EVALUATION OF ALTERNATIVE FUELS; THE TITAN KAMARI CASE

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SUMMARY

Cement manufacturing involves the combustion of solid fuels along with raw materials to produce clinker. Energy costs and environmental concerns have encouraged cement companies to evaluate to what extent conventional non-renewable fuels i.e. coal and petroleum coke can be replaced by alternative fuels such as waste oils, mixtures of non-recycled plastics and paper, used tyres and biomass wastes. Following international standards and industry best practice, cement companies use alternative fuels which trend to become more diverse and increase in quantities but quality-wise become more challenging.
A study was undertaken to identify and determine the characteristics of alternative fuels, based on Kamari's Plant of Titan Cement Company and their impact on the Clinker profile. Three different streams were evaluated, i.e. Tyres, ASF (Alternative Solid Fuel) and SRF (Solid Recovered Fuel). This paper comprises (a) an analysis of alternative fuel types and their quality characteristics and (b) a sensitivity analysis of the impact on the clinker quality, using as parameters different percentages of substitution rates and different inherent characteristics of fuels. Optimum fuel mix in terms of clinker quality, taking into account the fuels profile and Raw Material Mix design, will be targeted and discussed. The technical viability for each alternative fuel and potential optimum dosages or bottlenecks are discussed.

INTRODUCTION

One of the current trends for not only the Greek cement industry is utilizing alternative fuels. Alternative fuels are by-products or waste from other industries, waste treatment plant products, and materials that could not be recycled and which would otherwise result in landfill. These include secondary fuel (SRF/RDF), dried sewage sludge from waste water treatment plant, mineral oil residues mixed with sawdust, used oils and lubricants, packaging recycling residues, paper, wood, sawdust, fabrics, biomass from agricultural and forestry residues, feed and organic wastes such as plastics, end-of-life vehicles etc. Hellenic Cement Industry Association has entered into a Voluntary Agreement of Cooperation with the Ministry of Environment, Energy and Climate Change for the promotion of the use of alternative fuels, undertaking the obligation to implement the Directives and Best Available Techniques and also carry out stringent checks to ensure secure handling. (1) The use of alternative fuels in cement manufacturing, offers considerable energy cost reduction, but it also has significant ecological benefits of conserving non-renewable resources, reducing waste disposal requirements and emissions. Use of low-grade alternative fuels in some kiln systems reduces NOx emissions due to reburn reactions. There is an increased net global reduction in CO_2 emissions when waste is combusted in the cement kiln systems as opposed to dedicated incinerators. Moreover, they contribute to the concept of co-processing that consists an optimum way of recovering simultaneously energy and materials from the waste, thus is supplementary to the recycling of municipal and industrial waste. At the same time, the minerals in the alternative fuel become part of the product (clinker): the inorganic components of waste derived fuels ('ash') are broken down and incorporated into the clinker as minerals, thus replacing primary raw materials needed for the production of clinker. In co-processing due to the high temperatures and long residence time, the destruction of alternative fuels is very efficient and complete. It offers a safe and sound solution to society providing a low-cost handling of these materials and at same time reduces global CO_2 emissions and does not have a negative impact on production process emission. (2), (3)

EXPERIMENTAL PART

Materials and simulation tool

The purpose of this paper is to examine the effect of using alternative fuels on clinker quality and the way that the idea of co-processing influences the final product. It would be presented how the different types of alternative fuels, the inherent characteristics of them (e.g. different RDF properties) and their dosage could have impact on the quality of the final product. Due to the growing importance and strict environmental and quality constraints, the evaluation of alternative fuels utilization by changing the factors described above is quite important for the cement industry.

For assessing the impact of AF, an internally developed prediction tool was used. This uses the chemistry of raw materials and main fuel characteristics (such as CV, ash content and chemistry, etc.) to evaluate the impact of each parameter on raw meal and clinker characteristics, principally chemical profile. It is governed by well know design factors like LSF, SM, AM etc. and takes into account norm (e.g. alkali content) and/or environmental restrictions (e.g. Hg trapped). In the paper herein, the input (raw materials and fuels) refers to Kamari plant and is based on XRF (X-Ray Fluoresce) analysis of the materials and typical parameters for fuels that was analysed in accordance to standards proposed at EN15359:2011 for RDF/SRF. More specifically, the ash content is determined with standard EN15403, N.C.V. with EN15400:2011 and Cl with EN15408:2011.

Scenarios

The baseline scenario described herein consists of a mixture of fuels including Pet Coke and Bed Coke (by-product of petroleum refinery) used at the main burner and Coal and End-of-life Tyres used at riser duct. Although Bed Coke and End-of-life Tyres are considered alternative fuels, we assume that their fuel feeding rate is stable at the process and the quantitative availability of these materials in limited, so we don’t examine their substitution.

