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Co-processing of industrial waste in cement kiln – a robust system for material and energy recovery

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Abstract

Waste management is a serious issue around the world. It is most prominent in the developing countries. Non–hazardous industrial waste is another aspect at 100 million tons/year with coal ash accounting for 70 million ton/year in India. It is the second highest waste stream ending up in landfill site. The quantity is projected to be increased at faster rate in coming years with increasing industrialization. This industrial waste has characteristics of municipal solid waste with percentage of non-biodegradable waste on the higher side. Co-processing of this waste for energy recovery and as an alternative raw material in cement kiln can be an effective management methodology for this waste stream. This is being practiced sustainably in number of countries but in India the process lacks proper implementation. The auxiliary technological requirement is less and the process is highly economical and effective. This study specifically shows the effectiveness of the co-processing in cement plants in India, as a way for an effective utilization of energy and recoverable raw materials locked in the industrial waste. The robustness of the co-processing of industrial waste has been analyzed based on three cases studies in India. The findings revealed that it can be one of the most effective industrial waste disposal techniques in India and in other developing countries considering other practices of waste disposal methodology in terms of zero ash generation, emission, less auxiliary technology requirements, less set up cost, etc. The robustness of the co-processing as a waste disposal technique was also revealed by the economic and environmental statistical analysis. The study shows the sustainability of co-processing as an energy and material recovery process and addresses the issues related to sustainable management of industrial wastes. Number of study is available in the literature but analysis based on multiple case studies specific to Indian scenario is scarce.

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1. Introduction

India is the second largest producer of cement in the world. Cement production is an energy intensive process. The cement industry in India emitted 129.92 million tons of CO\textsubscript{2}, which is 32\% of the total CO\textsubscript{2} emissions from the industry sector in 2007\textsuperscript{1}. The production of cement is material and energy intensive and co-processing of waste-derived materials represents a common strategy to reduce the cost and environmental impact\textsuperscript{2, 3, 4}. Coupled with resource conservation and reduced carbon emissions, co-processing technology is a preferable alternative for sound and environmental friendly waste disposal over incinerators & non-scientific methods. It is not only solution to the waste disposal menace, but also reduces burden on secured landfills\textsuperscript{5}. The use of industrial wastes as an alternative fuel in the cement industry is a reality in several countries because wastes are removed and economic incomes are obtained preserving virgin materials\textsuperscript{6}. The use of alternative fuels and raw materials (AFR) for cement clinker production is certainly of high importance for the cement manufacturer and also for the society as a whole. Traditional kiln fuels are gas, oil and coal. Materials like waste oils, plastics, auto shredded residues, waste tyres and sewage sludge (SS) are now being proposed as alternative fuels for the cement industry. Also the slaughterhouse residues are used as fuel nowadays in cement plant. The plant to use any of the AFR in a cement kiln, it is necessary to know the composition of the fuel and raw material. The choice is normally based on price and availability. The energy and ash contents are also important, as are the moisture and volatiles contents\textsuperscript{7}. Alternative fuel and raw material utilization in cement kilns is still progressing. While in some kilns up to 100\% substitution rates have been achieved, but in some cases other prevailing conditions do not allow for higher rates of AFR\textsuperscript{8}. The cement industry has characteristics that make the burning of wastes viable, since it is characterized by high energy thermal process necessary to produce the clinker. The clinker is obtained from the grinding, homogenization and burning (high temperatures – 1450°C) inside rotary kilns with raw materials (limestone, clay, sand, iron ore). The next steps are the cooling of the clinker, grinding the clinker with gypsum and other additives to produce cement and finally storing, packaging and transporting the cement to the end user\textsuperscript{9, 10}. In any case, alternative fuel utilization requires the adaptation of the combustion process, though modern multi-channel burners and thermograph systems allow controlling the alternative fuel feed rate and the flame shape to optimize the burning behaviour of the fuels\textsuperscript{8}. Wzorek\textsuperscript{11} showed that the fuels manufactured with the use of sewage sludge and waste materials offered a satisfactory energy values for the cement industry as specified for alternative fuels. According to IEA statistics, the OECD cement industry used 66 PJ of combustible renewable waste in 2003, around half of it industrial waste and half wood waste. Worldwide, the sector consumed 112 PJ of biomass and 34 PJ of waste. There is apparently little use of alternative fuels outside the OECD, although the comparison of country data from various sources with IEA statistics tends to imply that alternative fuel use is under-reported. From a technical perspective, the use of alternative fuels could be raised to 1 to 2 EJ, although there would be differences among regions due to the varying availability of such fuels\textsuperscript{12}. Reusing industrial by-products is considered as the most promising and practical solution to reduce the portion going to the landfill. These by-products can be reused by mixing with raw materials and fed to cement process. Moreover these wastes can be substitute with clinker and can become a composition of final cement. Fly ash is an example of such material. In case of fly ash, the by-product not only contributes to reduce raw materials and energy requirement in the process but also able to improve concrete property. The organic part in the fly ash is burnt and acts as the source of thermal energy and the mineral part is integrated into the process and contributes as raw material and additive\textsuperscript{13, 14}. Blast furnace slag is another example of materials which are being utilized as a portion of feed. It consisted of silicates, alumina-silicates, and calcium-alumina-silicates thus it reduces need of limestone and in consequence mitigates CO\textsubscript{2} emissions due to limestone decomposition\textsuperscript{15}. An overall assessment of the environmental effects of co-processing of cutting oil emulsions in cement plants through the quantification of emissions of key pollutants, namely NO\textsubscript{x}, CO and VOC was presented by Giannopoulos et al.\textsuperscript{16}. Tiwary et al.\textsuperscript{5} showed that co-processing is efficient, economized and environmental friendly, particularly for a populated country, such as India, as there was no adverse effect on quality of cement, stack emission and air quality of environment due to co-processing of variety of identified wastes in cement kiln. Many tests have investigated the influence on the emissions and the product quality when waste materials are used to replace either fuels or raw materials in clinker production. So far, no adverse impacts have been identified\textsuperscript{17, 18, 19}. Yen et al.\textsuperscript{20} produced eco cement from industrial waste like marble sludge, sewage sludge, drinking water treatment plant sludge, and basic oxygen furnace sludge as a replacement for limestone, sand, clay, and iron slag, respectively. The utilization of
sewage sludge as an alternative fuel and its effect was analyzed covering all process, health, safety and environmental standard\(^2\). The objective of the paper is to present a review of the co-processing of industrial waste in cement kiln and its sustainability based on three case study approach. The study will show the economical and environmental gain achievable by using industrial waste as AFR in Indian cement kilns. The study also identifies the challenging issues in effective implementation of co-processing base on the literature and case study. The organization of the paper is as follows: section 2 deals with the methodology applied for the study. Section 3 discusses the present status based on three case studies in three different part of India and analyses the economical and environmental sustainability. Section 4 reveals the findings based on the analysis. Section 5 concludes the papers.

