



Energy and Exergy Assessment and Heat Recovery on Rotary Kiln of Cement Plant for Cooling Effect Production by Using Vapor Absorption Refrigeration System

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The main aim of this study is to use waste heat for cooling effect production from cement rotary kiln shell by applying vapor absorption refrigeration system. The plant has performance to manufacture 2000 tons of clinker per day. Energy and exergy analysis has been performed to assess first and second law efficiencies and rotary kiln is used as a control volume on dry type cement plant. Result shows that about 4.3MW energy is lost from kiln shell. From the analysis, 31.13% total exergy is wasted to the surrounding in case of pre-calcining and pre-heating of raw material. The overall result for exergy analysis of kiln indicates 59.46% of irreversibility and also the first and the second law efficiency of the rotary kiln is 53.39% and 40.54%, respectively. By using convective mode of heat transfer about 11% of energy is extracted by the generator for production of cooling effect which is wasted from kiln shell. About 300kW cooling effect is produced in the evaporator by applying absorption cycle with system performance 0.67 and exergetic efficiency 87%. From heat recovery there is direct savings by reducing fuel consumption and indirect savings by decreasing environmental impact. Hence, use of waste heat results in reduction of thermal pollution and energy consumption in auxiliary equipment.

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INTRODUCTION

Manufacturing cement is the most energy consuming industries in the world. It is used about 10-15% of industrial energy use. Generally, energy attains 35-45% of production cost in the cement industry. So it is interesting to reduce production cost. Due to energy analysis fails to show the transformation and location of energy degradation, exergy analysis is needed to determine quality and quantity of energy [1].

Exergy analysis is very important to show and analyze thermodynamic imperfections quantitatively and qualitatively which is caused by thermal and chemical processes. The first and the second laws of thermodynamics is used to analyze exergy, while the energy analysis is used the first law only. Exergy is expressed as the maximum available work which is getting from a system when it comes to equilibrium with a reference environment. It has also a feature to show the assessment of energy degradation quantitatively [1, 2].

Firstly, the rotary kiln system mass balance is determined. Then, by using the first law of thermodynamics enthalpies entering into and leaving the rotary kiln are assessed. Furthermore, according to the second law of thermodynamics

exergy is calculated. Finally, efficiencies based on the first and second laws are compared and also shown by using Grassman diagrams then by using vapor absorption refrigeration system some of the wasted energy from the rotary kiln shell is recovered for cooling effect production.

PROCESS DESCRIPTION

The main component of cement is limestone (CaCO_3) which is extracted from quarry. These large sized particles are crushed in to small units. These units are mixed with appropriate additives such as laterite and sweeteners, which makes important mixture and going into raw mill at which it changes into a powdered form called raw meal. This powdered form becomes preheated in the preheater before going into rotary kiln. The key process of cement manufacturing is clinkerisation which it takes place in the rotary kiln during combustion process. The clinker leaving from the kiln after cooling process in the cooler vent will sum up with some necessary amount of gypsum and fly ash, and changes into fine powder in the cement mill. Finally, it goes for packaging and shipping [3].

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Figure 1 shows a flow diagram for cement manufacturing process. Also, the overall method for the assessment of rotary kiln is shown in Figure 2.

THERMODYNAMIC ANALYSIS OF ROTARY KILN

Assumptions

It is appropriate to use the following assumptions for thermodynamic analysis rotary kiln:

- a) The system is steady state and open.
- b) Neglect change of kinetic and potential energies.
- c) Environmental temperature is constant i.e. $T_{\infty} = 297K$.
- d) The velocity of air is < 3 m/s.
- e) Consider the gases as an ideal gas.

Mass balance

The mass is conserved in rate form and can be defined as follows:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$

The mass balance of the kiln system is summarized in Table 1 and Figure 3.

