

Thermodynamic Analysis of Cement Production Process Plant in Nigeria

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Abstract—Cement production industry being highly energy intensive requires a major goal of minimizing energy cost and environmental effects. This paper presents the thermodynamic analysis of a cement production process in Nigeria. The process was simulated in HYSYS. Exergy analysis is an analytical tool that evaluates the irreversibility and the exergetic performance of a process as well as provides identification of possible improvements in the process. The study indicates the system has an exergy efficiency of 38.44% and about 60% exergy loss. With the inclusion of chemical exergy, the system exergy efficiency and exergy loss are 46.85% and 53.1% respectively. The study has identified degree and sources of inefficiency in the cement production process. The method proffered can also aid in making informed decisions in improving the efficiency of the process.

Index Terms—Cement, exergy efficiency, exergy loss, HYSYS simulation.

1 INTRODUCTION

CEMENT is one of the major materials use in the construction industry. It has found wide usage in the construction of buildings, concrete lined-drain, gravity dam, bridges and highway pavement. The cement industry however, is an energy intensive industry with a typical energy use of about 50-60% of the production cost [1]. The depletion of finite energy sources and the attendant ecological and environmental implications of indiscriminate use of energy make efficient energy usage by energy consuming processes of high priority for all stakeholders in the industry. Several attempts have been made to study the energy efficiency of chemical processes [2] with a view to reduce the inefficiency of such processes [3]. One method of analysis that has been of great importance in studying the true energy efficiency of processes is the analysis based on second law of thermodynamics. Exergy analysis is a measure of the quality of energy and is the maximum work produced or the minimum required depend-

ing on whether the system produces or requires work in bringing the system through reversible process with the environment. It is a key aspect of providing better understanding of the process [4]; quantifying sources of inefficiency [5] and distinguishing quality of energy used [6]. Detection of inefficient processes in terms of energy and cost allocation makes room for development of efficient process which will invariably lengthen reserves of existing energy sources and allow for optimum usage of material. Exergy analysis pinpoints the location and magnitude of the losses [7]. It is a tool for determining how efficient a process is [8].

Previous work on exergy analysis of cement has sometimes been focused on the sub systems such as the rotary kiln [9], and the raw mill [10]. Most work has been on using only the operating data of the cement industry for the exergy analysis. This

does not give room for parametric analyses that could give suggestions for improvement of the process. This work presents a thermodynamic analysis of a cement plant in Nigeria. The plant is simulated in HYSYS using the operating data. The paper is structured as follows. Section 2 presents the methodology for the research which include the system descrip-

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HYSYS simulation and exergy analysis. Section 3 presents the results and discussion and section 4 summarises the findings.

2 METHODOLOGY

2.1 System Description

Cement production involves a number of steps. The raw materials are extracted through mining and quarrying and are milled. Raw milling involves mixing the extracted raw materials to obtain the correct chemical composition and grinding them to achieve the proper particle-size to ensure optimal fuel efficiency in the cement kiln and strength in the final concrete product. Three types of processes may be used: the dry process, the wet process, or the semidry process. The wet process is used in this study. The raw mix is heated to produce portland cement clinkers in a process named as pyroprocessing. The pyroprocessing system involves three steps: Drying or preheating, Calcining (a heating process in which calcium oxide is formed), and Burning (sintering). Pyroprocessing operations take place in the rotary kiln, while drying and preheating and some of the calcination are performed outside the kiln on moving grates supplied with hot kiln gases. The product from the pyroprocessing operations is moved to the clinker cooling. The clinker cooling operation recovers up to 30% of kiln system heat, preserves the ideal product qualities, and enables the cooled clinker to be maneuvered by conveyors. The final stage is the finish milling stage. The clinker is ground with other materials (which impart special characteristics to the finished product) into a fine powder. Up to 5% gypsum and/or natural anhydrite are added to regulate the setting time of the cement. Other chemicals, such as those which regulate flow - ability or air entrainment are also added at this stage. Fig. 1 shows the block diagram for cement production processes.