The first scenario studies the impact of Pet Coke substitution by Alternative Fuels (AF), when we have the same analysis at the feeder’s chemistry. The examined alternative fuels are: SRF/RDF, ASF (Alternative Solid Fuel - a petroleum residue mixed with sawdust) and TST (textiles from shredded tyres). We considered the same fueling rate, in order to examine the heat substitution and the impact on final product caused by the incorporated ash residue. The percentages of substitution are based on the idea that we want a stable heat consumption in the kiln and the required kcal per hour arise from Kamari CCR (Central Control Room of the Kamari Plant). In this scenario we changed the alternative fuel and its substitution rate, in order to observe while the industry uses a stable clay pile during a specific time interval, which are the consequences on the clinker quality. The quality parameters taking into account are the LSF, SM and AM of the clinker and the C3S, an index combined with the final strength of cement. At the same time a stable substitution rate of each fuel is presented accompanied by the changes occurring in quality.

The second and third scenario are oriented to RDF because it is a heterogeneous material and although its quality should conform with EN 15359:2011, fluctuates frequently and affects the clinker. Moreover, a lot of traders could provide RDF, with different characteristics, so it is very important the evaluation of its use and especially the examination of increasing its substitution rate in fuel mix. In these scenarios we used two different qualities of RDF, with the Quality A having a higher N.C.V., a lower ash content and a more balanced chemical analysis of ash. (i.e. Quality A has a Si/Ca = 1,0 and RDF Quality B has a Si/Ca= 2,1) The target is to accomplish a sensitivity analysis using different percentages of ash content. Moreover, in third scenario we used a 10% or higher substitution of different quality of RDF in fuel mix. It should be mentioned that for the purposes of the research no adjustment was made in the raw mix. Usually different AF quality and substitution rates lead to adjustment of the raw mix in order to maintain the same clinker quality.

RESULTS

Different Fuel mix - Stable fuel feeding rate

The introduction of AF decreases the used percentage of conventional fuel (Pet Coke). The use of TST decreases approximately 30% the calorific participation of Pet Coke, comparing it with the corresponding 13% for the RDF and 15% for the ASF. The higher the N.C.V. of the AF the greater the Pet Coke replacement, so in the process we need high N.C.V. fuels. Concerning the quality, main changes arise especially with the use of RDF. The high percentage of ash incorporated to the clinker, in combination with the analysis of ash content which has increased concentration of SiO_2 (43%) and Al_2O_3 (17%), explains the 1unit decrease in clinker's LSF and the 2 units decrease in C3S. At the same time, we have a minor, but not insignificant, increase in C3S when we use TST. (Table 1)
Examining co-processing depending on fuel type and consequently the percentage of ash turned to clinker per fuel for the same feeding rate, RDF has the higher ash content while using TST is very close to the ash of the baseline scenario, a fact that affects slightly the concept of co-processing. ASF has a lower ash content compared to RDF, so it contributes to a lower extent to co-processing.

Table 1: *Clinker main indicators*

	Baseline Scenario	*Use of RDF*	*Use of ASF*	*Use of TST*
LSF (Clinker)	95,79	94,89	95,33	95,67
SM (Clinker)	2,19	2,19	2,18	2,20
AM (Clinker)	1,25	1,27	1,24	1,25
C3S (no alk. corr.)	60,00	***57,75***	59,00	**60,09**

Different Fuel mix - Stable Substitution Rate - 10%

Having a stable substitution of 10% Heat Consumption with AF in the fuel mix we conclude that in case of TST, we need the half the quantity of RDF and ASF. The conclusions concern the quality of clinker (Table 2) and the tons of ash incorporated to the final product are the same with the above mentioned, corresponding a stable fuel feeding rate.

Table 2: *Clinker main indicators*

	Baseline Scenario	*Use of RDF*	*Use of ASF*	*Use of TST*
LSF (Clinker)	95,79	95,10	95,49	95,75
SM (Clinker)	2,19	2,19	2,19	2,20
AM (Clinker)	1,25	1,27	1,24	1,25
C3S (no alk. corr.)	60,00	58,29	59,34	60,03

Different Quality of RDF, using a 10% substitution on Heat Consumption

The characteristics of the different qualities of RDF are represented on Table 3. The difference in Ash Analysis and the fact that the quality A has the half of SiO2 compared to the quality B, influences especially the LSF, the C3A and mainly the C2S. An important remark is that the C3S using RDF Quality A is 1 unit higher compared to the RDF Quality B (Table 4)

