International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 3 (2015) pp. 8129-8142

http://www.ripublication.com

# Energy and Exergy Analysis of A Double Entry Central Discharge-Raw Mill (DECD-RM) Used In A Cement Industry

**T. Ashok Kumar[a] & R. Chandramouli,[a*]**
*[a] School of Mechanical Engineering ,SASTRA University, Thanjavur, India-613401*
*[*]Corresponding author. Tel:+95 4362 264101, Fax: +95 4362 264120,*
*e.mail:cramaswamy@gmail.com(R.Chandramouli),takumar@mech.sastra.edu (T.Ashok Kumar)*

## Abstract

Cement industry to be the energy-intensive, consumes considerable amount of energy during the production process. In the present industrial scenario, importance is given to the energy-intensive sectors, in terms of energy and energy conversion efficiency. The present investigation concentrates on energy conversion and optimization of operational parameters of a cement industry, with respect to the factors such as increased competition, costs, reduced profit margin, impact on environment etc. To find a viable alternate to these factors, a case study has been undertaken on energy and exergy analysis in a Double Entry Central Discharge-Raw Mill (DECD-RM) of a cement plant with a capacity of 120 Tons per hour, situated in Tamil Nadu, India. The energy and exergy efficiencies of the DECD-RM are evaluated which are about 84.46% and 36.91% respectively and is inferred that there are some scope for improvements in raw mill operations.

**Keywords:** Cement Plant; Raw mill; Energy; Entropy; Exergy

## Introduction

Conventional sources of energy are being depleted fast due to the rapid industrialization. Therefore, an effective and efficient utilization of the available energy sources become warranted. In order to evaluate the possibilities of enhancing the energy efficiency of the process, the operational parameters have to be evaluated. This is required to maximize the energy usage, to save the energy loss, and in turn to save both energy and cost. The energy balance as per the first law of thermodynamics is a basic tool in order to investigate the various forms of energy conversions and losses. To account the variable quality of different disordered energy forms in thermal systems, a universal standard of quality is needed. The most natural and convenient standard is the maximum work which can be obtained from a given form of energy using the environmental parameters as a reference state. The standard of energy quality is called exergy. One of the major uses of this concept is to find the exergy balance for the analysis of thermal systems. Exergy balance is similar to energy balance. But it has the fundamental difference. The energy balance is the statement of law of conservation of energy.

At present, there has been an ever increasing interest in analyzing the utilization of energy and exergy for assessing the waste form of energy. This leads to an enhancement of energy utilization and energy savings, which results in financial and environmental benefits. The raw mill of a cement plant is one of the waste heat recovery units meant for removal of moisture from the raw material. These also produce fines of the raw materials for cement production. It utilizes energy in the form of heat from the waste gases of the kiln system. Its performance can be enhanced through system modification. From the available literatures, it is observed that for analyzing the exergy, the primary focus is the analysis using first law of thermodynamics. Tahsin Engin et al. [1] have conducted energy audit study for a dry type rotary kiln system in a cement plant. They designed a waste heat recovery steam generator to retrieve the waste heat, with payback of 17 months. Koroneos et al. [2] contented that the exergy analysis of a cement plant was found to be a method of minimizing the energy cost and environmental effects. Zafer et al. [3] have analyzed the energy and exergy balance of the raw mill of a cement plant and observed that there is a potential for enhancing the exergy utilization. Mont Hubbard et al. [4] have studied the oxide concentration in a raw meal (homogeneous mixture of raw material ready for clinker production) used in cement manufacturing by X- ray analysis. Their research concludes that the estimation has been made accurately at higher flow rates of the feed material. The formation of micro cracks during clinker production may influence the grindability of clinker, further addition of by product waste containing metallic particles influence to enhance the micro cracks on clinker material in kiln during clinker production, which is reported by Joseph O. Odigure [5]. Rasul et al. [6] assessed the thermal performance of a cement plant and suggested with that the drying the raw material in raw mill operation can be possible by the use of exhaust gas leaving from kiln system. Ziya Sogut et al. [7] have suggested a waste heat recovery system in order to make use of the waste heat in kiln system. The present study is aimed at both energy and exergy analyses as well as optimization of the exergy efficiency of a raw mill used in a cement industry in Tamilnadu, India. The primary focus of the study is to explore the possibilities of any scope for further improvements in the performance of the raw mill.

## The Cement Manufacturing Process

### Cement

Cement contains oxides of calcium, silicon, aluminum and iron is about 90% by mass. The remainder being the gypsum, small quantity of magnesium salt, potassium and other elements. When it is mixed with water, it gets hardened. The raw materials for cement manufacturing are limestone and clay. Additives such as bauxite, chert and laterite are also considered in order to produce the cement of desired quality.

