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Cement Industry, Alternate Fuel and Environmental Benefits

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Abstract

Cement production is an energy intensive process which consumes a large amount of thermal energy for clinker production. Nevertheless, for this purpose, thermal energy is generated through coal, gas or diesel. The rapid increase in cost of these fuels makes thermal energy generation more expensive which however, directly affects the cement prices in the country. Moreover, in order to minimize dependence on fossil fuels, alternate fuel could be used for generating thermal energy in cement plants for clinker production. In this regard, a study has been carried out in order to optimize the use of thermal energy and to minimize the emission by using Tire Derived fuel (TDF). Moreover, tires are being used in different ratios/percentages with coal for optimizing thermal energy. It also helps minimize the emission, which resides within the limits of Environmental protection Agency (EPA) of Pakistan. Furthermore, cement mineralogical analysis and tests for compression strength are conducted according to industrial standards for analyzing certain changes which occurs in the structure and strength of cement.

1. "Introduction"

In Pakistan, 29 cements plants produce a total of 44 million tons of cement annually [1]. Pakistan's utility grids show brown out and black out conditions randomly as a result, the running of industrial machinery on utility grid becomes neither suitable for equipment nor for production. Cement industry is an energy intensive sector which consumes a large amount of thermal energy, for example 3.3GJ thermal energy is required for one ton of cement production. The cost of Thermal energy generation contributes 30 to 40 percent in total cost of cement manufacturing [2] [3].

The main sources of thermal energy production in Pakistan cement industry are coal and natural gas. However, the shortage/load shedding of natural gas and high price of coal become responsible for low cement production and its high price respectively.

Moreover, the alternate fuels are both economically favorable and environment-friendly which can also replaces fossil fuels such as coal, pet coke, oil and natural gas [4]. Several types (Solid, Liquid and Gas) of alternative fuels have been categorized such as animal manure, plastic from vehicles or cables wires, municipal solid waste, sewage sludge, agricultural wastes, refused derived fuel (RDF) and TDF etc. [5] [6]. In addition, these alternate fuels are receiving enormous interest worldwide due to their carbon emission credits and lower cost.

In September 2011, EPA of Pakistan has given permission to cement companies for using alternate fuels (specifically TDF) for thermal energy generation.

The road conditions are not good in Pakistan as a result; a large number of waste tires are produced annually. Furthermore, the waste tires are of no use in Pakistan consequently, its price is cheap as compare to fossil fuel (i.e. coal or natural gas). Tires composition is based on 88% of carbon and oxygen, which causes its rapid combustion in cement kiln and pre-calciner [7]. Such high composition of previously stated materials makes its calorific value 32MJ/kg which is higher than coal 26MJ/kg [8].

High temperature of material ranges from 1400 to 1500 ^{0}C and long residence time in cement kiln provides an environment to burn tires content completely besides helping to reduce the emission [9]. The ash contents of burned tires are mixed up into clinker completely. The steel wires in tires help in reducing the quantity of some additives such as iron ore which also maintains low cost of cement [10]. Moreover, tire has low contents of sulfur if it is compared to coal. In terms of weight, sulfur ranges from 1.21 to 1.30% in tires while sulfur contents of coal which is used in cement plant is 1.9% [11].

The most accountable content that tires have extra in its composition is zinc [12] [13] [14]. This zinc, when mixed up with cement clinker causes a negative effect on cement settling time and water requirements [15] [16].

Scrap tires which are used for thermal energy generation can be divided into two groups i.e. Whole and Shredder [17]. Both the groups have their own advantages over each other: It is easy to weight whole tires (by simply hangs it up with a hook) and transport it for feeding into cement kiln. On the other hand, shredder tires had higher calorific value due to low quantity of steel wires and belts.

One ingredient which is used in large amount for cement manufacturing is calcium carbonate and it is best natural scrubber of sulfur gas.

In tower type cyclonic structure of cement plant in which material flows from top to bottom and gas flows from bottom to top is an ideal place for sulfur gas capturing. It is due to extremely high temperature in cement kiln that structural components of tires get shattered completely and the remaining ash mixed into clinker which cannot be separated again. Moreover, pollution control devices such as scrubbers or electrostatic precipitator can capture the fugitive particles in gases [18].