Energy balance

The total energy analysis for steady state process in rate form is described as follows:

$$\sum \dot{Q}_{in} = \sum \dot{Q}_{out}$$

where, $\dot{Q} = \dot{m} C_p \Delta T$

All entering and leaving energies is determined by using the above equation. The energy of clinker formation is calculated by using Zur-Strassen equation [4]:

$$\text{Clinker formation energy} = 2.22 [\text{Al}_2\text{O}_3] + 6.48 [\text{MgO}] + 7.66 [\text{CaO}] - 5.116 [\text{SiO}_2] - 0.59 [\text{Fe}_2\text{O}_3]$$

By using Dulong equation, the Gross Calorific Value of coal and pet coke can be determined [5].

$$GCV = 337 \times C + 1442 \left(H - \frac{O}{8} \right) + 93 \times S$$

There is also heat transfer between rotary kiln shell and the surrounding due to the temperature variation between outer and inner surface of rotary kiln. This is because of three modes of heat transfer, i.e. conduction, convection and radiation. This heat transfer can be calculated by the following equation [6]:

- Radiation from kiln surface

$$Q_{11} = \sigma \epsilon A (T_s^4 - T_{\infty}^4) / 1000 \times M_{clinker}$$

where: $\sigma = 5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$, $\epsilon = 0.78$ (oxidized surface, based on literature [7]), $T_s = 300 \text{ }^\circ\text{C}$, $T_{\infty} = 24 \text{ }^\circ\text{C}$, $A_{klin} = \pi DL$.

- Convection from kiln surface

$$Q = hA (T_s - T_{\infty}) / 1000 \times M_{clinker}$$

where: $h_{con} = K_{air} \times Nu / D_{klin}$, $Re = 375,617.8$ ($V_{air} = 3$ m/s), $Nu = 738$ (Hilbert's equation, based on literature [7]), $T_f = 162 \text{ }^\circ\text{C}$ (film temperature).

Therefore, the efficiency of the first law of thermodynamics is given by the ratio of energy output to input energy:

$$\eta_l = \frac{\sum Q_{out}}{\sum Q_{in}} = \frac{\sum (Q_{clinker} + Q_{gas} + Q_{dust})}{\sum Q_{in}}$$

The detailed assessment of energy is shown below in Table 2.

Exergy balance

Exergy is expressed as the maximum shaft work which has been done by the composite of the system and a given reference surrounding. Exergy is not only a thermodynamic characteristic, but rather it is the characteristic of a system and reference surrounding. It has a property which is conserved simply when all processes held on a system and the surrounding are reversible [8].

The exergy balance is used to evaluate the locations, kinds, and actual magnitudes of waste energy resource, so it plays a significant role for effective use of fuel. Exergy is destroyed when the process is irreversible. Thermodynamic imperfections are also considered as exergy destructions, which indicate energy quality lost [7].

