Food Residue Biomass Product as an Alternative Energy Source for the Cement Industry

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Abstract

In this paper we examine whether food residue biomass can be used as secondary fuel in the cement industry and how we may setup a pilot-scale plant for its processing. We gather samples from household waste in collaboration with the municipality of Haladri. The food residue is shredded and dried, leading to a high homogenous product. Using well-established international standards, we then measure certain key physicochemical properties such as its net calorific value, its concentration in heavy metals and chlorine content. The characterization allows assessment of its suitability as an alternative fuel in terms of economic and technical feasibility as well as environmental impact. This study concludes that food residue biomass is a good candidate as a secondary fuel for the cement industry.

Keywords: cement industry, alternative fuel, co-processing, Food Residue Biomass (FORBI**)**.

Introduction

The cement industry is one of the most energy-intensive industries due to operating conditions, with thermal and electrical energy needs typically accounting for about 40% of the operational costs [1]. Clinker production requires considerable energy consumption since the kilns temperature should exceed 2000 °C. According to Cembureau [2], each ton of cement produced typically requires 60 to 130 kilograms of fuel oil or equivalent, depending on the cement type and the kiln technology employed, and about 110 KWh of energy [2,3]. Both the high energy cost and the environmental impact of fossil fuel usage have led cement manufacturers worldwide to consider the replacement of conventional fuels by alternative fuels. Furthermore, co-processing of waste contributes to another solution regarding waste management offering an environmentally sound recovery option for many waste materials, while at the same time contributing to a more eco-efficient production [4]. Using cement kilns for the management of waste, social, environmental and economic benefits may be achieved, as the amount of landfilled waste and CO_2 emissions are reduced, avoiding at the same time investment required for new waste-to energy incinerators [5]. The utilization of alternative fuels for the production of cement has been receiving an increasing acceptance for more than 20 years. The co-processing of waste in cement kilns has advantages, such as high temperature and high residence time in an oxygen rich atmosphere, consumption of ashes through incorporation within the clinker (preventing the need for final disposal), an intensive contact between the solid and gas phases ensuring absorption and conversion of volatiles, absorption of SO_2 and neutralisation of acids [6]. Thus, in the recent years, fossil fuels have been partially substituted by alternative fuels, typically residue-based sources industrial solid wastes, municipal solid wastes (MSW), refuse derived fuel (RDF), tires, waste oils and solvents, plastics, textiles and paper waste, biomass, meat and bone meal (MBM), wood chips and wood waste, recycled paper, agricultural waste such as rice husks, sawdust, sewage sludge and biomass crops [7,8]. Some types of waste, such as industrial solid waste or municipal solid waste require pre-processing, in order to comply with the technical specifications of cement kilns' operating conditions [4]. The penetration of secondary fuels in EU cement industry has marked over 40% substitution of fossil fuels derived from waste and biomass [5].

Greece has the lowest co-processing rate in the EU, with an average fossil fuel substitution of only 7% compared to the EU average of 41%, due to limited availability of suitable waste and the cumbersome and lengthy co-processing permit acqusition process. Additionally, 88% of the total waste produced in Greece is landfilled and only an 11% is recycled. The highest EU court have imposed on Greece 10 million euros in financial penalties for failing to comply with the waste framework directives [5,9,10]. Although, the percentage of municipal waste is estimated around 10% of the total waste generated at the EU level [11], it is crucial from a political perspective, since municipal waste is connected to the protection of human health and the environment from the negative impacts of improper disposal of waste.

At the EU level, food waste is expected to rise to about 126 million tons by 2020, from about 90 million tons in 2006 [12] and, at the same time, the EU aims to abate the amount of biodegradable waste, targeting that only the 35% of the 1995 quantities to be landfilled by 2020 [13,14]. Therefore, it is imperative to use methods for the management of the biodegradable fraction of household waste reducing the quantity of organic matter that is landfilled. A potential solution for the management of household food waste is the use of fraction as a secondary fuel in the cement industry.