**Raw mill**

Raw mill used in this plant is a ball mill type, which is used for grinding the raw material into very fine particles. This is a closed circuit operation with suitable separator. Ball mill is a cylindrical shell rotating in horizontal axis filled with solid grinding media about 30 % of the inner volume of the ball mill. The removal of moisture present in raw material can be obtained by passing hot gases from the preheater of kiln exhaust system to enhance grinding efficiency. The specific drying capacity depends on chamber volume and hot gas temperature.

**Technical details of the raw mill**

The rated capacity of the raw mill is 120 tons per hour (tph) at 6 % moisture and mill size is 4.2m diameter and 13.25m in length. The feed of raw material to the mill is divided into two streams supplied through both inlet chambers of the mill. Similarly the hot gases are admitted in to both of the inlet chambers. The mill is designed to remove moisture up to 6%, but on-site the moisture possessed by the raw material is up to 12% and is even higher in winter season. A modification is made in the drying chamber length of the mill, which is modified from 1.45 m to 3.04 m, the grinding chamber-1 length is 3.66 m and grinding chamber-2, its length is 5m.

## The Present Study

Operational data pertaining to the operation of the DECD-RM was obtained on daily basis. The data obtained was used for the energy and exergy analysis, in order to understand the energy flow through the system in order to explore the possibility of enhancing the productivity of the raw mill.

## Theoretical Analysis

The engineering applications considered in this work are analyzed on control volume basis. According to the control volume formulations, the mass, energy and entropy balances presented in this description play an important role. Equations of mass, energy and entropy, work, heat interactions, irreversibility, energy efficiency and exergy efficiencies, differential equations and rate equations are taken from the existing literature. [ 8, 9, 10, 11 & 12].

The mass balance equation is as follows:

$$(dm_{cv}/dt) = \Sigma\dot{m}_{in} - \Sigma\dot{m}_{out} \quad \text{---} 1$$

where, $m_{cv}$ – mass accumulation in the control volume , $\dot{m}_{in}$ – inward mass flow rate, $\dot{m}_{out}$ – outward mass flow rate

For steady state, we can say;

$$\Sigma\dot{\mathbf{m}}_{in} = \Sigma\dot{\mathbf{m}}_{out} \quad \text{---} 2$$

The energy balance is made for the flow of materials through the mill to analyze the energy utilization and subsequently the exergy analysis also. The energy balance for the mill can be given as

$\dot{\mathbf{E}}_{in} = \dot{\mathbf{E}}_{out}$ ------------------------------------------------------------------------------- 3

$\dot{Q} + \Sigma\dot{m}_{in}h_{in} = \dot{W} + \Sigma\dot{m}_{out}h_{out}$ ------------------------------------------------------- 4

where, $\dot{E}_{in}$ – the rate of net energy entering into the system, $\dot{E}_{out}$ – the rate of net energy leaving the system

h – specific enthalpy

Considering the heat energy alone, the energy balance for the system may be expressed as:

$\dot{\mathbf{Q}} = \dot{\mathbf{Q}}_{net.in} = \dot{\mathbf{Q}}_{in} - \dot{\mathbf{Q}}_{out}$ ---------------------------------------------------------------- 5

The quantity of thermal exergy (E ) associated with heat transfer $Q_r$ across a system boundary r at constant temperature $T_r$ is

$Ex^Q = [\,1 - \frac{To}{Tr}\,]Q_r$ ------------------------------------------------------------------ 6

(or) as a rate equation,

$\dot{E}x^Q = \Sigma\,\dot{Q}[\,\frac{Tr - To}{Tr}\,]$ ------------------------------------------------------------------- 7

The rate of exergy entering into the control region is always higher than that of exergy leaving from the control region. The rate of loss of exergy is the difference in exergies entering and leaving the control volume and is called the irreversibility rate. This statement is applicable to all real processes.

$\Sigma\dot{E}x_{in} - \Sigma\dot{E}x_{out} = \Sigma\dot{E}x_{dest}$ or $= \Sigma\,\dot{Q}_k\,[1- (T_0/T_k)] - \dot{W} + \Sigma\dot{m}_{in}\,\psi_{in} + \Sigma\dot{m}_{in}\,\psi_{in}$ -------------8

Where, $\psi = (\,h - h_0) - T_0(\,s - s_0)$ -------------------------------------------------------9

(specific flow exergy)

Where, $\dot{Q}_k$ is the heat transfer rate through the boundary at temperature $T_k$ at location k, $\dot{W}$ is the work rate (which is zero for the present case). $\psi$ is the flow exergy. *s* is the specific entropy and the subscript zero indicates the properties at the dead state and $P_0$ and $T_0$ are the pressure and temperature corresponding to the dead state. The exergy destroyed or irreversibility may be expressed as follows:

$\dot{\mathbf{I}} = \Sigma\dot{\mathbf{E}}\mathbf{x}_{dest} = T_0\,\dot{\mathbf{S}}_{gen}$ --------------------------------------------------------------------- 10

where, $\dot{S}_{gen}$ is the rate of entropy generation and the subscript zero represents reference environment conditions. The exergy of an incompressible substance may be written as follows:

$\dot{\mathbf{E}}\mathbf{x}_{ic} = C(T - T_0 - T_0\,\ln(T/T_0))$ ---------------------------------------------------------11

where, C specific heat.

