Energy and Exergy Analysis in a Cement Plant

Jijesh V P, Shifin Yohannan, Jithin K Jose, Rahul C R, Jeshin Joy P, Leo A J

***Abstract*— Cement production has been one of the most energy intensive industries in the world. The exergy analysis has emerged as the most effective procedures for a successful energy management program. The main aim of this analysis is to provide an accurate account of energy consumption and energy analysis of different components to reveal the detailed information needed for determining the possible opportunities for energy recovery. Based on average actual operation data of the process, energy and exergy balances have been established around the preheater, rotary kiln and the cooler. The exergy efficiency will always be lesser than the corresponding energy efficiency of the system. This accounted reduction in efficiency is due to irreversibilities in the system.**

***Index Terms*—Cement Production Process, Energy and Exergy analysis, Rotary kiln, Preheater and Cooler**

I. INTRODUCTION

The exergy analysis is the modern thermodynamic method used as an advanced tool for engineering process evaluation. The energy analysis is based on the first law of thermodynamics where exergy analysis based on the combination of first and second laws of thermodynamics. [1] This analysis will be held on the most energy consuming units in a cement plant from which the data were taken. These calculations give a clear view of the performance of this plant. Based on these calculations, some suggestions will be given to improve the efficiency and energy status of the industry.

An energy analysis does not characterize the irreversibility of processes within the system. In contrast, exergy analysis will characterize the work potential of a system. Exergy is the maximum work that can be obtained from the system, when its state is brought to the reference or dead state. [3]

II. METHODOLOGY

For a general steady state, steady – flow process, the following balance equations are applied to find the work and heat interactions, the rate of exergy decrease the rate of irreversibility, the energy and exergy efficiencies. The mass balance equation can be expressed in the rate from as

$\Sigma m_{in} = \Sigma m_{out}$ [2]

Where m is the mass flow rate, and the subscript 'in' stands for inlet and 'out' for outlet. The general energy balance can be expressed as

$\Sigma E_{in} = \Sigma E_{out}$ [2]

$Q + \Sigma m_{in} h_{in} = W + \Sigma m_{out} h_{out}$

Where

$Q = Q_{net} = Q_{in} - Q_{out}$

$W = W_{net} = W_{out} - W_{in}$

h = Specific enthalpy

The general exergy balance can be expressed in the rate from as

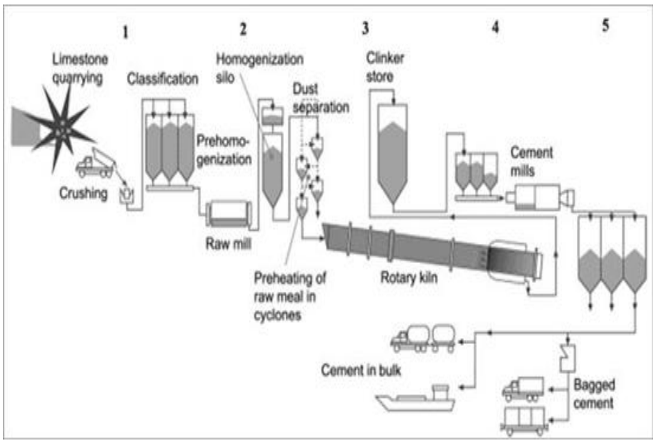
$\Sigma Ex_{in} - \Sigma Ex_{out} = \Sigma Ex_{dest}$ or

$\Psi = (h - h_0) - T_0 (s - s_o)$

Energy efficiency = (Energy output / Energy input) ×100

Exergy efficiency = (Exergy output / Exergy input) ×100 [2]

III. CEMENT PRODUCTION SYSTEM



The major constituent of cement is limestone which is mined from the quarry. These huge sized particles are crushed in the crushing units. The crushed particles are mixed with suitable additives like laterite and sweeteners, which makes the perfect mixture to enter into the raw mill at which it converts into a powdered form called raw meal. The raw meal get preheated in the preheater before entering into the rotary kiln. The important process of cement production which is clinkerisation takes place in the rotary kiln by the combustion of coal. The hot clinker comes out from the kiln after cooling in the cooler will added up with necessary amount of gypsum and fly ash, and will be converted into fine powder in the cement mill. Then it will go for packing.

IV. THE SYSTEM

The kiln is the most energy consuming part in the cement manufacturing process. Therefore, the system selected for this analysis is the kiln with pre heater and cooler. The raw meal of 50^0C enters the preheater together with the primary air. The preheating takes place with the supply of flue gas from the kiln and cooler. The preheated materials with a temperature of 890^0C enters the rotary kiln. The preheated materials get melted in the kiln. After clinkerisation the hot clinker with 1200^0C get cooled in the cooler to about 90^0C with supply of necessary amount of ambient air.

