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THERMODYNAMIC ANALYSIS OF CEMENT PROCESSING UNIT: A COMPREHENSIVE REVIEW

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Abstract:

Cement is the essential material utilized for structures and structural designing developments. Cement is a fine material shaped out of crude materials comprising calcium oxide, silica, aluminum oxide and iron oxide. Because of the developing vitality supply requests, Energy and Exergy investigation strategies can be connected to distinguish the wasteful aspects in the procedures followed. Energy and Exergy examination depends on the first and second law of thermodynamics.Sometimes, the system energy balance isn't adequate for the conceivable finding of the framework defects and through exergy examination, the energy losses occurring in a framework can be effortlessly found. Subsequently, it is a great instrument for the estimation of quality of energy, this helps to make complex thermodynamic frameworks more proficient. This paper is directed to those researches who are doing their exploration work in energy and exergy investigation on different power plants or on a particular power setup or power expending arrangement of a plant, to check the wasteful aspects in the framework. This audit additionally shows the extent of future research.

Keywords: cement; energy, exergy; exergy efficiency; exergy destruction and exergy improvement potential.

1. Introduction

In the today's world, energy resources are being exhausted rapidly and also some specific energy resources (e.g. coal, petroleum etc) are decreasing. So as to save these energy sources, various techniques are now being used. Due to this reason, data has been collected from various industries so that to make the industry energy efficient. Energy balance is the basic method to find out the efficiency of a component. By applying energy balance technique, we can find the efficiency of any component. We can also find through this that how much energy is being supplied, how much gets destroyed and what output we are getting. This also provides a direction to the industry for using best processes and better techniques for energy saving.

The exergy examination is the advanced thermodynamic strategy and a cutting edge thermodynamic analysis utilized for the procedure assessment of the quality of energy expended. As, energy investigation depends on the primary law of thermodynamics, the exergy examination depends on both the first and the second laws of thermodynamics. Both analyses utilize also the material balance for the considered system. Analysis and optimization of any physical or chemical process, using the energy and exergy concepts, can provide the two different views of the considered process. The main purpose of exergy analysis is to discover the causes and quantitatively estimate the magnitude of the imperfection of a thermal or chemical process. Exergy analysis leads to a better understanding of the influence of thermodynamic phenomena on the process effectiveness, comparison of the importance of different thermodynamic factors, and the determination of the most effective ways of improving the process under consideration. A true understanding of exergy and the insights it can provide into the efficiency, environmental impact and sustainability of energy systems are required for the engineer or scientist working in the area of energy systems and the environment.

Recently, there has been increasing interest in using energy and exergy analysis modelling techniques for energy-utilization assessments in order to attain energy saving, and hence financial savings. Energy and exergy analysis studies conducted on cement factories and thermal power plants. In this paper, we are going to study the various researches done by the researchers from time to time. We will study the difference in the results, methods applied and how efficient a component is.

2. Literature Review

Parmar et. al., (2016) performed a mass and energy balance and analysis, exergy analysis for the dry process cement industry. Operational data of rotary kiln was collected for 6 months. The amount of O_2 and CO coming out from the rotary kiln hot gas were 7.29% and .38% respectively. The energy going with the hot gas was about 19.50% of the energy input. It was suggested to paint the surface of the kiln so as to reduce the heat loss.

Nithyananth et. al., (2016) performed energy and exergy analysis of a raw mill and raw materials preparation unit in Malabar cements, Walayar, using the actual operational data. Results showed that special considerations should be given to large ball mills to utilize all the waste heat from the kiln. Ambient air conditions effect efficiency (efficiency get increased in summer but decreased during winter. Moisture content also plays a vital role thus effective drying techniques should be employed.

V P. et. al., (2015) performed energy and exergy analysis in a cement plant production system. The aim was to provide an accurate account of energy consumption and energy analysis of different components i.e. preheater, rotary kiln, cooler. It was found that utilizing the energy of preheater exit gases and the cooler exit gases can represent good potential for raising the process performance. The wastage can be plug into the system for process heating and power production so as to increase the overall efficiency of the plant.

Atmaca et. al., (2014) performed energy, exergy and exergoeconomic analysis of a cement plant situated in Gaziantep, Turkey. The exergy destructions, exergetic cost allocations, and various exergoeconomic performance parameters were determined by using the exergoeconomic analysis based on specific exergy costing method (SPECO) for the entire plant and its components.