2. Methodology

The study follows a case study approach and involves the following steps: firstly a detail literature review has been carried out to find out the practices on co-processing of waste in cement kiln around the world. Secondly three primary field studies were carried out to get a first hand view of the existing co-processing plant status and sustainability in term of economical and environmental aspect. Thirdly the case were discusses based on the detail data of last financial year obtained based on the primary field study. Fourthly the findings were discussed based on the case study and co-processing as an effective way of utilization of industrial waste was elaborated. Fifthly the study was concluded with emphasizing of industrial waste disposal in cement kiln.

3. Discussion and analysis

3.1. Case-I

The cement plant is one of the oldest plants in central part of India. It has three functioning kiln with two kiln i.e. kiln-1, kiln-2 which are running an outdated semi dry process system and kiln-3 has modern wet process system incorporating a five stage cyclone based pre heater system for clinker production. The plant has total capacity of 2400 ton/day. The kiln-3 has a feeding system for alternative fuel (AF). The AF feeding capacity is very less as it has a basic manual operated feeding system, the capacity of which is approximately 1.5 ton/day. The feeding requires five operators it is a labour intensive system and also safety of the worker is an issue, being a manual system with machine and man interface. The producer of industrial waste pays a certain tipping fee on per/ton basis and also provides free transport of the waste to the plant. The types of industrial waste which are co-processed as alternative fuel and raw material are dolachar, flue dust, coal rejects, trade rejects, spent carbon, ETP Sludge and expired trade products. The trade rejects mainly consists of expired products like shampoos, coffee sachet, napkins, toothpaste, noodles, sauce etc from major FMCG companies. There are also other non industrial wastes which are added as impregnation to reduce the water content, which includes saw dust and rice husk. The characteristics of the waste which is used as a alternative fuel is that of mixed waste with calorific value ranging from 1500 to 2200 kcal/kg the waste are generally of large size containing plastic, papers, organic fragments and to some extent glasses also. The waste is being directly feed in to a kiln inlet in combination with the secondary coal firing. The waste comes by trucks and this are unloaded manually and stored in the storage facility and from this storage facility the wastes are being taken and unpacked manually and feed in to the hopper through the lift system. This waste hopper has a feeding belt below it the waste is carried by this belt to the chute and through the chute the waste moves in to the kiln inlet via three shut of gate. This shut of gate prevents the back fire. The industrial waste as a raw material is used in the preparation of the raw meal. The total quantity of AR which is being in the year 2014 stands at 7,976 tons. The co-processing statistical data has been analysed to gauge the sustainability of using industrial waste. The quantity of AFR uses has been plotted for the year 2014 on a month wise basis and around 12054 ton of industrial waste has been used in the plant reducing the use of virgin fuel and raw materials. The use of alternative fuel and raw material was not uniform which has been contributed due to supply chain constraints and production fluctuation. The highest quantity of feed was carried out in the month of February with firing of 4187 ton of industrial waste.
(figure 1). The quantity of traditional fuel (TF) and traditional raw material (TR) replaced, shows a similar trends. The total amount of TF and TR saved due to utilization of AFR is amounting to 8861 ton (figure 2).