In fact, a large number of cement factories use TDF around the globe. However, in Pakistan, EPA has given permission to cement factories to use TDF as an alternate fuel or co-fuel with coal in late 2011. In addition to that, tire dumping can become a threat for human health and natural environment. Tire dump in terms of stock piles can become a habitat for mosquito and snakes [19].

Cement industries release around seven percent of the total global CO_2 emission [20]. This CO_2 emission of cement industry is mostly contributed by fuel burning. This paper is anticipated to show a series of full-scale experiments that were conducted at Bestway Group cement plant situated in Hattar industrial area of Pakistan. The endeavor of this experiment is to evaluate the deployment of TDF or tire chips. The dimensions of tire chips are approximately 3.8 cm to 7.6 cm wide, and used as co-fuel with coal for cement clinker production. This experimental study is carried out to:

- Evaluate the stability and operating conditions of kiln when using tire chips as co-fuel with coal
- Evaluate the environmental emission of different pollutants during tire chips usage
- Examine the cement clinker structure and strength by using tire chip
- Estimate the cost difference before and after usage of tire chips

2. "Experimental"

Experimental tests are carried out at Bestway Group cement plant located in Hattar industrial area of Pakistan. The specified cement plant where TDF burn tests are conducted was upgraded in 2008 by installing a new kiln and pre-calciner. This plant has clinker production capacity of 140 to 142 tons per hour and its pre-heater tower is installed with five stages of cyclone and it is equipped with an inline pre-calciner. Moreover, the cyclonic tower is the first stage of raw material firing in which dehydration and drying occurs, whereas calcinations take place in pre-calciner and clinker production process occurs in kiln which is rotary type. Figure 1 shows a five stage pre-heater tower and kiln with an inline pre-calciner, as installed on specified plant.

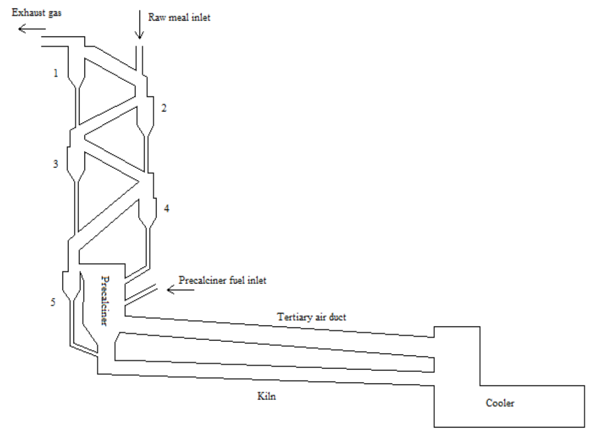


Figure 1: Pre-heater tower, pre-calciner and kiln

Top cyclone vessel of pre-heater tower connects to the electrostatic precipitator, which discharge the flue gas of kiln and pre-calciner. This discharged solid material removes later on and used as a raw material again.

Cement plants provide a great opportunity for testing alternate fuels such as RDF and TDF as co-fuel with coal or pet coke. However, for this purpose, cement plants need a minor modification for receiving and injecting of co-fuel, because kiln firing process and its thermal characteristics do not necessitate any major modification in plant operation and its design structure. However, during this experimental study, no modification was made for co-fuel injecting. Tire chips manually mixed up with coal and then injected this hybrid fuel in pre-calciner by using the same setup which used for coal injecting. First comparative analysis of TDF and coal was performed for knowing the ratio of hydrogen, carbon, sulfur and nitrogen, apparently this analysis also shows the calorific value. The results of analysis are also shown in Table 1.

Table 1: Comparative analysis of tire and coal

Analysis	TDF	Coal
Hydrogen %	4.5-8.9	5-9
Carbon %	84-89	80-85
Sulfur %	1.1-2.9	3-4.8
Nitrogen %	0.75-1.2	1.5-2.0
Volatility %	71-73	36.8
Lower Calorific value (kJ/kg)	31400	26880

The above result shows that TDF is an ideal candidate for alternate fuel or co-fuel as the values of important ingredients of coal and TDF have almost remained the same, for example, Hydrogen is almost same as coal whereas, carbon is relatively high in tire chips. Sulfur and nitrogen contents are lower in tire.