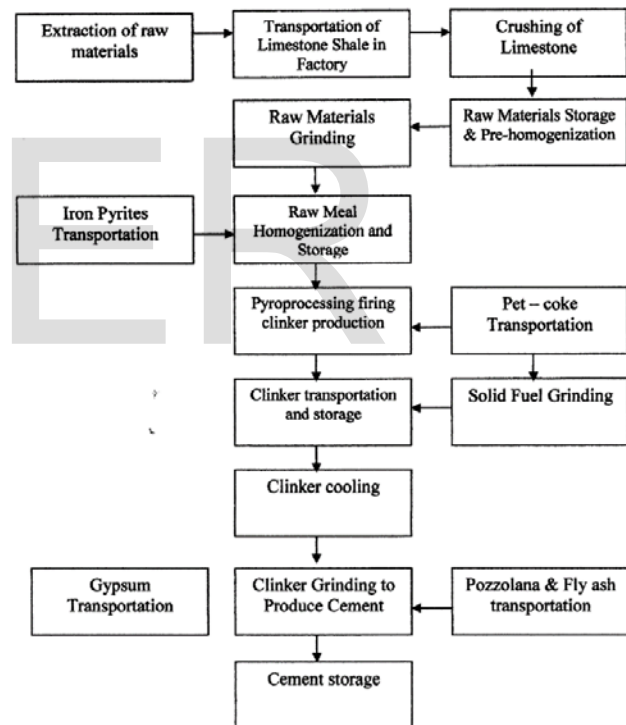
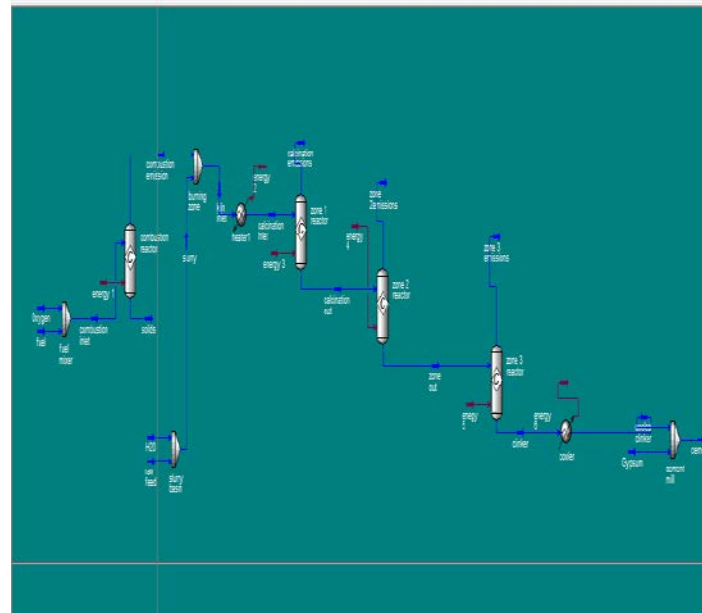


Fig. 1. Block diagram of cement production process

2.2 HYSYS Simulation

HYSYS software was used to simulate the system. This is with a view to determine the thermodynamic properties of each stream in the system in order to aid in the thermodynamic analysis of the system. The data used for the simulation is obtained from Lafarge cement Plant. Operating data such as stream flow rates, compositions, temperatures and pressure

were collected.

The known components were added in the simulation basis and the needed but unavailable components in the software were created. Physical and chemical properties of such components were determined from literatures and input to the software. A number of reactions involved in the process are added at the simulation basis. Some of these reactions are given in equations 1-8

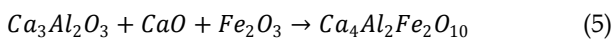


Fig. 2. HYSYS simulation of the process

In the simulation environment, the process is simulated beginning from the raw mill to the rotary kiln, the cooler and the cement mill. Fig. 2. shows a representation of the simulated system.

2.3 Exergy Analysis

Exergy analysis is a methodology for the evaluation of performance of devices and processes. Exergy is the maximum amount of work that can be obtained from a stream of matter, heat or work as it comes to equilibrium with a reference environment. The reference temperature and pressure used in the analysis of the work are $T_0=298K$ and $P_0 = 101.3kPa$.

The physical exergy of a given stream is given by

$$Ex_{phy} = m\{(h - h_0) - T_0(s - s_0)\} \quad (9)$$

where m is the molar flow, h is the specific enthalpy, s is the specific entropy.

The chemical exergy is calculated as

$$Ex_{ch} = (\mu^o - \mu_o^o) + RT_o \ln\left(\frac{C}{C_o}\right) \quad (10)$$

The work equivalent of a heat source is calculated as

$$Ex_{heat} = \left(1 - \frac{T_o}{T}\right) Q \quad (11)$$

The total exergy of a stream is then calculated as

$$Ex_{total} = Ex_{phy} + Ex_{ch} + Ex_{heat} \quad (12)$$

The exergy efficiency of each sub system and the overall system is calculated as

$$\eta = \frac{\text{Total output exergy}}{\text{Total input exergy}} \times 100 \quad (13)$$

The irreversibility is calculated as

$$\text{Irreversibility} = \sum E_{xin} - \sum E_{xout} \quad (14)$$

Where, E_{xin} is input exergy and E_{xout} is output exergy.