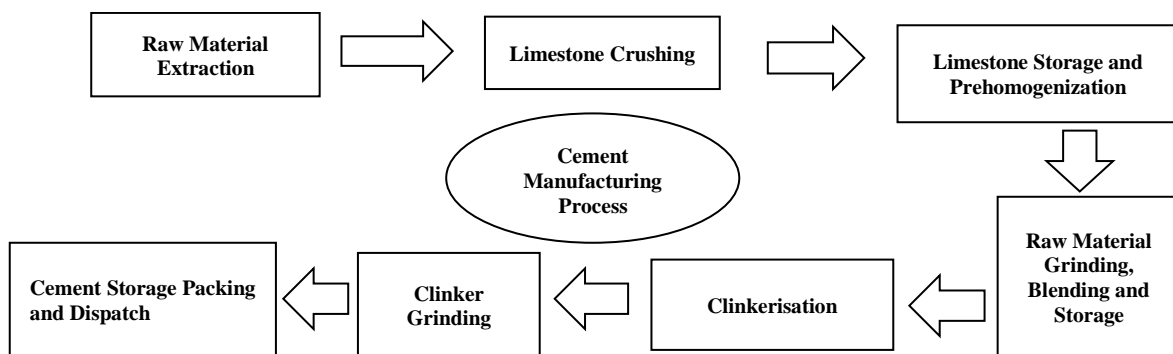


Figure 1. Cement manufacturing process flow diagram

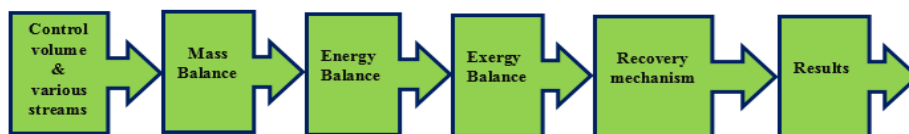
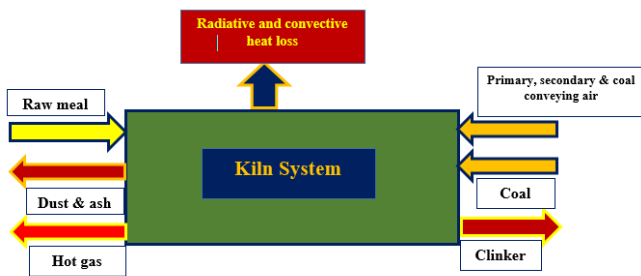


Figure 2. Overall method for the assessment of rotary kiln

TABLE 1. Mass balance in the kiln system

Component	Mass flow rate (kg/s)	Total
Input		
Raw meal	27.40	
Coal	1.17	
Primary air	1.05	41.50
Coal conveying air	0.33	
Secondary air	11.55	
Output		
Clinker	23.32	
Hot gas	17.18	41.50
Dust and ash	1.00	

**Figure 3.** Mass balance in the kiln system

Exergy efficiency is used to measure ideality approach (reversibility). It is not true for energy efficiency, because of misleading. Furthermore, exergy is expressed as the measurement of minimum work which is used to produce goods, assessment of energy conversion, and utilization [9].

Reference environment

The environment has to be considered a natural reference datum and in thermodynamic equilibrium without utilized energy when exergy of various systems is assessed. By considering any kind of process and environment which is netting from irreversibilities, environmental intensive property is not significantly varied [10].

Dead state

When the thermodynamic state (i.e. pressure, temperature, composition, velocity or elevation) of a system is deviate from the surrounding, there is a probability to enhance work. By changing the phase of the system with respect to the environment, the probability reduced, it doesn't exist when the two, at rest towards one another, are in equilibrium. This system phase is known as dead state. The four categories of exergy [11] are Physical exergy, Chemical exergy, Potential exergy and Kinetic exergy.

Potential and kinetic exergy

Kinetic energy and potential energy of various streams are forms of energy and have a full potential for converting to work. Consequently, when assessed towards with the

surrounding reference frame, which are equal to kinetic and potential exergy respectively. Hence:

$$KE = \frac{1}{2}mv^2$$

$$PE = mgz$$

Physical exergy

Physical exergy (EPH) is given by the maximum work available when the stream of substance is brought from its starting phase to the final phase of the surrounding described by P_0 and T_0 , by physical processes including simply thermal interaction with the surrounding. The physical exergy of a closed system at a given state is expressed as follows:

$$EPH = (U - U_0) + P_0(V - V_0) - T_0(S - S_0)$$

Chemical exergy

Chemical exergy is expressed as the maximum work found by considering the substance which is brought from the surrounding state to the dead state by processes including transfer of heat and exchange of substances only with the surrounding. The exergy balance of the rotary kiln is given by the following expression:

$$\sum \dot{E}x_{in} - \sum \dot{E}x_{out} = \dot{E}x_{dest}$$

$$\sum \left(1 - \frac{T_0}{T_S}\right) Q - W_{net,out} + \sum \dot{m}_{in} \Psi_{in} - \sum \dot{m}_{out} \Psi_{out} = \dot{E}x_{dest}$$

where Q is the heat transfer rate from rotary kiln surface.

By reducing exergy loss or irreversibility, the exergy efficiency of a process can be improved. Good exergy efficiency allows a convenient relation of energy sources and utilization.

$$\Delta h = \Delta u + v \Delta P$$

By neglecting change of pressure, the enthalpy change becomes;

$$\Delta h = \Delta u = CP \Delta T$$

The entropy change for ideal gases is given below:

$$\Delta s = C_p \ln \left(\frac{T_{in} - T_{out}}{T_0} \right) - R \ln \left(\frac{T_{in} - T_{out}}{T_0} \right)$$

By considering the fluid in the rotary kiln as incompressible fluid, the above equation becomes:

$$\Delta s = C_p \ln \left(\frac{T_{in} - T_{out}}{T_0} \right)$$

By evaluating the entropy and enthalpy values of the components, the exergy values can be obtained by;

$$\Delta \Psi = \Delta h - T_0 \Delta s$$

The second-law efficiency (exergy efficiency) is given by the ratio of output to input exergies:

$$\eta_{II} = \frac{\sum \Psi_{out}}{\sum \Psi_{in}}$$

The detailed exergy assessment is given in Table 2.