There are two types of fuels used in cement plant: coal and hybrid (mixture of coal and TDF). In first phase, cement plant runs solely on coal which dosed in kiln and pre-calciner. In second phase, kiln dosed with coal fuel while pre-calciner injected hybrid fuel. Hybrid fuel injected to pre-calciner with variant coal and TDF ratios. These ratios change at a specified interval till emission increase or anything else occur in the plant such as kiln disturbance etc.

Table 2: Hybrid fuel preparation quantities

Phases	Serial Number	Coal	TDF
Phase 1	Coal	12	0
	Hybrid 1	11.5	0.5
	Hybrid 2	11.0	1.0
Phase 2	Hybrid 3	10.5	1.5
	Hybrid 4	10.0	2.0
	Hybrid 5	9.5	2.5

In this experimental study, emission samples are collected from different points of production sequence as following:

- Kiln inlet (gases end)
- Pre-calciner
- Pre-heater (4^{th} cyclone)
- Electrostatic filters

3. "Result and Discussion"

TDF injected to the pre-calciner in variant ratios as mention in table 2. After injecting each hybrid fuel, emission reading of CO, SO_x, NO_x and particulate matters are measured. Tire chips burning tests are conducted for two consecutive months for more than 300 hours at different fuel ratios. Moreover, in order to get better results, the series of tests are performed two times. Final ratio tests, at which emission below the specified limit is conducted for five consecutive days with continuous dosing of hybrid fuel in the pre-calciner.

Cement plant was monitored continuously and intensively during the TDF trial burn tests for important parameters such as raw meal feed flow quantity, fuel utilization, temperature of raw meal at different stages, and flue gas (CO, NO_x, SO_x and PM). These measurements are taken with the help of standard equipments and instruments which were available at plant and used for regular process of monitoring and control.

Measurements of flue gas are performed in few campaigns which can be divided into two broad campaigns: first for phase 1 and second for phase 2. However, Phase 2 campaigns can be divided into five more sub-campaigns according to the fuel ratios as each fuel ratio has its own campaign data record. These campaigns are launched for inspecting the influence of TDF burning on environmental emission of most important normal pollutants such as CO, NO_x

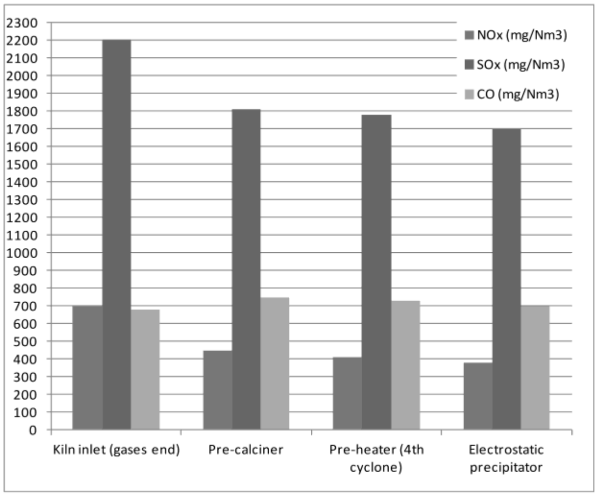
and SO_x besides tracing pollutants of heavy metals such as zinc and mercury.

The emission data of both phases are noted down and compared with the reference emission data of EPA limits for TDF fuel. This process is carried out with all hybrid fuel ratios until it crosses the emission limits of EPA.