Within the framework of the EU-funded H2020 research project Waste4Think, pilot-scale solutions are being studied for the valorization of household fermentable waste in the municipality of Halandri, Athens. Fermentable waste is collected from 230 households in the municipality and is first subjected to proper preprocessing (drying and shredding) yielding what is known as FORBI (food residue biomass product). FORBI occupies considerably less volume than the original waste and can be easily stored for long periods without deterioration of its physicochemical/thermal properties.

In order to assess the suitability of FORBI as alternative fuel, it is necessary to analyze its physical, chemical and thermal characteristics. In this work, we study the potential of exploiting FORBI as an alternative fuel in the cement industry as well as its appropriateness in terms of its physicochemical characteristics. We then proceed with its characterization and classification, and discuss its advantages and limitations in comparison with other fuels currently in use in the cement industry. The most important parameters: its calorific value, chloride and humidity content as well as its toxicity (are presented in Table 1).

Table 1. Main characteristics of Food Residue Biomass (FORBI)

Parameters	**Results**
Humidity (%w/w)	1.3
NCV (MJ/Kg)	17.92
Chloride (%w/w d)	0.50
Hg (%w/w)	n.d*

*not detected

Materials and Methods

In our experimental setting, FORBI is obtained from drying and shredding food waste at the municipality level. Household fermentable waste consists mainly of food residue, that is, food leftovers (besides bones), fruits, vegetables and used paper towels. The drying and shredding of the collected primary waste was done in a GAIA GC-300 dryer/shredder machine. Typical processing times were between 5 to 9 hours, yielding a product with humidity lower than 10% w/w. The preprocessing of the laboratory specimen was conducted according to the standard EN 15443 [15]. The mass of the specimen was reduced by *quartering*. The granularity of the specimen was measured with a Retsch AS 200 vibratory sieve shaker and was found to be below 4mm. For the subsequent analyses the granularity was reduced below 1mm, using a Retsch SM 200 cutting mill. We characterized a total of four sub-samples so as to check the homogeneity of FORBI. We mainly used laboratory standards for solid recovered fuels as, in this work, we focused on the possibility of using FORBI as an alternative fuel.

Experiments and Standards

The parameters required by Annex A of EN 15359:2011 [16] for the characterization and classification of FORBI as a secondary solid fuel were determined. We conducted a direct and elemental analysis, analysis for heavy metals, determination of the net calorific value (NCV), the gross calorific value (GCV) and the bulk density. We determined the humidity, the concentration of ash, volatile compounds and the fixed carbon by direct analysis. The fixed carbon is evaluated by subtracting the concentration of ash and volatiles from the total concentration of the sample. The elemental analysis of the sample involves the determination of carbon (C), oxygen (O), nitrogen (N), hydrogen (H), sulfur (S) and chlorine (Cl). In Table 2 the measured parameters and the corresponding measurement standards are listed.

Table 2. Standards used in the analysis of FORBI

Parameter	**Measurement standard**
Humidity	EN 15414-3:2011 [17]
Ash	EN 15403:2011 [18]
Volatile compounds	EN 15402:2011 [19]
Bulk density	EN 15401:2010 [20]
Calorific value	EN 15400:2011 [21]
Metals (As, Cd, Co, Cr, Cu, Hg, K, Mn, Na, Ni, P, Pb, Sb, Tl, V, Zn)	EPA 200.7 [22]
F, Cl, S	EN 15408:2011 [23]
C, H, N	EN 15407:2011 [24]
O	ISO 16993 [25]

Results and Discussion

In Tables 3, 4 and 5 the experimental results and comparisons with conventional and other alternative fuels are presented. Results for SRF, RDF and coal were obtained from the literature [26] and were converted to dry-matter-basis equivalents according to ISO 16993 [24] in order to compare them with FORBI.