The exergy efficiency ε is given as

$\varepsilon = (1 - (\text{exergy destroyed / exergy input}))$ -----------------------------------------12

exergy destroyed = exergy input – exergy utilized

## Results and Discussion

The modeling technique adopted in the study for the energy and exergy analysis made on the Double Entry Central Discharged Raw Mill (DECD-RM) using real operational data, is elaborated below.

### Mass balance in the DECD-RM

The mass balance of the DECD-RM of the input materials, which are fed inside the Mill Chamber-1 and Chamber-2, is tabulated as shown in Table1. Similarly, the mass balance of the discharged materials of the raw mill is shown in Table 2. The mass balance of the both input and discharged or output materials of the raw mill is evaluated using the law of conservation of mass, as provided below.

**Table 1:** Mass balance of the DECD-RM observed at inlet

| Sl. # | | Input material | ṁ ( tph ) | T ( $^o$C) |
|---|---|---|---|---|
| 1 | Raw mill Inlet chamber-1 | Feed material | 77.000 | 30 |
| 2 | | Hot gases from preheater | 124.702 | 300 |
| 3 | | Dust in preheater | 9.976 | 300 |
| 4 | Raw mill Inlet chamber-2 | Feed material | 33.000 | 30 |
| 5 | | Hot gases from preheater | 39.903 | 290 |
| 6 | | Dust in preheater gas | 3.192 | 290 |
| 7 | | Returns from turbo air separator | 88.220 | 81 |
| 8 | | Leaking air | 12.981 | 30 |
| | | Total | 388.974 | |

**Table 2:** Mass balance of the DECD-RM observed at exit

| Sl. # | Output material | ṁ (tph) | T ($^o$C) |
|---|---|---|---|
| 1 | To grit separator | | |
| | Moisture in leaking air | 0.260 | 98.000 |
| | Moisture in feed material | 11.000 | 98.000 |
| | Fines of feed material | 83.490 | 98.000 |
| | Moisture evaporated, leaking air and gas to grit separator | 159.991 | 98.000 |
| 2 | Mill discharge to elevator | 134.233 | 98.000 |
| | Total | 388.974 | |

$$\Sigma \dot{\mathbf{m}}_{in} = \dot{\mathbf{m}}_{fm-1} + \dot{\mathbf{m}}_{phg-1} + \dot{\mathbf{m}}_{dphg-1} + \dot{\mathbf{m}}_{fm-2} + \dot{\mathbf{m}}_{phg-2} + \dot{\mathbf{m}}_{dphg-2} + \dot{\mathbf{m}}_{rgs} + \dot{\mathbf{m}}_{rtas} + \dot{\mathbf{m}}_{la} \text{----13}$$

$\dot{m}$ – mass flow rate
$\dot{m}_{fm-1}$ & $\dot{m}_{fm-2}$ – mass flow rate of feed materials in the chambers 1 & 2
$\dot{m}_{phg-1}$ & $\dot{m}_{phg-2}$ – mass of pre-heater gas to the raw mill inlet chambers 1& 2

$\dot{m}_{dphg-1}$ & $\dot{m}_{dphg-2}$ – mass of dust in pre-heater gas to the raw mill inlet chambers 1 & 2

$\dot{m}_{rgs}$ & $\dot{m}_{rtas}$ – mass of returns from grit separator & turbo air separators

$\dot{m}_{la}$ – mass of leaking air

$$\Sigma\dot{\mathbf{m}}_{out} = \dot{\mathbf{m}}_{wvia} + \dot{\mathbf{m}}_{mfm} + \dot{\mathbf{m}}_{ffm} + \dot{\mathbf{m}}_{hgd} + \dot{\mathbf{m}}_{dbe} \quad (14)$$

