to a reduced number of new disposal sites, a limitation of the expansion of existing sites and will avoid the necessity to build incineration plants [24].

5.3. Chemical exergy assessment result

5.4. Chemical exergy in calcination

The following reactions are occurring in calcination process are represented by Equations (2) and (3) [25]:

$$CaCO_3 \rightarrow CaO + CO_2 \quad (2)$$
$$\Delta H_1 = 158KJ/\text{mol} \qquad \Delta G_1 = 135KJ/mol$$

$$MgCO_3 \rightarrow MgO + CO_2 \quad (3)$$
$$\Delta H_2 = 99.7KJ/\text{mol} \qquad \Delta G_2 = 47.2KJ/mol$$

The chemical composition of limestone and shale is given in table 5. The kiln feed is 75% limestone and 25% shale.

Table 5. The chemical composition of limestone and shale [25]

Component	Limestone	shale	Kiln feed
SiO_2	1%	52%	13.75
Al_2O_3	0.6%	14%	3.95
Fe_2O_3	0.2%	5%	1.4
CaO	53.4%	13%	43.3
MgO	0.8%	1.5%	0.975
K_2O	0.1%	2.5%	0.75
Na_2O	0.1%	1%	0.325
CO_2	42.8%	12%	35.1

The calcination exergy accumulation per kg clinker is:

$$\text{Exergy} = \frac{43.3}{100-35.1} * \frac{\Delta G_1}{Molar.\text{M}ass_{CaO}} + \frac{0.97}{100-35.1} * \frac{\Delta G_2}{Molar.\text{Mass}_{MgO}} = 1623 \frac{Kj}{Kg.Clin\ \text{ker}}$$

$$\text{Energy} = \frac{43.3}{100-35.1} * \frac{\Delta H_1}{Molar.\text{M}ass_{CaO}} + \frac{0.97}{100-35.1} * \frac{\Delta H_2}{Molar.\text{Mass}_{MgO}} = 1917 \frac{Kj}{Kg.Clin\ \text{ker}}$$

5.4.1. Chemical Exergy of the Fuels

Natural gas is the primary fuel for cement factory. According to calculations done above, 21.2% of natural gas has been replaced by RDF. Chemical composition of RDF and natural gas are given in table 6 and table 7 [26-27].

Table 6. Chemical composition of RDF by mass [26]

Waste part	H_2O	C	H	O	N	S
Paper	24.07	34.65	5.64	33.46	0.16	0.02
Plastic	21.22	50.93	8.49	19.36	0	0
Textile	10	49.5	5.94	28.08	4.05	0.18
Rubber	10	48.42	8.01	20.97	0.75	0.51
Wood	20.33	39.84	4.88	34.71	0.16	0.08
RDF	**19.53**	**42.19**	**6.75**	**25.68**	**0.56**	**0.07**

Due to increased natural gas consumption in residential homes in the cold season, alternative fuel should be used for cement plants. Table 7 shown chemical composition of natural gas:

Table 7. Chemical composition of natural gas by mass [27]

Component	Typical analysis (%)	Kg per ton clinker
Methane	94.9	67.3
Ethane	2.5	1.773
Propane	0.2	0.1418
Isobutane	0.03	0.02127

n-Butane	0.03	0.02127
Isopentane	0.01	0.007092
n-Pentane	0.01	0.007092
Hexane	0.01	0.007092
Nitrogen	1.6	1.135
Carbon dioxide	0.7	0.4964
Oxygen	0.02	0.01418
Hydrogen	trace	-

The chemical exergy of the ideal gas and liquid mixtures is computed from [28]:

$$E_{Ch}^{NG} = \sum_i x_i \varepsilon_{oi} - \bar{R}T_0 \sum X_i \ln y_i x_i \quad (4)$$

Standard molar chemical exergy for RDF and natural gas are shown in table 8.

Table 8. Standard molar chemical exergy

Chemical composition of RDF	Standard molar chemical exergy (KJ/kmol)	Chemical composition of natural gas	Standard molar chemical exergy (KJ/kmol)
$H_2 0$	45	Methane	824348
C	404589	Ethane	1482033
H	320822	Propane	2154000
O	231968	isobutane	2668920
N	453821	n-butane	2805800
S	598158	Iasopentane	3463300
		n-pentane	3463300
		Hexane	4134590
		Nitrogen	639
		Carbon dioxide	14176
		oxygen	3951

According to the type and amount of the waste, Specific exergy of chemical composition of RDF and natural gas is shown in the table 9.