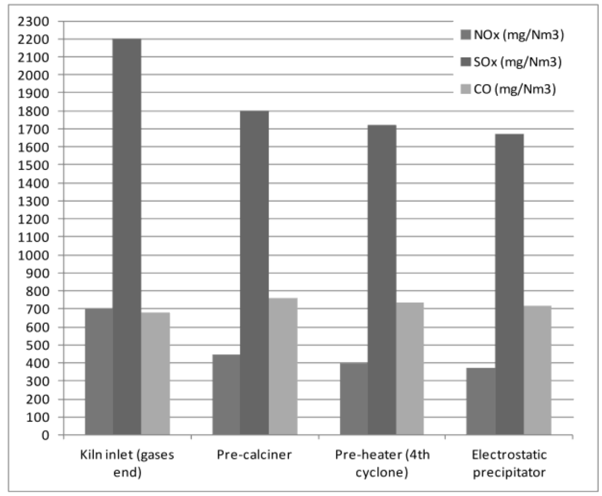
The major process parameters which monitored during trial burn tests of TDF are compared with coal parameters and baseline parameters specified by the EPA, and the observation of this comparison is given as following:

- Kiln is insensitive to the injection of TDF for all percentages even the last one at which emission limit exceeds the specified limit.
- TDF does not result to influence any major parameter i.e. raw meal feel flow ratio or pre-calciner temperature.
- Conveyer system which is used for coal previously shows no disturbance when used for TDF. It works precisely as calibrated with pre-calciner temperature and fuel feed quantity.

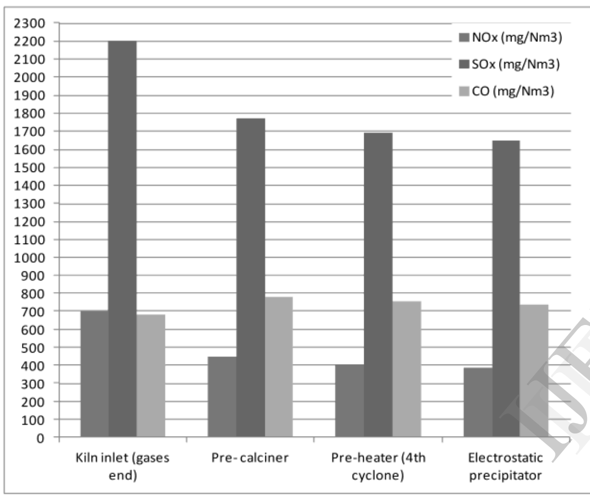
The emission results of coal and hybrid fuel ratios are shown in figure 2.