![Figure 1. Quantity of AFR fired in the year 2014](image1)

![Figure 2. Quantity of TF & TR replaced in the year 2014](image2)

The thermal substitution rate (TSR %) which is being achieved shows an effective energy recovery potential from the industrial waste without any hindrance to the normal firing and energy need (figure 3). The economical analysis based on the total financial benefit achieved by the plant in last year shows an enormous amount with huge economical gain (figure 4). The TSR % achieved also shows the environmental sustainability of the co-processing methodology.

![Figure 3. Thermal Substitution Rate achieved (TSR%) for the year 2014](image3)

![Figure 4. Trends in cash benefit of using AFR in the year 2014](image4)

3.2. Case-2

The case organization has three kilns with AFR feeding system incorporated in to the kiln-3. The kilns present in the plant are a dry process type. The kiln-3 has a similar feeding system arrangement as discussed in the case-1. The feeding system requires five operators and the capacity is 3 ton/day. The producer of industrial waste pays a tipping
fee on per/ton basis and also provides free transport of the waste to the plant but the plant also uses some biomass which is being brought by the plant and transportation cost is barred by the plant. The co-processing capacity of AF is limited as the feeding system doesn’t allow feeding in bulk quantity and absence of pre-processing platform doesn’t allow feeding of large size waste. The type of industrial waste co-processed are ETP sludge, iron slug, grinding muck, grinding dust, boiler carbon, boiler ash, chemical sludge, brake shoe liner, spent carbon, paint sludge, trade rejects, oily rags, ETP bio sludge, expired products from FMCG companies. The characteristics of the waste as an AF are that of mixed waste with calorific value ranging from 321 to 5396 kcal/kg. The waste are generally of large size as no pre-processing platform exists, the waste consists of plastic, papers, organic fragments and to some extent glasses also. The size and metal contents is an issue for feeding. The supply chain frame work is similar to the case-1 as discussed above. The alternative raw material is used in the preparation of raw meal. The quantity of AR which has been used in the year 2014 is 6,467 tons. The co-processing statistical data from the last year has been analysed to gauge the sustainability of using industrial waste as a substitute for virgin material. The quantity of AFR uses has been plotted for the year 2014 on a month wise basis and around 9098 ton of industrial waste has been used. The use of alternative fuel and raw material feeding was non-uniform due to supply chain constraints and production fluctuation. The highest quantity of feed was carried out in the month of April with firing of 1951 ton of industrial waste (figure 5). The quantity of traditional fuel (TF) and traditional raw material (TR) replaced, shows a similar trends in firing. The total amount of TF and TR saved due to utilization of AFR is amounting to 9422 ton (figure 6).

The thermal substitution rate (TSR %) follows a similar trend, the fluctuation in graph is directly proportional to the feeding rate, high rate of TSR% has been achieved by the plant thus showing high energy recovery potential from the industrial waste without any hindrance to the normal firing and energy need (figure 7). The economical analysis based on cash benefit achieved by the plant in last year shows an enormous amount with high economical gain (figure 8). The TSR % and quantity of TR and TF saved shows high environmental sustainability of co-processing methodology. The month of December is not presented in the analysis as the kiln was in a shut down state for the annual maintenance.
3.3. Case-3