Table 3. Direct analysis of FORBI, SRF, RDF, coal and petcoke ([1]dry matter basis).

	Humidity (%)	Ash (%)[1]	Volatiles (%)[1]	Fixed carbon (%)[1]
FORBI	1.1-1.4	8.0-8.7	75.3-78.1	13.2-16.4
SRF[26]	3.0	11.4	82.1	6.5
RDF[26]	30.4	23.3	66.2	10.5
Coal[26]	6.2	12.2	35.2	52.7
Petcoke[28]	7	0.7	12.1	87.4

The results show that FORBI exhibits high homogeneity, therefore, we judge that the use of the particular dryer/shredder as well as the used sampling protocol are effective. The bulk density of FORBI was found to be 690kg/m^3 while the apparent densities of SRF and RDF were 120kg/m^3 and 42Kg/m^3 respectively [27]. The average humidity (1.3% w/w), ash (8.3% w/w) and volatiles (76.5% w/w) are on a par with those of SRF [26]. The chlorine concentration is rather high (0.45-0.55%w/w), but this is to be expected because of the provenance of the material. The values of gross (19.44 KJ/kg d) and net (18.14 KJ/Kg d) calorific values are satisfactory. Moreover, the sulfur concentration in FORBI is significantly lower than that of conventional fuels as shown in Table 4.

Table 4. Elemental analysis, NCV and GCV of FORBI, SRF, RDF, coal and petcoke on dry matter basis.

	C (%)	H(%)	N(%)	S (%)	O (%)	Cl (%)	NCV (MJ/Kg)	GCV (MJ/Kg)
FORBI	47.9-48.7	6.16-6.26	2.29-2.31	0.13-0.16	33.0-34.2	0.45-0.55	18.09-18.38	19.32-19.65
SRF[26]	41.8	5.46	0.03	0.07	-	0.02	12.28	13.40
RDF[26]	40.4	4.89	1.41	0.46	-	0.36	20.26	21.26
Coal[26]	70.7	4.48	1.28	1.81	-	0.30	28.50	29.42
Petcoke[28]	68.12	3.63	1.94	4.73	20.5	-	34.38	-

The total amount of heavy metals in FORBI is low compared to the fuels shown in Table 5, whereas its potassium concentration is ten times that of the one in coal. We remarked that Hg, Cd and Tl were not detected in FORBI and almost double the nitrogen concentration of coal. These elements are critical parameters for the operating characteristics of clinker production units, production constraints (mainly thermal characteristics of the fireproof coating of the kiln and the flue gas ventilation systems), the clinker production rate as well as the environmental impact which are to be taken into account in the overall evaluation of FORBI.

Table 5. Concentration of metals (mg/Kg) on dry matter basis of FORBI and comparison with SRF, RDF, Coal, petcoke

	Cd	Hg	Tl	K	Na	Sum (As+Co+Cr+Cu+Sb+Pb+Mn+Ni+V)
FORBI	n.d*	n.d*	n.d*	15,006-16,516	3,738-4,636	49.3-57.4
SRF[26]	0.05	0.07	<0.1	92	247	51.6
RDF[26]	0.3	0.19	<0.1	3,454	5,362	329
Coal[26]	0.07	0.3	<0.3	1,845	868	261
Petcoke[28]	-	-	-	-	-	620

*not detected

According to EN 15359 standard [16], the net calorific value and the chlorine and mercury concentrations are indices used for classification (see Table 6). These properties are of interest because the net calorific value serves as an *economic index* as it reflects the thermal efficiency of the fuel. Chlorine concentration is a *technological index* as it quantifies the risk of corrosion in the combustion chamber and mercury is an *environmental index* because of its likely transfer, as a volatile compound, in gaseous emissions. FORBI's net calorific value in the studied samples was 17.96MJ/kg, its chlorine concentration (on dry matter) was 0.50% w/w and its mercury concentration below 0.006mg/MJ.