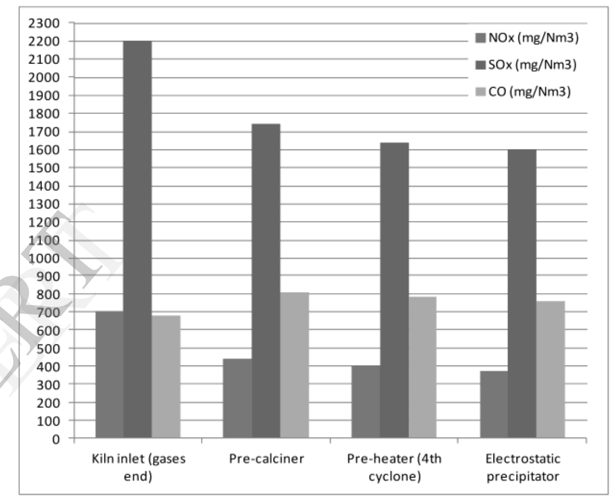
(a) Coal



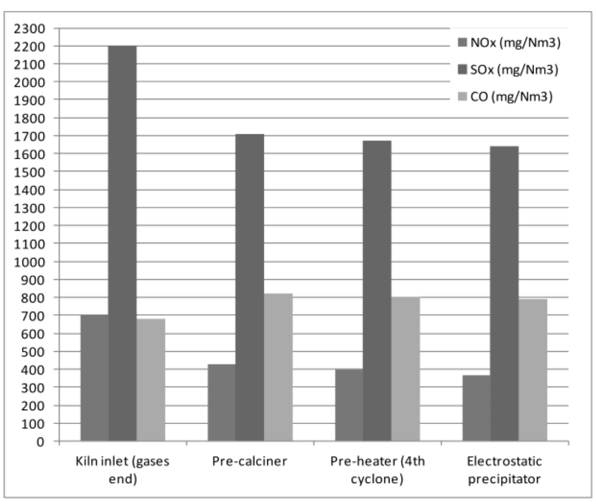
(b) Hybrid 1



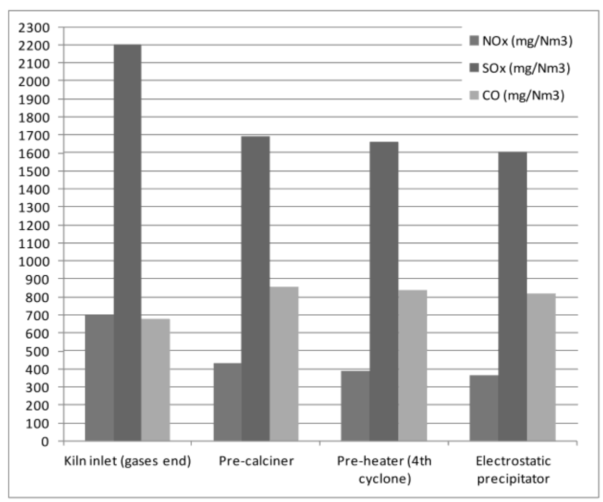
(c) Hybrid 2



(d) Hybrid 3



(e) Hybrid 4



(f) Hybrid 5

Figure 2: Pollutants emission data results of all campaigns

It can be seen in all graphs (a to f) of figure 2 that SO_x decreases from kiln inlet (gases end) to electrostatic precipitator level. This is however, due to falling of raw material which is a natural scrubber of SO_x. Whereas, NO_x shows a minor change in downward direction plus a high quantity of NO_x is produced in kiln's high temperature. However, the temperature drops significantly on reaching in pre-calciner due to 'substoichiometric' O_2 environment. This environment reduces the formation of NO_x and destroys a portion of NO_x which is generated in kiln main burner relatively low flame temperature of TDF burning as compare to kiln flame temperature. On the other side, CO increases during hybrid fuel burning. This increases the amount of CO due to the low amount oxygen in pre-calciner.

Table 3 is for comparison of selected hybrid fuel emission data with coal and base line data.

Table 3: Pollutant comparison with baseline data

Pollutant (mg/Nm^3)	Coal	Hybrid fuel	Baseline
SO_x	1695	1640	1700
NO_x	300	385	400
CO	700	790	800
Zinc	-	65	200
Particulate matter	280	290	300

The complete results of final data of each campaign demonstrating the emission rise and fall of different pollutants is given in figure 3.

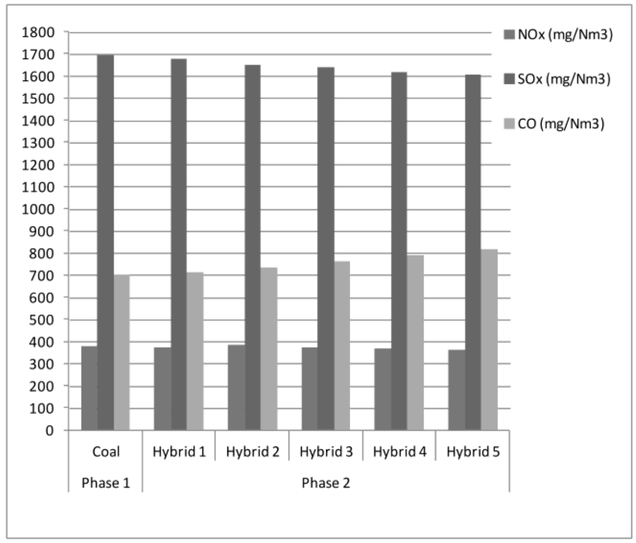


Figure 3: Final results of emission of each campaign

It can be seen in figure 3 that SO_x and NO_x decrease when quantity of TDF increases and coal quantity decreases in hybrid fuel. However, CO increases by increasing the TDF quantity in hybrid fuel. Zinc is not present in coal, so it is not included in comparison figure. But it is worth mentioning that zinc value at selected fuel ratio is 65 mg/Nm^3 whereas, the baseline limit for zinc particles is 200 mg/Nm^3.