Bouapetchet al., (2014) performed energy and exergy analysis of the boiler and autoclave used in fiber cement composite production. The process consumes extremely high fuel. The results show that the main energy loss was due to the exhaust gas with energy loss of 34%. And for the autoclave, the main energy losses were exhaust steam, condensate, and autoclave shell heat loss.

Ramesh et. al., (2013) performed an energy audit of thermal utilities in a cement plant at Karnataka i.e. a detailed analysis of kiln, grate cooler, Preheater, Precalciner, raw mill, coal mill and gas conditioning tower. Technical opportunities were identified in order to decrease the energy consumption of the plant and improve the production process. The major heat losses for the system were identified as the preheater exhaust gases and heat carried away by cooler vent air. On successful implementation of the suggestions given for each energy conservation there will be the net saving of 9159000 MW.

Ari (2011) performed an energy and exergy analysis of a rotary kiln system and the first and second law efficiencies get calculated. This determines the effect of two cogeneration systems (which use the waste heat from both pre-heater and clinker cooler exhaust gases to produce either electricity or to preheat the raw material before entering the kiln system) on the overall efficiency of the system. The energy and exergy efficiencies calculated were 54.9% and 28.1%. With the cogeneration, the energy efficiencies increased to 70.6% (by using waste heat recovery steam generator) and 81.5% (by preheating the raw material) thus depicting a remarkable improvement.

Sogut et. al., (2009) performed energy and exergy analysis of a trass mill in a cement plant using actual operational data. The energy and exergy efficiencies were found to be 74% and 10.68%. It was suggested that by using energy recovery systems, the energy and exergy efficiencies can be improved to 84% and 48%. The study indicated that exergy utilization at the trass mill was even worse than the energy utilization. Certain measures should be taken like waste energy improvement, temperature check of hot gases through a continuous period, energy recovery system establishment.

Utlu et al., (2006) performed energy and exergy analysis of a raw mill (RM) and raw materials preparation unit in a cement plant in Turkey using the actual operational data. Both the energy and exergy efficiencies of raw mill were investigated for the plant performance analysis and improvement and are determined to be 84.3% and 25.2 % respectively. Heat losses that comes out especially at the beginning stage of the process can be highly reduced thus saving a lot a fuel. They also indicated that exergy utilization in the raw mill was even worse than energy utilization i.e. there is a big potential for increasing the exergy efficiency.

Khurana et. al., (2001) performed energy analysis of a cement plant (using 1 MT per annum) using operational data and by using Sankey diagram. It was found that 35% of the input energy is being lost with the waste heat streams. A steam cycle was selected to recover the heat from the streams using a waste heat recovery system generator and estimated that 4.4 MW of energy can be generated by the plant. The overall thermal efficiency of the plant was found to be 50% and was close to the best practice with the technological limitations of that time. It was found that around 30% of the energy requirement of the plant can be met from the cogeneration system.

Koroneous et al., (2005) examined cement production in Greece using exergy analysis tool. Due to the high temperatures required for the reactions, losses were quite big. The major exergy loss in the plant (approx. 30%) was due to the irreversibility's i.e. Preheating of raw feed, Cooling of clinker, Combustion of pet coke. It was recommended that rotary kilns should use biomass or scrap tyres as fuel as kilns are very good incinerators.

Kolip et al., (2010) developed a mathematical model related to energy and exergy balance for four stage cyclone precalciner type cement plant. A computer code was developed in GW-BASIC language to perform energy and exergy computations. The system developed was also able to determine optimum apertures in terms of energy costs and efficient usage of the units.

Engin et al., (2004) did an energy audit analysis of a dry type rotary kiln system working in a cement plant in turkey. The total loss in energy was found to be 40% [Flue gas (19.5%), cooler stock (5.61%) and kiln shell (15.11%) convection plus radiation]. It was recommended that a secondary shell system should be adopted and designed for the kiln surface and it will lead to an overall energy saving of 15.6% of the total energy input.

Kolet al., (2013) performed exergy analysis of Birla cement plant Satna. Based on the actual operational data of the process, exergy balances have been established around the preheater, rotary kiln, rotary cooler and the whole process. As per analysis, it was found out that 4180000 kwh/year electricity demand can be reduced by using waste heat recovery system.