$\dot{m}_{wvia}$ – mass of water vapour in air

$\dot{m}_{mfm}$ – mass of moisture in feed material

$\dot{m}_{ffm}$ – mass of fines in feed material

$\dot{m}_{hgd}$ –mass of hot gas discharge

$\dot{m}_{dbe}$ – mass of discharge to bucket elevator

## Energy analysis of DECD-RM

*Evaluation of the average input temperature of the DECD-RM*

The input materials are fed on either side of the raw mill consisting of two receiving chambers. The chamber-1 is provided with drying and grinding zone and the chamber-2 has only grinding zone as it carries returns along with 30% fresh feed materials. The grounded materials from the two chambers are carried by the hot gases with leaking air through grit separator and the remaining is discharged through the central discharger. The average temperatures of both the chambers are evaluated based on the enthalpy balance considering the Standard Temperature and Pressure (STP) as a reference. The average temperature of the raw mill chambers 1 & 2 are calculated using the Law of Conservation of Energy and the results are given in the Table 3 and Table 4. The average temperatures of chambers 1& 2 have been determined by the following equations:

$$\Sigma\dot{\mathbf{m}}_{in}\, h_{sp-1} = \dot{\mathbf{m}}_{fm-1} C_{p-fm-1}\, t_{fm-1} + \dot{\mathbf{m}}_{phg-1}\, C_{p-phg-1}\, t_{hg-1} + \dot{\mathbf{m}}_{dphg-1}\, C_{p-dphg-1} t_{dphg-1} \quad (15)$$

$[h_{sp} = C_p\, t]$

$h_{sp}$ – specific heat, $C_p$ – specific heat capacity, t – temperature of substance

$$\Sigma\dot{\mathbf{m}}_{in}\, C_{p-1} = \dot{\mathbf{m}}_{fm-1} C_{p-fm-1} + \dot{\mathbf{m}}_{phg-1}\, C_{p-phg-1} + \dot{\mathbf{m}}_{dphg-1}\, C_{p-dphg-1} \quad (16)$$

Average temperature of mixture in DECD-RM chamber-1

$$t_{mixch-1} = \Sigma\dot{\mathbf{m}}_{in}\, h_{sp-1} / \Sigma\dot{\mathbf{m}}_{in}\, C_{p-1} \quad (17)$$

$$\Sigma\dot{\mathbf{m}}_{in}\, h_{sp-2} = \dot{\mathbf{m}}_{fm-2}\, C_{p-fm-2}\, t_{la-2} + \dot{\mathbf{m}}_{phg-2}\, C_{p-phg-2}\, t_{phg-2} + \dot{\mathbf{m}}_{dphg-2}\, C_{p-dphg-2}\, t_{dphg-2} + \dot{\mathbf{m}}_{rtas}\, C_{p-rtas} t_{rtas} \quad (18)$$

$$\Sigma\dot{\mathbf{m}}_{in}\, C_{p-2} = \dot{\mathbf{m}}_{fm-2}\, C_{p-fm-2} + \dot{\mathbf{m}}_{phg-2}\, C_{p-phg-2} + \dot{\mathbf{m}}_{dphg-2}\, C_{p-dphg-2} + \dot{\mathbf{m}}_{rtas}\, C_{p-rtas} \quad (19)$$

Average temperature of the mixture in DECD-RM chamber-2

$$t_{mixch-2} = \Sigma\dot{\mathbf{m}}_{in}\, h_{sp-2} / \Sigma\dot{\mathbf{m}}_{in}\, C_{p-2} \quad (20)$$

**Table 3:** The total enthalpy of flow stream DECD-RM observed at inlet chamber – 1

| Sl. # | | Input material | ṁ (tph) | $C_p$ (kJ/kg-K) | T ($^oC$) | ṁ* $C_p$*T ( kJ/kg-K) |
|---|---|---|---|---|---|---|
| 1 | Inlet chamber-1 | Feed material | 77.000 | 0.837 | 30 | 1934301.600 |
| 2 | | Hot gases from preheater | 124.702 | 1.118 | 300 | 41820487.157 |
| 3 | | Dust in preheater | 9.976 | 0.837 | 300 | 2506096.609 |

**Table 4:** The total enthalpy of flow stream DECD-RM observed at inlet chamber – 2

| Sl. # | | Input material | ṁ (tph) | $C_p$ (kJ/kg-K) | T ($^oC$) | ṁ* $C_p$*T (kJ/kg-K) |
|---|---|---|---|---|---|---|
| 1 | Inlet chamber -2 | Feed material | 33.000 | 0.837 | 30 | 828986.400 |
| 2 | | Hot gases from preheater | 39.903 | 1.118 | 290 | 5983623.835 |
| 3 | | Dust in preheater gas | 3.192 | 0.837 | 290 | 12935900.000 |
| 4 | | Returns from turbo air separator | 88.220 | 0.837 | 81 | 775185.019 |
| | | Total | 388.974 | | | 20523695.250 |

The average temperatures of the raw mill input materials receiving chambers are calculated to be 217.97$^0$C and 137.95$^0$C respectively. The drying zone temperature is considered to be the log mean temperature of the average inlet temperature of flow stream and discharge temperature of the flow streams of DECD-RM. As there is a logarithmic relation between the temperature of drying zone and the temperature of mill grinding zone, the average discharge temperature of the mill can be calculated using the following relation.