Table 6. Classification criteria for alternative solid fuels – EN 15359

Classification characteristic	Statistic measure	Unit	Class				
			1	2	3	4	5
NCV	Mean	MJ/Kg (ar)	≥25	≥20	≥15	≥10	≥3
Chlorine	Mean	% w/w (d)	≤0.2	≤0.6	≤1.0	≤1.5	≤3
Mercury	Median 80th percentile	mg/MJ (ar) mg/MJ (ar)	≤0.02 ≤0.04	≤0.03 ≤0.06	≤0.08 ≤0.16	≤0.15 ≤0.30	≤0.50 ≤1.00

In Table 7 we present limit values for alternative fuels set by authorities for individual permits for cement plant in Spain, Belgium and France [4] compared to those of the FORBI. FORBI could be used as alternative fuel in all three countries as its results are lower than respective limit values.

Table 7. Limit values for alternative fuels for different countries based on individual permits [4]

Parameter	Unit	Spain	Belgium	France	FORBI
Halogens (exp .as Cl)	%	2	2	2	0.49
F	%	0.20	-	-	<0.10
S	%	3	3	3	0.14
Hg	mg/Kg	10	5	10	n.d*
Cd	mg/Kg	100	70	-	n.d*
Tl	mg/Kg	100	30	-	n.d*
Sum Hg + Cd + Tl	mg/Kg	100	-	100	n.d*
Sb	mg/Kg	-	200	-	<2.00
Sum(Sb+As+Co+Ni+Pb+Sn+V+Cr)	mg/Kg	5000	2500	2500	18.4
As	mg/Kg	-	200	-	<2.00
Co	mg/Kg	-	200	-	2.13
Ni	mg/Kg	-	1000	-	6.05
Cu	mg/Kg	-	1000	-	7.19
Cr	mg/Kg	-	1000	-	4.25
V	mg/Kg	-	1000	-	<2.00
Pb	mg/Kg	-	1000	-	12.1
Mn	mg/Kg	-	2000	-	21.4
Zn	mg/Kg	-	5000		20.9

*not detected

Moisture effect in energy requirements

In our study we calculate the total energy consumption in kWh / tn for producing FORBI at 1.1%, 5%, 10% and 15% from food waste (Table 8). Final moisture content 15% is the maximum moisture for classifying the product in Class 3, LHV ≥ 15 MJ / kg. Food waste moisture levels of is at 78%.

Table 8. Drying energy requirements to produce FORBI Class 3- FORBI maximum moisture (for Class 3, LHV ≥ 15 MJ/kg):15%

Food waste (kg)	Food waste moisture	Food waste Dry matter (Kg)	FORBI moisture	Water evaporation (Kg)	FORBI (kg / tn Food waste)	FORBI LHV (MJ/kg)	Energy for water evap. (MJ / kg FORBI)
1000	78%	223	1.1%	775	225	17.9	9.8
1000	78%	223	5.0%	766	234	17.1	9.3
1000	78%	223	10.0%	753	247	16	8.7
1000	78%	223	15.0%	738	262	15	8.0

The results of Table 8 are depicted in Figure 1.