Table 9. Specific exergy of chemical composition of RDF (according to the type and amount of waste) and natural gas

Chemical composition of RDF	Specific exergy (KJ/kg)	Chemical composition of natural gas	Specific exergy (KJ/kg)
$H_2 0$	0.4878	Methane	48770
C	14210	Ethane	1232
H	21490	Propane	97.68
O	182.4	isobutane	13.78
N	3723	n-butane	14.48

S	13.54	Iasopentane	4.8
		n-pentane	4.8
		Hexane	4.797
		Nitrogen	0.365
		Carbon dioxide	2.255
		oxygen	0.02469

Chemical exergy amount of natural gas and RDF are calculated:

$$E_{Ch}^{NG} = 50140 \frac{KJ}{kg} \qquad E_{Ch}^{RDF} = 39620 \frac{KJ}{kg}$$

Table 10. Exergy of fuels

fuel	Specific exergy (KJ/kg)	Consumption clinker (KG/ kg)	Exergy input KJ/kg clinker
RDF	39620	0.061	512.6
Natural gas	50140	0.072	2845
total	-	-	3357

Taking into account the chemical exergy accumulated in the product, the exergy efficiency of the reaction for natural gas (NG) and NG+RDF are presented in the following values:

Reaction Exergy Efficiency (NG) = $\frac{1623}{3610.08} = 44.95\%$

Reaction Exergy Efficiency (NG + RDF) = $\frac{1623}{3357} = 48.37\%$

Reaction Energy Efficiency (NG) = $\frac{1917}{3610.08} = 53.1\%$

Reaction Energy Efficiency (NG + RDF) = $\frac{1917}{3357} = 57.1\%$

To find material component of RDF effect on reaction exergy efficiency, the amount of this composition increase to 100% individually. Exergy value by taking above changes is shown in Figure 4.