From Messebo Cement Plant line 1 large number of data have been collected for a long time and different measurements are used in 12 months and averaged and interpolated values are used in this study.

Exergy analysis of producing 'cooling effect' by using heat exhaust from kiln shell by means of 'absorption cycle'

Absorption cycle

Absorption cycle is operated by heat for obtaining cooling and this heat replaces mechanical work. In this system, mechanical compression is substituted by a thermal compression by thermal compressor which is a combination

TABLE 2. Energy and exergy analysis of rotary kiln

	Composition	%	m (kg/s)	Cp [12] (kJ/kg.K)	T _{in} (K)	T _{out} (K)	Δh (kJ/kg)	ΔS (kJ/kg.K)	ΣmΔh (kW)	ΣmΔΨ (kW)
Input										
Raw meal	CaO	42.37	18.02	0.67	1250	297	638.51	0.895	11505.95	6715.87
	SiO ₂	13.2	5.18	0.70	1250	297	667.1	0.996	3455.58	1923.27
	Al ₂ O ₃	3.4	1.44	2.00	1250	297	1906	2.902	2744.64	1503.51
	Fe ₂ O ₃	2.3	1.12	4.15	1250	297	3954.95	6.007	4429.54	2431.38
	H ₂ O	0.02	0.83	4.17	1250	297	3974.01	6.036	3298.42	1810.50
	MgO	1.69	0.52	0.38	1250	297	362.14	0.534	183.31	105.84
	SO ₃	0.5	0.15	0.68	1250	297	648.04	0.896	97.21	57.29
	K ₂ O	0.26	0.10	4.30	1250	297	4097.9	6.224	409.79	224.94
	Na ₂ O	0.08	0.04	4.35	1250	297	4145.55	6.296	165.82	91.03
Total		100.00	27.40						26290.26	14863.63
Coal	C	82.09	0.42	0.03	340	297	1.29	4.013*10 ⁻³	0.54	0.043
	H	6.61	0.1	14.33	340	297	616.19	1.916	61.62	4.71
	N	1.75	0.027	1.03	340	297	44.29	0.139	1.20	0.081
	S	1.59	0.026	5.63	340	297	242.09	0.754	6.29	0.472
	O	4.95	0.078	0.93	340	297	40.00	0.123	3.12	0.271
	Ash	3.01	0.049	1.31	340	297	56.33	0.174	2.76	0.228
	Total		100.00	0.70						75.53
Pet-cock	C	74.90	0.24	0.03	340	297	1.29	4.013*10 ⁻³	0.31	0.024
	H	4.30	0.07	14.33	340	297	616.19	1.916	43.13	3.30
	N	1.80	0.023	1.03	340	297	44.29	0.139	1.02	0.069
	S	3.20	0.020	5.63	340	297	242.09	0.754	4.84	0.363
	O	4.80	0.075	0.93	340	297	40.00	0.123	3.00	0.260
	Ash	11.00	0.042	1.31	340	297	56.33	0.174	2.37	0.195
Total		100.00	0.47						54.67	4.211
Combustion of pet cock	-	-	0.47	1.16	1220	297	29740	1.614	13977.80	13752.50
Combustion of coal	-	-	0.70	1.20	1220	297	39460	1.670	27622.00	27274.81
Primary air	-	-	1.05	1.006	324	297	27.16	0.084	28.52	2.32
Conveying air	-	-	0.33	1.006	324	297	27.16	0.084	8.96	0.73
Secondary air	-	-	11.55	1.18	1340	297	1230.74	1.756	14215.05	8191.35
Electrical work	-	-	-	-	-	-	-	-	3404	
Output										
Clinker	CaO	66.72	14.24	0.62	1523	297	760.12	0.997	10824.11	6607.52
	SiO ₂	21.14	4.39	0.74	1523	297	907.24	1.194	3982.78	2426.01
	Al ₂ O ₃	4.12	1.38	2.17	1523	297	2660.42	3.496	3671.38	2238.51
	Fe ₂ O ₃	3.96	2.05	4.43	1523	297	5431.18	7.141	11133.92	6786.12
	MgO	2.38	0.52	0.39	1523	297	478.14	0.633	248.63	150.87
	SO ₃	1.06	0.37	0.89	1523	297	1091.14	1.431	403.72	246.47
	K ₂ O	0.36	0.32	4.78	1523	297	5860.28	7.71	1875.29	1142.53
	Na ₂ O	0.26	0.05	4.71	1523	297	5774.46	7.601	288.72	175.85
Total		100	23.32						32428.55	19773.88
Hot gas	-	-	17.18	1.18	1200	297	1065.54	1.670	18305.98	9784.87
Dust & ash	-	-	1.00	1.05	650	297	370.65	0.797	370.65	133.94