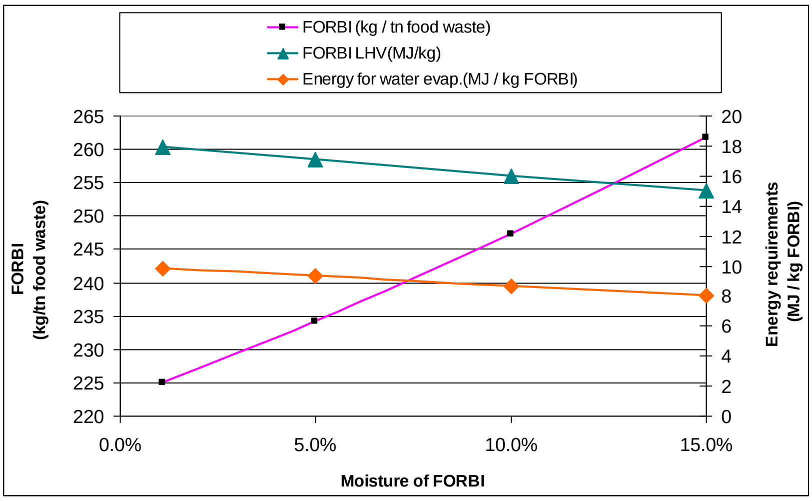

Figure 1. Energy requirement to produce FORBI.

From this analysis it becomes apparent that the energy content of FORBI is approximately twice the energy required for its production.

FORBI's effect in flue gases and fuel mixture

Two scenaria are considered in order to assess the effect of FORBI in flue gases and fuel mixture. Scenario 0 (base case) with fuel mixture calorific composition of 30% calorific coal, 70% petcoke and Scenario 1 with fuel calorific composition of 30% coal, 50% petcoke, 20% FORBI (1.5% moisture). Figures 2 and 3 show the results of the substitution of 20% petcoke with FORBI as an alternative fuel in a cement kiln (Scenario 1). Flue gas mass ratios in Scenario 1 with respect to Scenario 0 of the following parameters are depicted: Non Biogenic CO_2, SO_2, NO_X, HX in figure 2 and also mass ratios in Scenario 1 with respect to Scenario 0 of non volatile metals and also of alkalis K, Na, in the entire fuel mixture in figure 3.

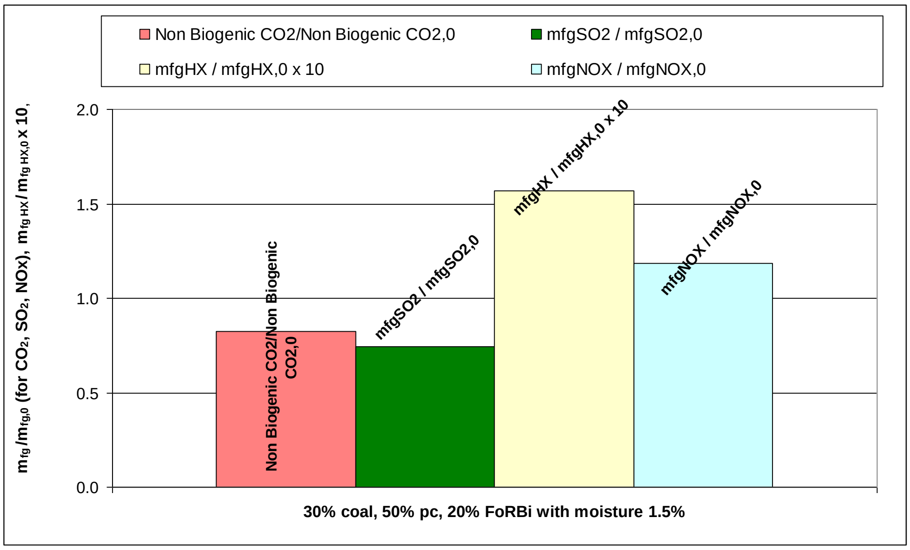

Figure 2. Characterization of Food Residue Biomass (FORBI) as an alternative fuel in cement kilns: petcoke calorific substitution by FORBI: 20%, base case (0):30% calorific coal, 70% calorific petcoke. Mass ratio of non Biogenic CO_2, SO_2, HX and NO_X in combustion flue gas. $m_{fg,0}$: mass in flue gas mixture in Scenario 0 (base case) (30% calorific coal, 70% calorific petcoke). m_{fg}: mass in flue gas mixture in Scenario 1 (30% calorific coal, 50% calorific petcoke, 20% calorific FORBI)