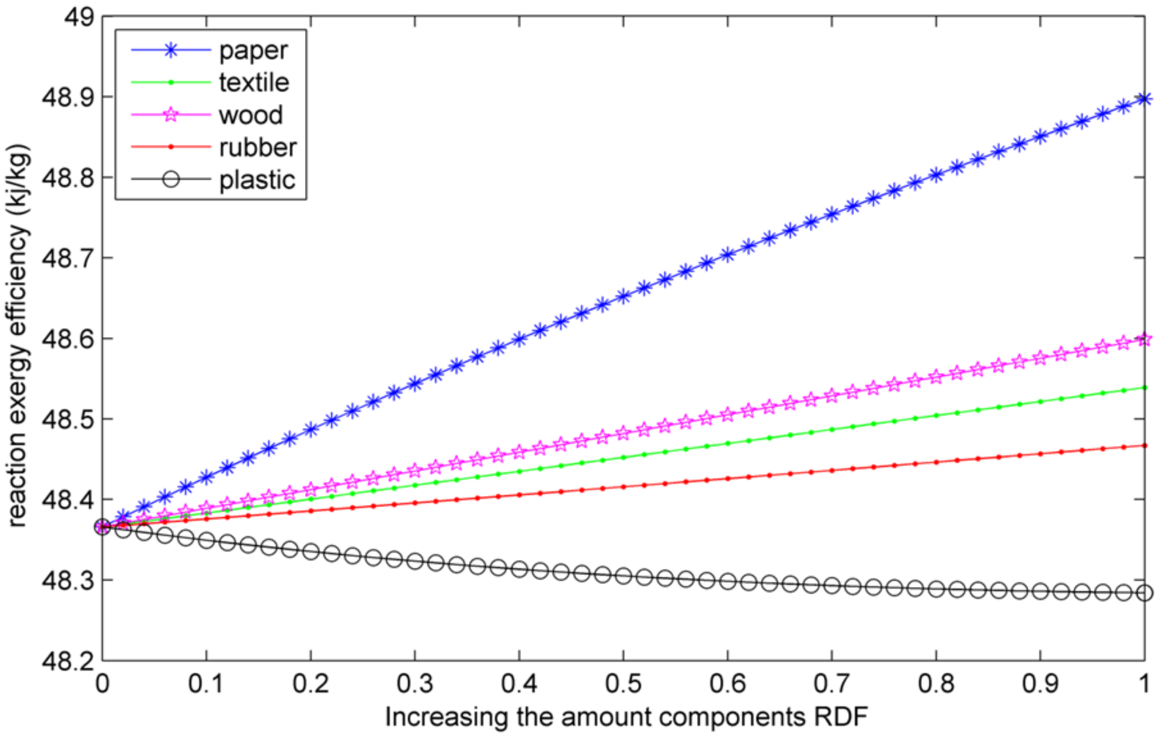

Fig. 3. RDF effect on reaction exergy efficiency

According to Fig. 4 can be seen that by increasing the amount of paper to 2 times as much as before, exergy increase rate is higher. Wood, textile and rubber, after paper have the highest reaction exergy efficiency increment rate respectively. By increasing the amount of plastic to 2 times as much as before exergy increase rate reduced. The amount of N and S for chemical composition of plastic is zero and considering standard molar chemical exergy (table 5,7 respectively), the reaction exergy efficiency with increasing the amount of plastic is reduced. Chemical composition of component of RDF and standard molar chemical exergy are effective on exergy increase rate.

6. Summary and Conclusion

Regarding to increasing constructions and industrial plans in country, cement utilization is increasing. Cement factories need energy for production which is secured by fossil fuels. Lowshan cement factory is not an exception and to solve this problem in this study the Rasht residue derived fuel (RDF) is used to replace fossil fuels. Regarding to our research, Rasht residues could produce 168 tons/day RDF for Lowshan cement factory. Fluff RDF has been selected. This selection is due to complete burn of this kind RDF in cement oven and its size which is less than 25 mm.. 168 tons of RDF with heating value of 17790KJ/kg would fulfill 21.1% of the energy demand of supplying the cement factory. CO2 production for the amount of RDF will increase to equivalent of 296.75 tons per day.

Taking into account the chemical exergy accumulated in the product, the exergy efficiency of the reaction for natural gas (NG) is 44.95% and for NG+RDF is 48.37%. By increasing the amount of paper to 2 times as much as before, exergy increase rate is higher. Wood, textile and rubber, after paper have the highest reaction exergy efficiency increase rate respectively. By increasing the amount of plastic to 2 times as much as before exergy increment rate is reduced.

The following results are derived from this study:

- The possibility of using alternative refuse-derived fuel (RDF) from Rasht city for Lowshan Cement Factory is explored.
- The amount and the type of waste is determined.
- It was determined that the use of RDF as an alternative fuel could raise heating value and lower production costs.
- Exergy efficiency of the reaction is increased by applying RDF.
- The material component of RDF effect on reaction exergy efficiency is investigated.
- Exergy increase rate is higher by increasing the amount of paper to 2 times as much as before.

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Appendix:

Appendix 1 The amount of waste landfilled

Year	Waste Accepted		Waste-In-Place	
	(Mg/year)	(short tons/year)	(Mg)	(short tons)
1984	220	242	0	0
1985	222	244	220	242
1986	226	249	442	486
1987	230	253	668	735
1988	238	262	898	988
1989	218	240	1,136	1,250
1990	230	253	1,354	1,489
1991	245	270	1,584	1,742
1992	258	284	1,829	2,012
1993	270	297	2,087	2,296
1994	295	325	2,357	2,593
1995	320	352	2,652	2,917
1996	356	392	2,972	3,269
1997	386	425	3,328	3,661
1998	390	429	3,714	4,085
1999	390	429	4,104	4,514
2000	396	436	4,494	4,943
2001	400	440	4,890	5,379
2002	422	464	5,290	5,819
2003	434	477	5,712	6,283
2004	456	502	6,146	6,761
2005	462	508	6,602	7,262
2006	470	517	7,064	7,770
2007	471	518	7,534	8,287
2008	471	518	8,005	8,806
2009	473	520	8,476	9,324
2010	472	519	8,949	9,844
2011	474	521	9,421	10,363
2012	475	523	9,895	10,885
2013	475	523	10,370	11,407
2014	478	526	10,845	11,930
2015	478	526	11,323	12,455