of an absorber, a generator, a pump, and an expansion valve. Pure water (refrigerant vapor) from the evaporator is extracted by a lithium bromide (strong solution) in the absorber to form weak solution. This solution is pressurized by pump and fed to the generator where the vapor refrigerant (pure water) is generated again using a waste heat from rotary kiln by convective modes of heat transfer. The strong solution (Li-Br) is return back to the absorber via an expansion valve [13]. Figure 4 illustrates a schematic view of Vapor absorption (H₂O-LiBr) refrigeration system.

Process 1-2: high temperature pure refrigerant vapor is condensed and heat of condensation (Q_c) is rejected to the external heat sink.

Process 2-3: pure refrigerant is throttled to the evaporator.

Process 3-4: heat is transferred from the low heat source to the evaporator to produce cooling effect (Q_e).

Process 4-5: refrigerant vapor and strong solution mix together in the absorber and heat of absorption is rejected (Q_a).

Process 5-6: weak solution (H₂O-LiBr) is pumped to the generator via HX.

Process 6-7: weak solution is sensibly heating in the generator.

Process 7-8: heat is absorbed from rotary kiln (Q_g) and refrigerant vapor to the condenser and strong solution to the absorber is generated.

Process 8-9: heat is rejected sensibly from strong solution in the HX.

Process 9-10: strong solution is throttled to the absorber.

Condenser

Energy Balance:

$$Q_{con} = \dot{m}_r(h_1 - h_2)$$

Exergy Balance:

$$Ex_{d,con} = \dot{m}_r(ex_1 - ex_2)$$

$$\dot{I}_{con} = \dot{E}x_{d,con} = T_0(\dot{m}_r(S_2 - S_1))$$

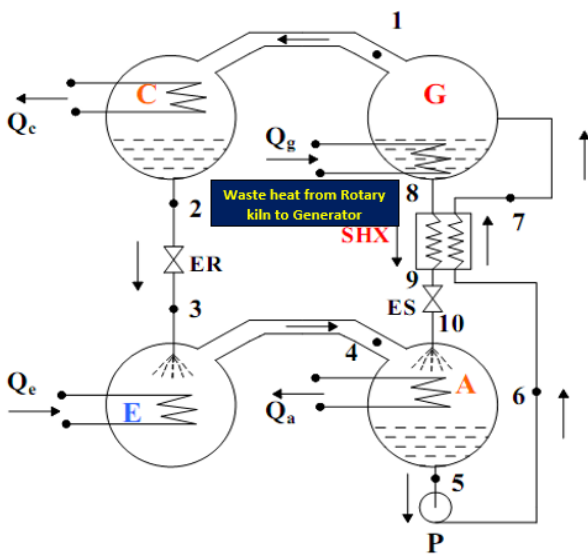


Figure 4. Vapor absorption (H₂O-LiBr) refrigeration system; A: absorber; C: condenser; E: evaporator; G: generator; P: pump; ER: refrigerant expansion valve; ES: solution expansion valve; SHX: solution heat exchanger

Expansion valve (Refrigerant)