Furthermore, cement structural and cement strength analyses are also performed during this experimental research. For cement, structural analysis of two different samples is collected: first when using coal as fuel and second sample is collected during the selected percentage of hybrid fuel (Hybrid 4).

The analytical technique which used for mineralogical and structural analyses of cement clinker samples is X-Ray Diffraction (XRD).

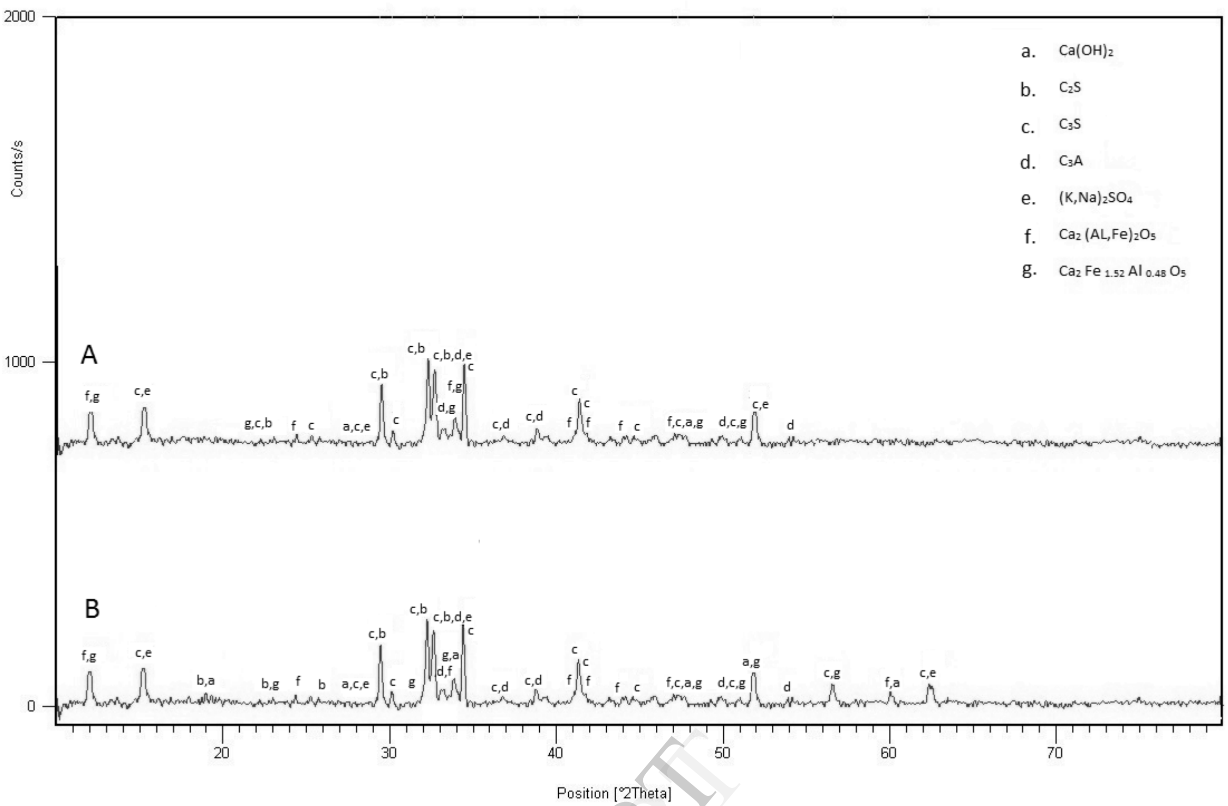


Figure 4: Spectrum (A) Clinker without TDF and spectrum (B) Clinker with TDF

Figure 4 shows the patterns of XRD which are performed for mineralogical analysis of cement clinker. Spectrums in figure 4 show that the main compounds are found in both samples and on almost equal intervals. The only minor negligible change was found in spectrums which could be the burning temperature difference of both samples.

This XRD analysis shows that compound formation occurs in a similar way and there is no major or noticeable difference between the two XRD patterns. The patterns also show that TDF does not affect clinker making process by creating any undesirable compound.