Farag(2012) performed energy and exergy analysis of an Egyptian dry process cement kiln plant. Using actual operational data of the cement plant, the energy and exergy efficiencies were found out to be 40% and 25.7% respectively. It was recommended to decrease the kiln gas by-pass ratio, utilizing energy of preheater exit gases and bypass gases, replacing the rotary cooler by grate cooler. By adopting these, the efficiencies could be obtained up to 52% and 34%.

Madlootet al., (2012) performed energy and exergy analysis of a Grate Cooler in an Iraqi cement industry. Grate coolers are used in cement industry in order to recover heat from hot clinkers coming out of rotary kilns. Using the actual operational data of Al-Muthana cement plant in the south of Iraq.

Renoet al., (2013) performed exergy analysis for a dry type cement plant that presents pre-heater cyclone calciner with four stages. Basically, it was an exergy analysis of the clinker production using scrap tyres as fuel. The various improvement factors suggested were; 1. Recycling waste energy from hot gases. 2. By increasing the tertiary air temperature. 3. By applying the mineralizers (i.e. adding CaF_2 and $CaSO_4$) in raw materials. 4. Alternative fuel can also be used instead of scrap tyres.

Atmaca A (2018) performed energy, exergy and exergoeconomic analysis of a burner (dry type) in a cement facility in Sanhurfa, Turkey. Small improvements in the operation system was considered more beneficial than large improvements (exergy utilization).

Osuake et al., (2015) performed energy and exergy analysis ofSapele steam power plant in Nigeria. From the results, it was detected that maximum exergy loss occurred at the boiler i.e. 87.3%. For moderate change in the environment state temperature, (283K, 288K, 293K, 298K, 303K) no exceptional change was seen.

Guoqiang et al., (2011) performed energy and exergy analysis of 300MW Thermal system of Xialongton power plant. The results showed that 51.57% energy losses were occurring in the condenser and 6.64% energy losses were occurring in the boiler. The calculated thermal efficiency of the cycle was 37.99%. The main exergy destruction was present in the boiler i.e. 67.78% of fuel was destroyed. Also, energy destruction in the condenser was 13%.

Buhler et al., (2013) performed a detailed analysis of the Danish industry using energy, exergy and embodied energy methods. 22 industrial sectors were studied in Denmark for the year 2006 to 2012. To reduce the embodied losses, it was suggested to make continuous efforts to avoid electric heating if the electricity originates from other sources than wind power.

Atmaca et al., (2014) performed thermodynamic analysis of the kiln to find the effects of refractory bricks and formation of anzest layer on the specific energy consumption of rotary kiln. Actual data was taken from the cement plant located in Gaziantep, Turkey. The first law efficiency of rotary kiln was found to be 55.8% and second law efficiency was 38.7%. After the application of anzest layer and new refractory bricks inside the kiln, the first and second law efficiencies get improved to 61.2% and 45.1%.

Francis et al., (2014) performed energy and exergy analysis of a wet type rotary kiln system working in a white cement plant in South India. The efficiency that came out was very low due to large amount of water content. Heat losses by conduction, convection and radiation from the kiln were found to be 16.83%. The irreversibility of the system was 73.11% (7111 kj/kg-clinker). This analysis indicated that exergy utilization at the kiln was even worse than energy utilization.

Osuolateet al., (2016) performed thermodynamic analysis of a cement production process in Nigeria. The study states that chemical energy contributes significantly to the efficiency and exergy loss of the system. It was suggested that parametric analysis and optimization of the efficiency of the simulated system should be carried out.

Rafique et al., (2016) performed thermodynamic analysis of a solar desiccant cooling system. Desiccant cooling is one of the alternative to conventional air conditioning systems which can solve many problems related to air conditioning. The transport of exergy between the system components and destructions of energy accompanied with each component of the system were determined using average parameters calculated from theoretical analysis. The results showed that the desiccant wheel and solar collector shares the major part of the exergy destruction i.e. about 65%. The analysis showed the direction for exergy destruction minimization by identifying and quantifying the sites with exergy losses.