3 RESULTS AND DISCUSSION

The HYSYS simulation of the system gave the physical and chemical properties of each stream. Some of these properties are used to calculate the physical exergy of all the streams in the system. The chemical exergy was also calculated for streams with chemical reactions. The results of the physical exergy using (9) is given in Table 1. Enthalpy and entropy were calculated at reference state and at the operating conditions of the streams. Table 2 gives the results of the chemical exergy in and out of the sub systems. The work equivalent of the heat sources in the sub systems using (11) are also given in table 2.

The results as presented was used to calculate the overall exergy efficiency of the whole plant without the chemical exergy. It was found to be 38.44%. This conforms to the pattern found in previous exergy analysis of cement production process [13],[15]. The total amount of exergy into the system is 412.7MJ/hr and the total exergy out is 153.8MJ/hr. The exergy loss of the system is 246.2MJ/hr. This translates to about 60% of exergy loss in the system. An earlier research shows about 50% of exergy loss despite the recovery of a large amount of heat [16]. The simulation from HYSYS can be said to be reliable from the exergy analysis of the simulated system.

The overall exergy of the system with the inclusion of the chemical exergy is 46.85%. The total exergy input and output are 991.34MJ/hr and 464.22MJ/hr respectively. The exergy

loss of the system reduces to 53.1% in contrast to 60% from the earlier calculation. The contribution of chemical exergy to the efficiency and exergy loss of the system is really significant. There is an improvement of 11.5% in the efficiency when chemical exergy is included in the calculation. Cement production system is not only energy intensive but it involves a lot of chemical reactions. A true exergetic efficiency analysis of the system should reflect the chemical exergy as well.

Combustion emission	2151	-98400	265.9	80030	108.3	166300000
Raw Feed	543.2	1904	2008	15970	49.86	7997000
Slurry	1343	-169400	843.7	6416	20.36	7944000
Kiln Inlet	3496	-125700	549	51640	126.2	169500000
Calcination inlet	3496	-100300	573.8	77080	151.1	256300000
Calcination Emission	3207	-176000	239.9	47130	107.8	142500000
Calcination Out	434.5	354400	2395	354400	503.5	148500000
Zone2 out	335.4	566000	3173	566000	723.8	183700000
Clinker	284	643200	3728	643200	839.1	176700000
Cooled Clinker	284	42380	3016	42880	126.5	11280000
Cement	294	41410	3025	41410	122.8	11270000

The system is seen to be grossly inefficient in terms of energy usage. Parametric studies could be conducted on the simulated system to seek for combinations of operating conditions that could improve the efficiency of the system. The resulting conditions could guide operators and designers in making informed decisions to see to the energy efficiency improvement of the process. In addition, optimization procedures can be carried out on the ensued results to further improve the efficiency of the system. These studies can be made possible on the simulated system and can then be validated on the real process.

Table 2
Chemical exergy and heat source exergy of sub-systems

Unit	Chemical exergy in	Chemical exergy out	Heat source exergy
Combustion Reactor	431400000	23550000	212500000
Heater 1			88950000
Zone1 Reactor	42570000	37150000	60000000
Zone2 Reactor	33820000	70240000	35810000
Zone3 Reactor	70240000	22660000	7163000
Cooler			170500000

Table 1
Physical exergy of streams in the system

Streams	m kJ/hr	h kJ/kmol	s kJ/kmo IK	Δh kJ/kmo I	Δs kJ/kmo IK	Ex kJ/hr
Oxygen	1850	-156.1	163.7	-146.6	-0.3864	-176400
Fuel	1288	837	64.63	834.9	2.658	990100
Combustion inlet	3138	251.7	126.7	255.7	0.9246	730000

4 CONCLUSION

The study presented the thermodynamic analysis of a cement production plant in Nigeria that was simulated using HYSYS. The simulated system was found to be a true representation of the actual plant. Thermodynamic analysis of the plant reveals an exergetic loss of about 53% with an efficiency of 46.58%.

The chemical exergy contributes significantly to the efficiency and exergy loss of the system. It should be carefully considered in the thermodynamic analysis of the system. The system has a great potential for improvement. It is suggested that parametric analysis and optimization of the efficiency of the simulated system be carried out. The resulting solution can then be applied on the real plant for validation. The presented methods is proposed as a useful tool in the analysis of the exergy efficiency of a cement plant and in providing energy conservation method for the plant. It could also find relevance in developing energy policies for the cement production process.

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