The case organization has single kilns with AFR feeding system it is one of the oldest plant in western part of India it has been established in 1917. The kiln in the plant is a dry process type. It has a similar type of feeding arrangement for the AF, it has feeding capacity of 3 ton/day. The plant setup is of the same make as the other two cases discussed above. Like other two cases the producer here also pays a tipping fee on per/ton basis and also provides free transport of the waste to the plant. The plant also uses saw dust which is being brought by the plant and transportation cost is barred by the plant. The co-processing capacity is limited due to the feeding system which doesn’t allow feeding in bulk quantity and absence of pre-processing platform doesn’t allow feeding of large size waste. The type of industrial waste co-processed is ETP sludge, paint sludge, trade rejects, carbon black, spent carbon, ETP bio sludge, dying sludge and expired products from FMCG companies. The characteristics of the waste are that of mixed waste with calorific value ranging from 435 to 4936 kcal/kg. The supply chain frame work is similar to the Case-1 as discussed above. The co-processing statistical data from the last year has been analysed to gauge the sustainability of using industrial waste as a substitute for virgin material. The quantity of AFR uses has been plotted for the year 2014 on a month wise basis and around 98693 tons of which bulk of the portion are Alternative raw material. The quantity of AR used in the raw meal is amounting to 92,730 tons and the rest of the material was AF. The fluctuation of feeding is contributed to supply chain constraints and production fluctuation. The highest quantity of feed was carried out in the month of February with firing of 14440 ton of industrial waste (figure 9). The quantity of traditional fuel (TF) and traditional raw material (TR) replaced, shows a similar trends as AFR firing. The total amount of TF and TR saved due to utilization of AFR is amounting to 91957 tons (figure 10).
The thermal substitution rate (TSR %) follows a similar trend as the quantity of AFR and quantity of TF and TR replaced, the TSR% is directly proportional to the fluctuation in feeding rate, high rate of TSR% has been achieved by the plant thus showing high energy recovery potential from the industrial waste (figure 11). The economical analysis revealed enormous amount of cash gain (figure 12).

4. Findings

The robustness of co-processing of industrial waste in Indian cement plant has been revealed based on the three case analyses. There is high economical gain and environmental sustainability achievable in term of using AFR. The cement production process is highly suitable of treating industrial waste and in some cases also enhances the product property. The co-processing of industrial waste is an effective methodology for CO₂ mitigation as it reduces the carbon emission by reducing the use of virgin material. The process is highly sustainable in number of countries but still lacks full scale implementation in India due to number of supply chain constraints which needs proper addressing. The major constraints as coined by number of literature and also revealed by the case studies are
availability of waste, transportation and storage, installation requirement-technological aspect, composition of the waste, quality of clinker, emission factors and government support\textsuperscript{7, 8, 22-24}. The three cases showed that high quantity of industrial waste as a raw material has been utilized, in all the cases, based on the statistical data of last year and the analysis showed that the bulk of the ARF material is AR which thus reduces the consumption of natural resources and decreases the carbon emission which would have otherwise taken place if the conventional fuel were used. The co-processing also leads to the reduction of waste going to the land filled thus also reduces indirect GHG emission which would have taken from the landfill site. Even in the present scenario the co-processing is showing a high sustainability and if the constraints are addressed it can lead to most effective waste management solution for a populated country like India. The economical aspect gauged, based on the quantity of TFR saved and TSR\% achieved for the three cases is immense, the cases indicates highly profitability of the process and the cash benefits achieved runs to crore of INR. The emission and setup cost for co processing is very less compared to the other waste disposal technology and plant requirements, India being the second largest cement producer, with high number of cement plants can dispose of large quantity of industrial waste and even municipal solid waste if the supply chain constraints are removed. The co-processing is zero waste process without generation of by products like ash, slag etc. The emission equipment already present in cement plants are enough in-term of the feeding rate practiced which is a deciding factor for emission an quality of the clinker number of parameters effects the quality of the finished products. Thus the co-processing in cement plant is highly robust process as mentioned from the analysis and also the auxiliary technology requirement is less thus making the process a sustainable waste disposal and carbon mitigation process.

5. Conclusion

The paper presents a study based on the present practices of industrial waste recycling and energy recovery in cement plant by the process of co-processing. The economical and environmental sustainability of the co-processing process in India has been shown via a three case analyses. The findings reveals if the process is implemented effectively the waste going to the landfill can be reduced and plants carbon foot print can be reduced. The financial gain is also immense and conventional fuel is also saved. There exists some pertaining issues in the supply chain which are to the some extend hindering the implementation of the co-processing process.

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