$\Delta t_{avgch-1} = (t_{mixch-1-} t_{exit}) /( \ln (t_{mixch-1}/t_{exit})$------------------------------------------------ 21

$\Delta t_{avgch-2} = (t_{mixch-2-} t_{exit}) /( \ln (t_{mixch-2}/t_{exit})$----------------------------------------------- 22

The logarithmic mean temperatures of the raw mill chambers 1 &2 chambers are 155.7$^0$C and 117.87$^0$C respectively.

*Heat losses from the raw mill*

The various heat losses from the raw mill have been determined by the basic convective, conductive and radioactive heat transfer equations. Initially the heat loss mainly takes place due to conduction through the mill wall then convected and radiated out. The losses are estimated from the first principle. Baris Özerdem [13] has experimentally studied and developed the correlation to calculate convective heat transfer coefficient of outer surface of a rotating cylinder in quiescent air and found that the heat transfer rate depends only on Reynolds number and the average Nusselt number increases with increase in the speed of rotation of cylinder. Seghir-Ouali et al.[14] have conducted an experiment to study the inside convective heat transfer coefficient of rotating cylinder with an internal axial air flow, and developed three methods to evaluate the heat transfer coefficient. Finally they concluded that the convective heat transfer of the inside surface depends on speed of rotation of cylinder and axial air flow parameter and at the higher speed of rotation of cylinder. The heat transfer depends only on Reynolds number.

$Q_{loss} = [Q_{cv1} + Q_{cv2}]$ heat convected to inside wall of DECD-RM ------------- 23

$= [Q_{cd1} + Q_{cd2}]$ heat conducted through the wall of DECD-RM ------------ 24

$= [Q_{cv1} + Q_{cv2} + Q_{rad1} + Q_{rad2}]$ ------------------------------------------------------------ 25

(heat convected and radiated from the outside of DECD-RM)

$Q_{cv1} = hA(t_{avch1} - t_{wi})$ chamber -1 --------------------------------------------26

$Q_{cv2} = hA(t_{avch2} - t_{wi})$ chamber -2 --------------------------------------------27

$Q_{cd1} = k\,A\,(t_{wi1} - t_{wo})$ chamber -1 ------------------------------------------ 28

$Q_{cd2} = k\,A\,(t_{wi2} - t_{wo})$ chamber -2 ------------------------------------------ 29

$Q_{rad1} = \sigma \epsilon A(t_{wo1}^4 - t_a^4)$ chamber -1 --------------------------------------------30

$Q_{rad2} = \sigma \epsilon A(t_{wo2}^4 - t_a^4)$ chamber -2 --------------------------------------------31

h = heat transfer coefficient -W/(m$^2$-K)
A = heat transfer area -m$^2$
k = thermal conductivity -W/(m-K)
σ – Stefan Boltzmann constant -W/(m$^2$-K$^{4)}$
Є – emissivity

using the above formulae the convective and radiation heat loss from the DECD-RM is calculated as 1.40915 x $10^6$ kJ/h. which is 2.1% of the energy entering the system. The unaccounted heat loss evaluated by energy balance is 2.528 x $10^6$ kJ/h, which is 3.7% of the heat entering to the system.

**Energy analyses of the DECD-RM**

The raw mill was analyzed thermodynamically with the following assumptions: (a) The mill is a steady state and steady flow system. (b) The changes in the kinetic energy and potential energy of input and output flow streams are neglected. (c) There is no heat transfer from the surroundings to the system. (d) Electrical energy is used to drive the DECD-RM and its auxiliaries of the systems. (e) The changes of surrounding temperature with respect to seasonal change are ignored.

The available operational data and the assumptions made above have been considered in order to account for calculating the energy flow across the DECD-RM. While doing energy balance, STP is taken as a reference temperature. Tables 5 & 6 shows the energy content of flow streams at inlet and outlet of the DECD-RM system. The energy analysis shows that 527.67 kJ/kg of heat energy are required for drying raw material for the raw mill operation. The source of heat energy supplied to the raw mill system is the waste hot gases leaving the preheater of the kiln system.