Peinado et al., (2011) performed energy and exergy analysis of a rotary dryer employed in a hot mix Asphalt (HMA) plant for heating and drying of the aggregates in the mixture. The energy losses were mainly due to the flue gases. A parametric study was conducted for the plant under various operational production parameters, including different humidities of aggregates and filler content in aggregates, working temperature and ambient conditions, in order to determine the parameters that effect the plant performance.

Boyaghchi et al., (2013) performed energy and exergy analysis of calcium oxide formation, CO_2 emissions and environmental effects during the clinker production process in rotary kiln. The exergy destruction due to irreversible calcination and fuel combustion process was 40.6% of inlet energy. Results also showed that 18.4% of exergy input was lost due to exhaust hot gases.

Koroneus et al., (2014) performed exergy analysis of residential and industrial sector in Greece to show that exergy analysis can lead to energy sustainability. Exergy analysis was used as an analysis method for Industrial symbiosis. The work analysed energy and exergy utilization considering the energy and exergy flows for the years 1990-2004.

Gutierrez et al., (2013) analysed the energy and exergy consumption of the calcination process in vertical shaft kilns, in order to identify the factors affecting fuel consumption.Data on energy and exergy consumption and losses throughout the calcination process was given for two shaft kilns.Results also showed that the most irreversible processes taking place in the kiln was the exergy destruction due to fuel combustion and the exergy destruction due to internal heat and momentum transfer both accounting for about 40% of the efficiency loss.

Han et al., (2018) created a new simplified model to characterize the integrated system involving waste heat recovery power generation system and cement production system. By combining pinch analysis and exergy analysis methods, the energy process of the integrated system was studied in detail.By reducing the heat transfer across pinch points and exergy destruction of the integrated system, an optimized mode of WHRPGS was identified and the power generation capacity of it can be increased by 7.559% theoretically. The optimized WHRPGS was applied in a 2500 t·d-1 clinker production line in Northwest China. Comparing the operational results of WHRPGS in original and optimized modes for 24 hours respectively, the power generation capacity of the optimized system was increased by 4.96% on average.

Table: Literature Review in Tabulated Form

S.No.	Authors	Research Paper	Component	Energy Efficiency	Exergy Efficiency
1	Parmar et. al., (2016)	Energy and exergy analysis of Cement Rotary Kiln.	Rotary Kiln	51.90%	38.29%
2	Nithyananth et. al., (2016)	Energy & exergy Balance of Raw mill in Cement Plant: A case study.	Raw Mill	77.54%	11.56%
3	V P. et. al., (2015)	Energy and exergy analysis in a cement plant	Cement Plant	54.93%	38.68%
4	Atmaca, A., &Yumrutas, R. (2014).	Thermodynamic and exergoeconomic analysis of a cement plant	Cement Plant	59.37%	38.99%
5	Bouapetch et al., (2014)	Energy and Exergy Analysis of Steam Boiler And Autoclave in Fiber Cement Process	Boiler & Autoclave	72.04%	69.98%
6	Ramesh et. al., (2013)	Energy Audit of Thermal Utilities in a Cement Plant,	Cement Plant	41.83%	-
7	Ari, V. (2011)	Energetic and exergetic assessments of a cement rotary kiln system.	Rotary Kiln	54.9%	28.1%
8	Sogut et. al., (2009)	Energetic and Exergetic assessment of a trass mill process in a cement plant	Trass Mill	84%	48%
9	Utlu et al., (2006)	Energy and Exergy analysis of a raw mill in a Cement production,	Raw Mill	84.3%	25.2%
10	Khurana et. al., (2001)	Energy balance and cogeneration for a cement Plant.	Cement Plant	50%	-
11	Koroneous et al., (2005)	Exergy analysis of cement production	Cement Plant	68%	50%
12	Kolip, A., &Savas, A (2010)	Energy and exergy analyses of a parallel flow, four-stage cyclone precalciner type cement plant	Four Stage Cyclone Precalciner	51%	28%