Another analysis of this research is to check the compression strength of cement. Cement compression strength analysis is performed according to BS 4550: section 3.4 1978.

For compression strength analysis, total sixteen blocks are made, eight blocks from cement without TDF and other eight blocks from cement which are made by using hybrid fuel. Testing of two blocks of each sample on specified time interval gives better average results, which can help for accurate analysis. Table 4 shows the average results of cement compression tests and figure 5 represents the table 4 data in graphical form.

Table 4: Compressive strength analysis of cement

Time Duration	With coal (MPa)	With hybrid fuel (MPa)
1 day	18.1	16.5
3 days	28.5	29
7 days	42.3	46.1
28 days	61	62.3

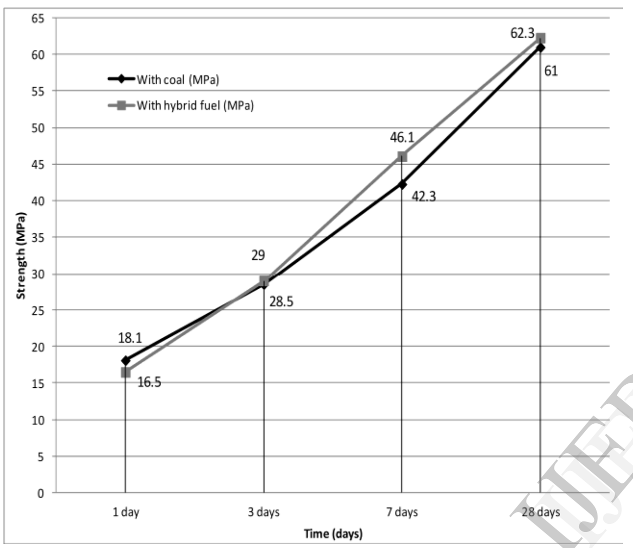


Figure 5: Cement compressive strength graph

4. "Conclusion"

Cement plants are extremely feasible for testing of alternative fuel behavior. For this reason, full scale industrial level tests are conducted for assessment of alternative fuel using TDF to substitute the conventional fuels like coal, pet coke and natural gas. The plant, where the test trials conducted is installed rotary kiln with an inline pre-calciner and five cyclones pre-heater tower and a conveyer system is used for coal. The system has been used for hybrid fuel without any modification. To attain considerable fuel replacement (about 20%) and maintain stable operation, pre-calciner chooses to inject hybrid fuel.

Considerable reduction is observed in the environmental emission of SO_x and NO_x during TDF usage as a co-fuel. And this is due to lower contents of sulfur and nitrogen in tire composition.

Emission of flue gas contents like SO_x and NO_x are reduced during the usage of hybrid fuel due to low contents tires of sulfur than coal. Moreover, as a result, this low sulfur and nitrogen of tire reduces the overall emission of SO_x and NO_x to the environment and supports the analysis of [21] [7]. Therefore, the emission of SO_x and NO_x to the environment is lowered by burning of hybrid fuel instead of coal.

Emission of zinc particles to the environment is much lower than the specified emission limit. The specified limit for zinc particles is 200 mg/Nm^3 where the emission reading from electrostatic precipitator is 61 to 65 mg/Nm^3. Zinc particle emission occurs only when TDF is used with coal as co-fuel as tire have a small percentage of zinc contents in its composition. Most of the zinc mixed up with cement clinker during the calcinations process and clinker making process, consequently a small number of zinc particles make escape possible to the environment. Particulate matters show a very slight change during the TDF burning, although the change is very minor which may not be taken into account at all.

During continuous plant operation, the fact is revealed that same quantity of hybrid fuel burn for more time than the same quantity of coal, this support the research of [22].

Electrostatic precipitator efficiency is 91 to 93 percent. At this efficiency, the atmospheric emission of major concerned gases and particulate matters are higher but however, it does not exceed the baseline limits of EPA. However, if the efficiency of electrostatic precipitator improves by any mean up to

97 - 98 percent or installed another filter, like fabric filter, then the emission could be further lowered.