**Table 5:** The rate of mass and energy balance of flow stream of DECD-RM at inlet

| Sl. # | | Input material | $\dot{m}$ ( tph ) | $C_p$ (kJ/kg-K) | T ($^oC$) | $\dot{Q}$ ( kJ/h ) |
|---|---|---|---|---|---|---|
| 1 | Inlet chamber-1 | Feed material | 77.000 | 0.837 | 30 | 1934301.600 |
| 2 | | Hot gases from preheater | 124.702 | 1.118 | 300 | 41825141.046 |
| 3 | | Dust in preheater | 9.976 | 0.837 | 300 | 2505019.181 |
| 4 | Inlet chamber-2 | Feed material | 33.000 | 0.837 | 30 | 828986.400 |
| 5 | | Hot gases from preheater | 39.903 | 1.118 | 290 | 12937339.540 |
| 6 | | Dust in preheater gas | 3.192 | 0.837 | 290 | 775185.019 |
| 7 | | Returns from turbo air separator | 88.220 | 0.837 | 81 | 5983623.835 |
| 8 | | Leaking air | 12.981 | 78 | 32 | 1012492.472 |
| | | Total | 388.974 | | | 67803166.520 |

**Table 6:** The rate of mass and energy balance of flow stream at exit of DECD-RM

| Sl. # | Output material | $\dot{m}$ (tph) | $C_p$ (kJ/kg-K) | T ($^oC$) | $\dot{Q}$ ( kJ/h ) |
|---|---|---|---|---|---|
| 1 | To grit separator | | | | |
| | Moisture in leaking air | 0.260 | 2.01 | 98.000 | 747686.748 |
| | Moisture in feed material | 11.000 | 2667 | 98.000 | 29337000.000 |
| | Fines of feed material | 83.490 | 0.837 | 98.000 | 6851296.267 |
| | Moisture evaporated, leaking air and gas to grit separator | 159.991 | 1.015 | 98.000 | 15914342.650 |
| 2 | Mill discharge to elevator | 134.233 | 0.837 | 98.000 | 11015359.042 |
| | Convection and radiation heat loss | | | 32.000 | 1409149.52 |
| | Total | 388.974 | | | 65274834.227 |

**Energy efficiency of the DECD-RD**

Energy efficiency of the DECD-RM is evaluated by using the following expression:

$$\eta = \frac{\Sigma m_{out}\, h_{out}}{\Sigma m_{in}\, h_{in}} \qquad \text{-------------------------------- 32}$$

The energy efficiency of the DECD-RD found to be 96.27%. The higher efficiency value shows the good governance of the equipment with the best practice of technological operation of the system. The heat loss value of 4% is nominal for any thermal systems. Figure 1 shows the energy flow in and out of the raw mill.

**Exergy analysis of the DECD-RM**

The heat supplied to the system is comprised of both exergy as well as anergy. The irreversibility of the components of DECD-RM can be evaluated from the exergy equations. The exergy of the system can be calculated by using entropy balance. The entropy generation and exergy of the flow streams of raw mill are evaluated as depicted in Tables 7 & 8. For the evaluation of entropy generation and exergy values, the following assumptions are made: (a) The system is assumed to be a steady state and steady flow one. (b) The chemical exergy of the flow stream is ignored. (c) The kinetic and potential exergies of the flow streams are neglected. (d) The dead state temperature is taken as $25^0$C.

Exergy efficiency of the DECD-RM mill is evaluated by using the following exergy equation

$$\varepsilon = \frac{\dot{\mathbf{E}}\mathbf{x\ in} - \dot{\mathbf{E}}\mathbf{x\ destroyed}}{\dot{\mathbf{E}}\mathbf{x\ in}} \quad \text{------------------------------------------} \quad 33$$

$$\varepsilon = \frac{\Sigma \mathbf{m_{out}}\, \psi_{\mathbf{out}}}{\Sigma \mathbf{m_{in}}\, \psi_{\mathbf{in}}} \quad \text{------------------------------------------} \quad 34$$

Figure 2 depicts the exergy flow inlet and exit of a raw mill.

**Table 7:** The rate of entropy and exergy of the various streams in the DECD-RM as evaluated at inlet

| Sl. # | | Input material | ṁ ( tph ) | $C_p$ (kJ/kg-K) | T ( $^o$C) | Δs kJ/K-h | Ψ (kJ/h) |
|---|---|---|---|---|---|---|---|
| 1 | Inlet chamber-1 | Feed material | 77.000 | 0.83736 | 303.15 | 1072.31 | 2673.35 |
| 2 | | Hot gases form Preheater | 124.702 | 1.118 | 573.15 | 91116.17 | 11173425.37 |
| 3 | | Dust in pre-heater gas | 9.976 | 0.837 | 573.15 | 5457.19 | 669206.23 |
| 4 | Inlet chamber - 2 | Feed material | 33.000 | 0.83736 | 303.15 | 459.56 | 1145.72 |
| 5 | | Hot gases form Preheater | 39.903 | 1.118 | 563.15 | 28370.66 | 3363338.64 |
| 6 | | Dust in pre-heater gas | 3.192 | 0.83736 | 563.15 | 1699.93 | 201525.96 |
| 7 | | Returns from Turbo Air Separator | 88.220 | 0.83736 | 354.15 | 12715.11 | 345814.90 |
| 8 | | Leaking air | 12.981 | 78 | 305.15 | 0.26 | 81920.21 |
| 9 | | Electrical energy supplied to drives | | | | 8652357.14 | 15839050.38 |