Energy Balance:

$$\dot{m}_r h_2 = \dot{m}_r h_3$$

Exergy Balance:

$$Ex_{d,ER} = \dot{m}_r(ex_3 - ex_2)$$

$$\dot{I}_{ER} = \dot{E}x_{d,ER} = T_0(\dot{m}_r(S_3 - S_2))$$

Evaporator

Energy Balance:

$$Q_{evap} = \dot{m}_r(h_4 - h_3)$$

Exergy Balance:

$$Ex_{d,evap} = \dot{m}_r(ex_4 - ex_3)$$

$$\dot{I}_{evap} = \dot{E}x_{d,evap} = T_0(\dot{m}_r(S_4 - S_3))$$

Absorber

Energy Balance:

$$Q_{abs} = \dot{m}_r h_4 + \dot{m}_{ss} h_{10} - \dot{m}_{ws} h_5$$

Exergy Balance:

$$Ex_{d,abs} = \dot{m}_r ex_4 + \dot{m}_{ss} ex_{10} - \dot{m}_{ws} ex_5$$

$$\dot{I}_{abs} = \dot{E}x_{d,abs} = T_0(\dot{m}_{ws} S_5 - \dot{m}_r S_4 + \dot{m}_{ss} S_{10})$$

Pump

Energy Balance:

$$W_P = \dot{m}_{ws}(h_6 - h_5)$$

$$\eta_{S,P} = \dot{m}_{ws} \frac{h_{5s} - h_6}{W_P}$$

$$h_5 = \frac{h_{5s} - h_6}{\eta_{S,P}} + h_6$$

Exergy Balance:

$$Ex_{d,P} = W_P + \dot{m}_{ws}(ex_6 - ex_5)$$

$$\dot{I}_P = \dot{E}x_{d,P} = T_0(\dot{m}_{ws}(S_5 - S_6))$$

Heat exchanger

$$\varepsilon = \frac{T_8 - T_9}{T_8 - T_6}$$

Energy Balance:

$$\dot{m}_{ss}(h_8 - h_9) = \dot{m}_{ws}(h_7 - h_6)$$

Exergy Balance:

$$Ex_{d,HX} = \dot{m}_{ws}(ex_7 - ex_6) + \dot{m}_{ss}(ex_9 - ex_8)$$

$$\dot{I}_{HX} = \dot{E}x_{d,HX} = T_0(\dot{m}_{ws}(S_7 - S_6) + \dot{m}_{ss}(S_9 - S_8))$$

Expansion valve (Refrigerant)

Energy Balance:

$$\dot{m}_{ss} h_8 = \dot{m}_{ss} h_9$$

Exergy Balance:

$$Ex_{d,ES} = \dot{m}_r(ex_3 - ex_2)$$

$$\dot{I}_{ES} = \dot{E}x_{d,ES} = T_0(\dot{m}_{ss}(S_9 - S_8))$$

Therefore, the internal exergy destruction of the system is equal to the sum of exergy destruction at each component:

$$\sum \dot{E}x_{d,i} = \dot{I}_{gen} + \dot{I}_{abs} + \dot{I}_{HX} + \dot{I}_{ER} + \dot{I}_{con} + \dot{I}_{ES} + \dot{I}_{evap} + \dot{I}_P$$

The mass of H₂O-LiBr solution or weak solution (\dot{m}_{ws}), strong solution (\dot{m}_{ss}) and mass of refrigerant vapor (\dot{m}_r) with their mass fraction is related by circulation ratio (λ) and is given by:

$$\lambda = \frac{\dot{m}_{ss}}{\dot{m}_r} = \frac{\varepsilon_{ws}}{\varepsilon_{ss} - \varepsilon_{ws}}$$

where; $\dot{m}_{ws} = \dot{m}_{ss} + \dot{m}_r$

The system coefficient of performance and exergetic efficiency of vapor absorption refrigeration system is given as follows:

$$COP = \frac{Q_e}{Q_g} ; \quad \eta_{II} = \frac{Q_e}{Q_g} \left(\frac{T_g}{T_g - T_e} \right) \left[\frac{T_c - T_e}{T_c} \right]$$

Consider the operating temperatures of generator, evaporator, condenser and absorber are 110°C, 7°C and 40°C, respectively with effectiveness of heat exchanger $\epsilon = 0.94$ and the heat that supplied from the rotary kiln shell to the generator is 450kW by using convective mode of heat transfer.