Cement composition and strength characteristics do not alter significantly. However, Mineralogical analysis shows a minor difference in cement clinker composition due to different burning temperature and burning conditions at hybrid fuel. This slight mineralogical change doesn't affect the cement strength considerably.

The hydration requirements are changed slightly from 24% to 27.5% which can be adjusted by altering the gypsum ratio into clinker.

The TDF is relatively cheaper than coal and natural gas, so its ultimate benefit is for both the cement company and the environment.

Acknowledgment

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References

1. PEPA, P.E.P.A., *Guidelines for using Tire Derived Fuel (TDF) in Pakistan cement industry*. 2011.
2. Genon, G. and E. Brizio, *Perspectives and limits for cement kilns as a destination for RDF.* Waste management, 2008. **28**(11): p. 2375-2385.
3. Mokrzycki, E. and A. Uliasz-Bocheńczyk, *Alternative fuels for the cement industry.* Applied Energy, 2003. **74**(1): p. 95-100.
4. Tsiliyannis, C.A., *Alternative fuels in cement manufacturing: Modeling for process optimization under direct and compound operation.* Fuel, 2012.
5. Jenkins, B. and S. Mather, *Fuelling the demand for alternatives.* The Cement Environmental Yearbook, 1997: p. 90-97.
6. CEMBUREAU, *Co-processing of alternative fuels and raw materials in the European cement industry.* Sustainable cement production, 1999.
7. Giugliano, M., et al., *Experimental evaluation of waste tires utilization in cement kilns.* Journal of the Air & Waste Management Association, 1999. **49**(12): p. 1405-1414.
8. Sienkiewicz, M., et al., *Progress in used tires management in the European Union: A review.* Waste Management, 2012.
9. Gupta, R., et al., *Particulate matter and elemental emissions from a cement kiln.* Fuel Processing Technology, 2012.
10. Blumenthal, M., *The use of scrap tires in the US cement industry.* World cement, 1992. **23**(12): p. 14-20.
11. Gray, T. *Tire derived fuel: environmental characteristics and performance*. in *Presented by Terry Gray, President, TAG Resource Recovery at the First Northeast Regional Scrap Tire Conference, Albany, New York*. 2004.
12. Atal, A. and Y.A. Levendis, *Comparison of the combustion behaviour of pulverized waste tires and coal.* Fuel, 1995. **74**(11): p. 1570-1581.
13. Pipilikaki, P., et al., *Use of tire derived fuel in clinker burning.* Cement and Concrete Composites, 2005. **27**(7): p. 843-847.
14. Fiksel, J., et al., *Comparative life cycle assessment of beneficial applications for scrap tires.* Clean technologies and environmental policy, 2011. **13**(1): p. 19-35.
15. Reisman, J.I. and E. Pechan, *Air emissions from scrap tire combustion*. 1997: US Environmental Protection Agency, Office of Research and Development.
16. Murray, A. and L. Price, *Use of Alternative Fuels in Cement Manufacture: Analysis of Fuel Characteristics and Feasibility for Use in the Chinese Cement Sector. China Energy Group, Ernest Orlando Lawrence Berkeley National Laboratory, US Department of Energy*. 2008.
17. Association, R.M., *US scrap tire markets 2001.* Rubber Manufacturers Association, Washington, DC, 2002.
18. Fodor, Z. and J.J. Klemeš, *Waste as alternative fuel–Minimising emissions and effluents by advanced design.* Process Safety and Environmental Protection, 2012. **90**(3): p. 263-284.
19. Li, X.-g., et al., *Thermogravimetric analysis of the co-combustion of the blends with high ash coal and waste tires.* Thermochimica acta, 2006. **441**(1): p. 79-83.
20. Deja, J., A. Uliasz-Bochenczyk, and E. Mokrzycki, *CO< sub> 2</sub> emissions from Polish cement industry.* International Journal of Greenhouse Gas Control, 2010. **4**(4): p. 583-588.

21. CEMBUREAU, *Co-processing of alternative fuels and raw materials in the European cement industry.* Sustainable cement production, 2009.
22. Venta, G.J., *Use of alternative fuels in the Canadian and US cement industry: opportunities and barriers.* Natural gas. **45**(5.9): p. 5.3.