Table 3: *RDF profile – chemical analysis*

		RDF Quality A	RDF Quality B
NCV	(cal/g)	4.000	3.600
Ash	%	16	21
Ash Analysis			
Si/Ca		1,0	2,1
SiO2	%	28,6	42,8
CaO	%	29,2	20
K2O	%	1,2	3,0
Na2O	%	3,1	5,2
SO3	%	3,6	1,5

Table 4 : *Clinker main indicators - 10% utilization rate in fuel mix*

	Baseline Scenario	*Quality A of RDF*	*Quality B of RDF*
LSF (clinker)	95,79	95,61	95,10
SM (clinker)	2,19	2,19	2,19
C3S (no alk. corr.)	60,00	59,57	58,29
C2S	16,37	16,81	17,96
C3A	6,80	6,90	6,98

Different Quality of RDF, increasing the ash content from 11% to 29%

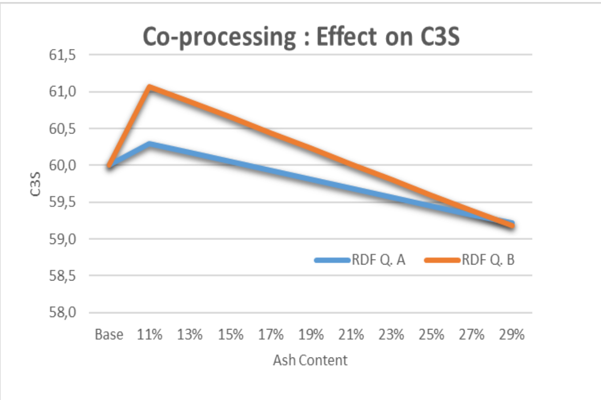

Figure 1: *clinker C3S in relation to ash content of RDF*

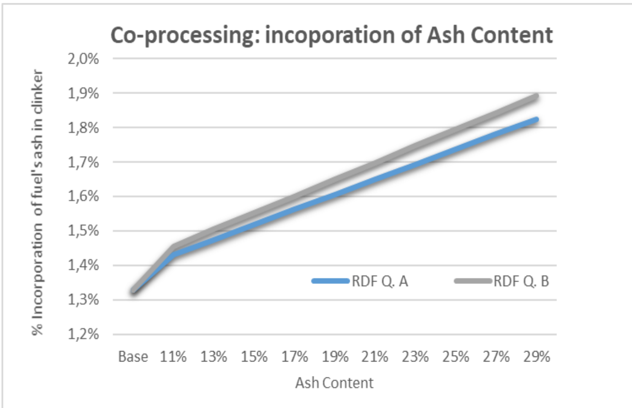

Figure 2: *% ash in clinker vs % ash content in RDF*

Obviously the RDF Quality A appears a more modest change for C3S. For an increase of 2% in ash content we have a decrease of 0,12 in C3S for RDF Quality A Si/Ca = 1,0 and a respectively 0,21 decrease for the RDF Quality B Si/Ca= 2,1. However, in 29% of Ash content the two qualities have the same C3S (approximately 59,2). (Figure 1) It is important to highlight that the lower the ash content, the higher the C3S. Therefore, the lower ash content minimizes the ash residues and as a result the advantages of co-processing. (Figure 2)

Different Percentages of Substitution for Two Different Qualities of RDF

In this scenario we used the two different qualities of RDF presented above. We made substitution of Pet Coke with RDF from 10% to 50%. Table 5 represent the changes occur in the analysis of fuel mix's ash, in case we increase the utilization rate of RDF.

***Table 5** : Fuel Mix Analysis for two different qualities of RDF and utilization rate up to 50%.*

	RDF Quality A						RDF Quality B					
Fuel Mix Ash	**0% RDF**	**10% RDF**	**20% RDF**	**30% RDF**	**40% RDF**	**50% RDF**	**0% RDF**	**10% RDF**	**20% RDF**	**30% RDF**	**40% RDF**	**50% RDF**
SiO_2	14,32	18,48	21,64	24,12	26,15	27,80	14,32	23,69	29,72	33,88	36,96	39,33
Al_2O_3	5,63	7,98	9,76	11,16	12,31	13,23	5,63	9,55	12,07	13,80	15,09	16,08
Fe_2O_3	2,08	2,41	2,66	2,86	3,02	3,16	2,08	2,40	2,61	2,76	2,87	2,95
CaO	1,79	8,13	12,96	16,74	19,82	22,33	1,79	7,38	10,98	13,46	15,29	16,70
MgO	0,54	0,91	1,19	1,41	1,59	1,73	0,54	1,08	1,43	1,67	1,85	1,98
K_2O	0,40	0,61	0,77	0,89	0,99	1,08	0,40	1,22	1,74	2,11	2,37	2,58
Na_2O	0,30	0,97	1,47	1,87	2,19	2,46	0,30	1,79	2,74	3,40	3,89	4,26
SO_3	72,78	55,18	41,78	31,28	22,72	15,75	72,78	49,59	34,67	24,37	16,77	10,90
Cl	0,09	1,76	3,03	4,03	4,84	5,51	0,09	0,93	1,47	1,85	2,13	2,34