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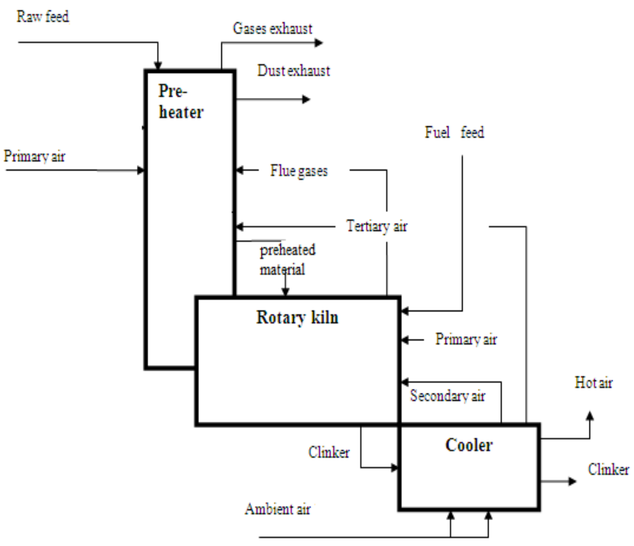


V. Observations And Calculations

Mass, Energy and Exergy Balance of Preheater

Input Items	Mass (Kg)	Temp (K)	C_p (KJ/KgK)	Energy (KJ/Kg)	Exergy (KJ/Kg)
Raw meal	1.57	323	0.83	420.90	0.8523
Primary air	0.58	303	1.004	176.44	0
Flue gas	1.01	1423	1.09	1566.58	717.90
Tertiary air	0.73	1073	1.08	845.95	304.99
Water vapour	0.03	1073	2	64.38	23.47
Output Items					
Hot meal	1.01	1163	1.002	1176.98	457.97
Flue gas	2.74	633	1.09	1890.51	318.97
Flue dust	0.165	543	1	89.59	10.44

Mass, Energy and Exergy Balance of Rotary Kiln

Input Items	Mass (Kg)	Temp (K)	C_p (KJ/KgK)	Energy (KJ/Kg)	Exergy (KJ/Kg)
Coal comb-ustion	0.189	Gcv=21036		3988.42	3988.42
Hot meal	1.01	1163	1.002	1176.98	457.96
Primary air	0.269	303	1.004	81.83	0
Seco-ndary air	0.64	1073	1.08	741.65	267.38
Output Items					
Clinker	1	1473	1.09	1605.57	753.52
Flue Gas	1.01	1423	1.09	1566.58	717.9

Mass, Energy and Exergy Balance of Cooler

Input Items	Mass (Kg)	Temp (K)	C_P (KJ/KgK)	Energy (KJ/Kg)	Exergy (KJ/Kg)
Hot clinker	1	1473	1.09	1605.57	753.04
Ambient Air	2.33	303	1.004	708.81	0
Output Items					
Clinker	1	363	0.7691	279.18	4.11
Hot Air	0.9	463	1.0069	433.56	29.53
Secon-dary Air	0.65	1073	1.08	753.24	271.59
Tertiary Air	0.75	1073	1.08	869.13	314.64

Energy efficiency of the system = Total useful energy output / Total energy input

= 6250.68 / 11377.51

= 54.93 %

Exergy efficiency of the system = Total useful Exergy output / Total exergy output

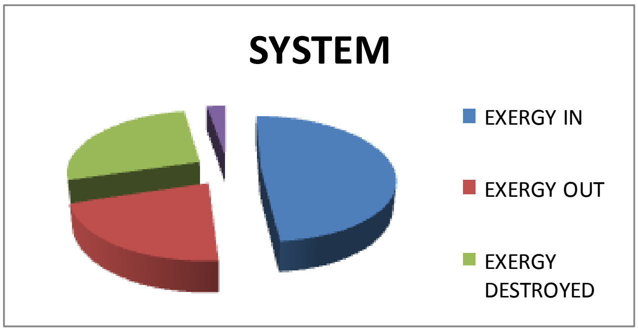
= 2519.73 / 6514.02

= 38.68 %

Amount of heat wasted per 1 kg of clinker = 747.43 KJ/Kg

= 358.94 x 54 x 1000

= 19382.76 MJ/hr



Graphical Representation of Exergy Distribution in the System

VI. Results

The aim of this analysis is to determine and analyze exergy utilization and their irreversibility in Malabar cement plant. Exergy analysis is carried out using actual plant operational data. The major heat loss sources have been determined as preheater and cooler. The results obtained by conducting energy & exergy analysis are as follows.

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1. Energy efficiency = 54.93 %
2. Exergy efficiency = 38.68 %
3. Amount of heat wasted = 19382.76 MJ/hr

VII. Conclusions

Exergy analysis is a powerful tool, which has been successfully and effectively used in the performance evaluation of energy related systems. Exergy efficiency will always be less than the energy efficiency, and here the reduction is about 16.25 % due to irreversibilities in the system. Utilizing the energy of preheater exit gases and the cooler exit gases represents good potential for raising the process performance. Since here significant amount of heat is wasting which arises the scope for waste heat recovery. This wastage can be plug into the system itself for process heating or can be go for power production, which in turn will increase the overall efficiency of the plant.

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