13	Engin, T., & Ari, V (2004)	Energy auditing and recovery for dry type cement rotary kiln systems	Rotary Kiln	60%	-
14	Kol, S., &Chaube, A.(2013)	Exergy analysis of Birla cement plant Satna: A case study, International Journal of Scientific & Engineering Research	1. Preheater &Precalciner 2. Rotary Kiln Rotary Cooler	-	1. 58.2% 2. 77.82% 3. 83.72%
15	Farag, L.,(2012)	Energy and Exergy Analyses of Egyptian Cement Kiln Plant with Complete Kiln Gas Diversion through by Pass, International Journal of Advances in Applied Sciences	Cement Plant	40%	25.7%
16	Madloot et al., (2012)	Energetic and Exergetic Efficiencies of a Grate Cooler in an Iraqi Cement Industry	Grate Cooler	45.19%	54.55%
17	Reno et al., (2013)	Exergy analysis of the clinker production applying scrap tyres as fuel	Pre-heater cyclone calciner	-	37%
18	Atmaca, A.(2018)	Energy, Exergy and Exergoeconomic assessment of a dry type rotary kiln	Burner	54%	29%
19	Osuake et al., (2015)	Energy, Exergy and Exergoeconomic assessment of a dry type rotary kiln	Turbine Boiler 3. Condenser	30.315% 11.003% 59.8%	12.7%
20	Guoqiang et al., (2011)	Energy and Exergy Analysis for 300MW Thermal system of Xiaolongtan Power plant	Condenser Boiler	48.43% 93.36%	37.99%
21	Buhler et al., (2013)	Energy and Exergy Analysis of the Danish Industry Sector.	Danish Industry sector	40%	-
22	Atmaca, A.(2014)	Analysis of the parameters affecting energy consumption of a rotary kiln in cement industry	Rotary Kiln	55.8%	38.7%
23	Francis et al., (2014)	Energy and Exergy analysis of a white cement kiln plant	White Cement Plant	12.2%	8%
24	Osuolale, F., &Osuolale, O, (2016)	Thermodynamic Analysis of Cement Production Process Plant in Nigeria	Cement Production Process in Nigeria	46.85%	46.9%
25	Rafique et al., (2016)	Energy, Exergy and Anergy Analysis of a Solar Desiccant Cooling System,	Solar desiccant cooling system	-	35%
26	Peinado et al., (2011)	Energy and exergy analysis in an asphalt plant's rotary dryer	Rotary Dryer	89%	18%
27	Boyaghchi et al.,(2013)	Thermodynamic and Environmental Impact Assessment of Calcium Oxide Formation in Clinker Production	Rotary Kiln	53.4%	28.6%
28	Koroneus et al., (2014)	The Impact of Exergy analysis in the Symbiosis of the Energy use,	Residential and industrial sector in Greece	22.36%	20.92%
29	Gutierrez et al., (2013)	Energy and exergy assessments of a lime shaft kiln	Vertical Shaft Kiln	71.6%	40.8%

3. Conclusion

In the earlier times, energy analysis or thermal efficiency or we can say thermodynamic efficiency was the main important parameter for the appropriate evaluation of a thermal system. But in the recent years, the exergy analysis has become an important tool for the evaluation of a thermal system. So, both the energy (1st law efficiency) and exergy (2nd law efficiency), play a vital role in the analysis of a cement plant production system or a thermal system. Exergetic analysis is primarily based upon the quality of energy and its destruction in an irreversible process and that too at elevated temperature condition which account for higher exergetic destruction compared to system performing at low temperature conditions. Thus it further laid down the concept of economic evaluation which is totally based upon the exergetic evaluation of any thermal system.

The exergo-economic analysis generated more focus upon the improvement or developmental potential existing in constructional features of any thermal system. To formulate the exergetic measure of any thermal system; the thorough understanding of its components, constructional features, design and operating conditions is required as the different parameters are going to affect the systems' exergy efficiency in a different way. The thorough analysis of energy, exergy makes a clear distinction about the avoidable and unavoidable causes of exergy destruction and improvement thereof in any plant system.

In the wake of above said literature conclusions; this is identified that energy analysis is the basis of exergetic evaluation and which further acts as base to economic evaluation of individual component and associated process parameters without which the complete analysis of plant would remain incomplete. Now as far as the key gaps are concerned; the above discussion definitely brings the items to be investigated in greater depth, to the fore. First and foremost, item that has been identified is that apart from Thermal Power, Rubber Processing and Cement Processing Plants; there are thousands of plants of different products which exist in our surrounding, the energy and exergy analysis has yet not been explored or in other words; the exergy formulations has yet not been developed and actually implemented in order to obtain the optimized performance out of plant and simultaneous reduction in waste potential.

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