**Table 8:** The rate of entropy and exergy of the various streams in the DECD-RM as evaluated at outlet

| Sl. # | Output material | ṁ ( tph ) | $C_p$ (kJ/kg-K) | T ( $^oC$) | Δs kJ/K-h | Ψ ( kJ/h) |
|---|---|---|---|---|---|---|
| 1 | To grit separator | | | | | |
| | Moisture in leaking air | 0.260 | 2.01 | 371.15 | 114.28 | 4019.23 |
| | Moisture in feed material | 11.000 | 2667 | 371.15 | 76450.00 | 5147450.00 |
| | Fines of feed material | 83.490 | 0.837 | 371.15 | 15311.22 | 538476.53 |
| | Moisture evaporated, leaking air and gas to grit separator | 159.991 | 1.015 | 371.15 | 35565.24 | 1250785.21 |
| 2 | Mill discharge to elevator | 134.233 | 0.837 | 371.15 | 24617.03 | 865750.38 |
| | Convection and radiation heat loss | | | 305.15 | 4554.26 | 4554.26 |
| | | | | | | 7806481.36 |

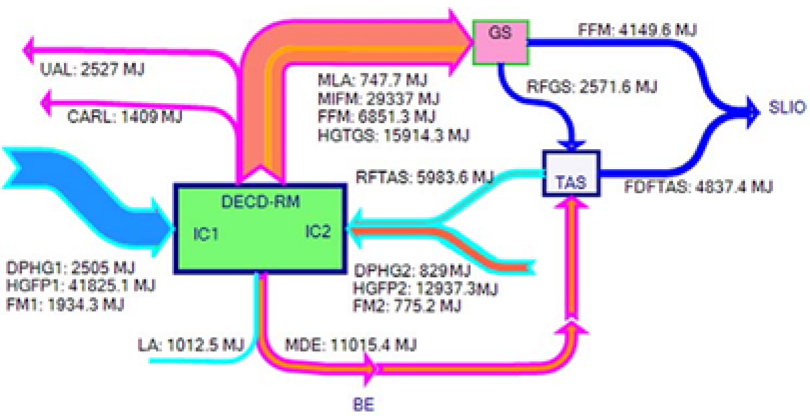


**Figure 1:** Energy flow through DECD-RM per hour

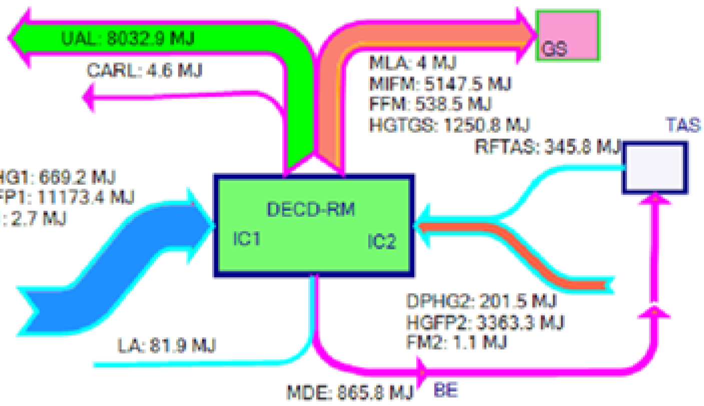


**Figure 2:** Exergy flow through DECD-RM per hour

**5.6 Correlations between Feed rate of raw material, Gas Temperature (GT), Moisture and Exergy Efficiency.**

The various results pertaining to the feed rate of the raw material namely gas temperature, moisture and expected exergy efficiency are analysed using Design Expert® software Design Expert-8, and these four parameters are correlated with each other using response user-defined design analysis of the Design expert-8 software. The corresponding correlations between feed rate of raw material, gas temperature, moisture and expected exergy efficiency is as follows:

Feed rate (tph) =
(0.4660 * GT) – (6.80798 * Moisture %)+(3.93338 * Exergy Efficiency%)
– ( 0.033045 * GT * Moisture%) + (0.010002 * GT * Exergy Efficiency%)
– (0.32153 * Moisture %* Exergy Efficiency%) –(1.88605E-004 * $GT^2$
+ (0.90783* Moisture$\%^2$)
+ (1.7 8141E-003 * Exergy Efficiency$\%^2$ ) – (68.13524) -------------------------- 35

This equaiton has a correlation coefficienct value $R^2$ and adjusted $R^2$ value is unity the ANOVA results sataets that the model terms for the analysis are significant.