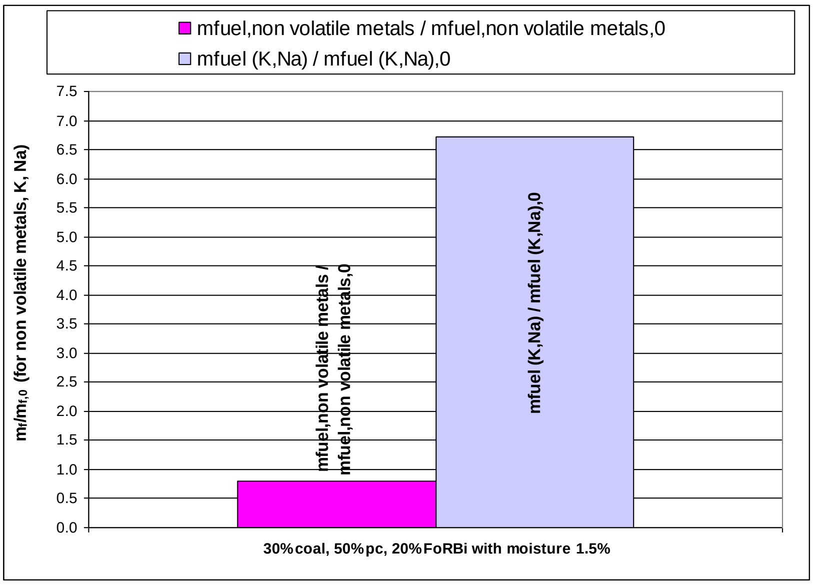

Figure 3. Characterization of Food Residue Biomass (FORBI) as an alternative fuel in cement kilns: petcoke calorific substitution by FORBI: 20%, base case (0): 30% calorific coal, 70% calorific petcoke. Mass ratio of non volatile metals, Na and K in fuel. *$m_{fuel,0}$: mass in fuel mixture in Scenario 0 (base case) (30% calorific coal, 70% calorific petcoke). m_{fuel} : mass in fuel mixture in Scenario 1 (30% calorific coal, 50% calorific petcoke, 20% calorific FORBI)*

Conclusions

FORBI is classified as a non-dangerous waste according to EWC 20 01 08, European Commission Decision 2014/955 and according to *EN 15359* it is classified as category 3, 2 and 1 with respect to NCV, Cl and Hg respectively. Additionally, due to its low humidity and ash content, together with its high calorific value, several technical problems such as pipe clogging can be avoided through its use. Its low concentration in heavy metals deems FORBI more favorable from the environmental perspective compared to other fuels. The FORBI meets the specifications set by authorities for individual permits for cement plants in Spain, Belgium and France (Table 7). With a moisture of food waste at 78%, the energy content of FORBI is twice the energy required for its production.

In terms of flue gases and fuel mixture, 20% calorific substitution of petcoke by FORBI (1.5% moisture) results in an overall fuel mixture with 80% of the nonvolatile metals of the base case and 6.7 times higher K, Na with respect to the base case (Scenario 0). Also, combustion flue gases containing: 80% of Non Biogenic CO_2 emissions of the base case, SO_2 70% of the base case, 16 times higher HX and 1.2 times higher NO_X compared to the base case (Scenario 0).

Chlorine content is a major concern in regard to flue gas presence of pollutants. Also, the high nitrogen content is a potential disadvantage, mainly, in regard to non-thermal NOx emissions since, as of 01/01/2016, EU regulations impose new, lower, limits (500mg/Nm^3 instead of 800mg/Nm^3). There exist, however, techniques for the reduction of NOx: either using low-NOx furnaces or with catalytic or non-catalytic stripping from the flue gases. The energy demands for the drying process of food waste are high, especially for a 78% moisture content of food waste. Techniques for reducing drying costs are important and should be further investigated. The latter can be reduced if the energy required for drying is obtained by partial use of the product (FORBI) as a fuel.

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