The above table is important in order to be perceived the influence of the ash incorporated in clinker to the quality of clinker. One important characteristic, linked to the final strength is the C3S (important parameters to calculate C3S are SiO_2, Al_2O_3, Fe_2O_3, CaO & SO_3). An increase in SiO_2 increases the C3S, whereas the increase of other chemical compounds has a contrary result.

$$C3S = 4{,}071*(SiO_2) - 7{,}6* Al_2O_3 - 6{,}718* Fe_2O_3 - 1{,}43* CaO - 2{,}85* SO_3 \quad (1)$$

However, the figure 3 indicates that a high concentration of SiO_2 doesn't mean that it would affect positively the C3S. The most important is the balance between SiO_2 and CaO (i.e. the RDF of Quality A), which drive to a smooth decrease of C3S that doesn't require a lot of changes in the design of the raw mix (i.e. design a raw mix with higher LSF). Concerning C2S and C3A, the ash incorporated influences positively these parameters. This change has a positive effect as it reduces the demands on correction factors.

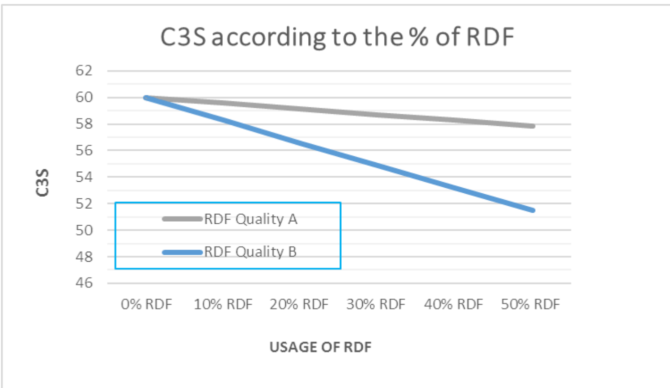

***Figure 3 :** Influence of RDF quality (ash) on C3S content*

CONCLUSIONS

The use of alternative fuels in the cement industry is a complex issue that requires knowledge, experience and a management on daily basis and always leads to an impact on process, products quality and production cost. If the available quantity is known then the impact is related with the quality variability (N.C.V., % ash, chemical analysis and trace elements) and the issue is managed by adjustment of the raw material design and appropriate operating arrangements (feed input, emissions monitoring, etc.), resulting in an increase of operating costs. If incoming volumes of alternative fuels varies, situation becomes more challenging. Considering the above, this study examined AF utilization scenarios mainly based on type (RDF, ASF, TST were examined), different substitution rates (vs. conventional fuels) and different inherent characteristics of fuels. Major conclusions drawn are as follows:

- RDF (which is expected to be the dominant AF in cement industry globally) was found to be able to substitute Pet coke. A 13% utilization rate affects especially C3S, driving at the same time in a decrease of 1 unit at LSF. ASF having the same N.C.V. with RDF could be used in the fuel mix and its use at a 15% utilization rate does not cause significant changes at the quality.
- Textiles from Shredded Tyres (TST) could substitute (a 28% substitution in heat consumption was examined) almost equally Pet Coke because they have a similar N.C.V., and they do not particularly affect the LSF of the clinker. Due to their low ash content, their effect on quality and co-processing rate is limited.
- The ash content of AF has a notable impact on clinker quality; if not considered in the design phase, it usually affects negatively its reactivity via decreased LSF and C3S content. For a range between approx. 10% and 30% of ash content examined, C3S was found to be decreased between 1,1 to 1,9 units respectively for the two different qualities of RDF.
- The chemistry of the ash itself has a great impact on the clinker quality and the critical ratio of Si/Ca in ash chemistry affects the C3S. More specifically Si/Ca=1,0 results to a decrease of 1 unit at C3S in case of the higher utilization rate examined (50%). Otherwise ash profile rich in SiO_2 (Si/Ca =2) may result in a significant decrease of up to 8 units of C3S for a fuel usage close to 50%. This underlines that the higher the Si/Ca ratio, the greater the adjustment that needs to be performed in raw mix design. This need becomes even greater when the AF participation exceeds 50%, and underlines the importance of a balanced ash content analysis.

All the impacts mentioned in this paper can be compensated by adjusting the raw mix design in a routine basis to maintain the clinker and cement quality standards. Therefore, it is of high importance to understand the implications of AF variability as was the initial purpose of this exercise.

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