## Conclusions

The following are the important conclusions of the present study. The optimum temperature of the hot gas admitted to the DECD-RM as evaluated for maximum heat energy utilized for moisture removal is $315^0$C. There exists much scope for the improvement in thermal performance of the raw mill operation. This can be envisaged in terms of the following: The leaking air entering the mill circuit is estimated by balancing the hot gas admitted into the mill and leaving from the mill by considering the moisture present in the raw material, which evaporates in vapour state (the value of water vapour is 0.0913$m^3$/kg). The leaking air, which enters through the discharge end of the mill, can be lowered by providing minimum gap as well as the use of better leakage arresting mechanisms. The entry of leaking air can be lowered by admitting additional hot gases into the raw mill from pre-heater. The approximate heat consumption per kg of moisture evaluated is 5276 kJ. The length of the grinding chambers is different and the moisture drying capacity also different. Hence, the raw material feed and pre-heater gas flow to both ends of the mill should be controlled for optimum performance. The calculations indicate that around 24.2% volume of pre heater gas intake is being diverted to the second chamber. It is necessary to balance the moisture level and the grinding chamber power absorbing capacity. This can be done through diversion of feed material to individual grinding chamber. The residue of the sum total of the material leaving the raw mill to elevator and gas stream passing through Girt Separator (GS) and cyclone separator is calculated to be 60% and 40% respectively. This is slightly more than the normal expected value which is in the range of 40 to 45 % (GS). The percentage of fines (90microns) collection in GS is 45% which is comparatively high. The Turbo Air Separator (TAS) (90microns) efficiency is measured around 53.59% which is found to be above the normal value for a mechanical separator. The correlation between the raw material, gas temperature, moisture and expected exergy efficiency is arrived, which can be utilized directly in cement industries to obtain a correct feed rate of raw material. In a nutshell, it is understood from the present study that there is still much scope for improving the performance of the DECD-RM mill.

## Acknowledgements:

The authors express their sincere thanks to Prof. R. Sethuraman, Vice-Chancellor, SASTRA University, Thanjavur, for granting permission to publish this research work. The authors are also grateful to the authorities of TANCEM, Ariyalur for providing the operational data of the cement plant.

## References

[1] Tahsin Engin, Vedat Ari, 2005, "Energy Auditing and Recovery for Dry Type Cement Rotary Systems – A case study, Energ Convers Manage", 46 pp:551-562.

[2] C. Koroneos, G. Roumbas and N. Moussiopoulos, 2005, "Exergy Analysis in Cement Production", Int. J. Exergy, vol.2 No. 1, pp:55-68.

[3] Zafer utlu, Ziya Sogut, Arif hepbasli, Zuhal Oktay, 2006, "Energy and Exergy Analyses of A Raw Mill in Cement Production", Appl Therm Eng, 26, pp:2479–2489.

[4] Mont Hubbard and Tom DASilva, 1982, "Estimation of Feedstream Concentrations in Cement Raw Material Blending, Automatica", vol. 18, No. 5, pp: 595-606.

[5] Joseph O. Odigure, 1999, "Grindability of Cement Clinker From Raw Mix Containing Metallic Particles", Cement Concrete res 29, pp:030-307.

[6] M.G. Rasul, W.Widianto, B. Mohanty, 2005, "Assessment of Thermal Performance and Energy Conservation Opportunities of A Cement Industry in Indonesia", Appl Therm Eng, 25, pp:2950-2965.

[7] Ziya Sogut, Zuhal Oktay, Hikmet Karakoc, 2010, "Mathematical Modeling of Heat Recovery from Rotary Kiln", Appl Therm Eng, 30, (2010), pp: 817-825.

[8] Ibrahim Dincer and Yunnis A Cengel, 2001, "Energy and Exergy Concepts and Their Roles in Thermal Engineering", Entropy, 3,pp:116-149.

[9] Adrian Bejan, Advanced Engineering Thermodynamics, second edition, A Wiley-Inerscience Publications, John Wiley & sons, Inc.

[10] Adrian Bejan, George Tsatsaronis, Michael Moran. Thermal Design and Optimization. A Willy-Interscience Publications, John Wiley & sons, Inc.

[11] T.J. Kotas, The Exergy Method of Thermal Plant Analysis. Butterworths .

[12] Göran Wall, Exergetics, Exergy Ecology Development, Bucaramanga - 2009.

[13] Baris Özerdem, 2000, “Measurement of Convective Heat Transfer Coefficient for A Horizontal Rotaing In Quiescent Air”, Int. Comm. Heat Mass transf, vol.27, No. 3, pp:389-395.

[14] S Sghir-Ouali, D. Saury, S. Harmand, O. Phillipart, D. Laloy, 2006, “Convective heat transfer inside a rotating cylinder with axial air flow”. Int J Therm Sci, 45, pp: 1166-1178.