The properties for H₂O–LiBr solution and their operating conditions are listed in Table 3. The results of energy and exergy analysis for each component are summarized in Table 4.

RESULT AND DISCUSSION

By using the above equations, the first and the second law efficiency of the rotary kiln is 53.39% and 40.54% respectively. In addition to that the energy and exergy analysis are represented by Grassman diagram in Figures 5 and 6.

From the diagram 41.66% energy is wasted while 0.443MW is unaccounted loss. But the energy which is transferred through the kiln shell is recoverable for production of cooling effect by using convective mode of heat transfer. In this study the generator uses 450kW from the rotary kiln shell for 300kW (85.31TOR) cooling effect production in the

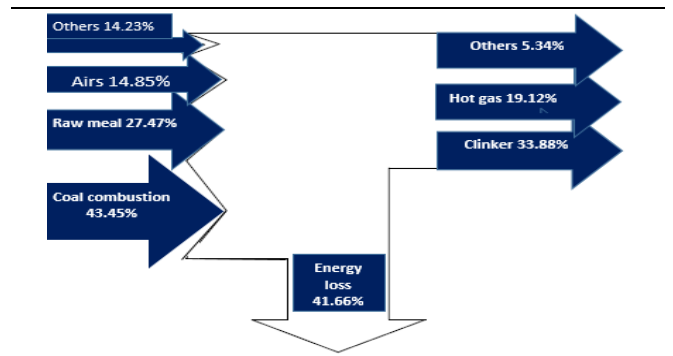


Figure 5. Grassman diagram of rotary kiln energy analysis

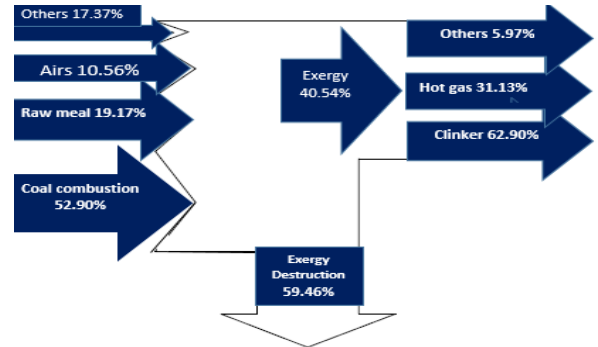


Figure 6. Grassman diagram of rotary kiln exergy analysis

TABLE 3. Properties of H₂O–LiBr solution with their operating conditions

State point	T (°C)	ϵ (mass fraction)	P (mbar)	H (kJ/kg)	S (kJ/kg K)
1	110	-	123.29	2708	7.2387
2	40	-	123.29	167	8.257
3	7	-	9.81	167	0.2124
4	7	-	9.81	2514	8.984
5	40	0.55	9.81	110	0.2638
6	40	0.55	123.29	110	0.2638
7	105.8	0.55	123.29	228	0.6964
8	110	0.64	123.29	256	0.6531
9	44.2	0.64	123.29	118	0.2551
10	40	0.64	9.81	118	0.2308

TABLE 4. Energy and exergy analysis result for each component

No	Component	Energy (kW)	Exergy (kW)
1	Generator	450.00	198.723
2	Condenser	271.887	-32.360
3	ER	17.869	-255.650
4	Evaporator	300.00	278.750
5	Absorber	272.450	269.082
6	Pump	0.0072	0.00
7	HX	89.840	-20.822
8	ES	76.818	76.952
Total		1261.775	514.675

evaporator in the vapor absorption refrigeration system with system performance 0.67 and exergetic efficiency 87%. Also rotary kiln irreversibility is accounted 59.46% this indicates destruction of exergy into the system while 31.13% exergy is leaving with the hot gas that can be retrieved by arranging some auxiliary components. The calculated results are presented in tabulated form in Table 5.

TABLE 5. Final results

Component	m(kg/s)	Q(kW)	Ψ (kW)
Input			
Raw-meal	27.40	26290.26	14863.63
Pet-cock & coal	1.17	130.2	10.01
Combustion of coal & pet-cock	-	41599.8	41027.31
Primary air	1.05	28.52	2.32
Coal conveying air	0.33	8.96	0.73
Secondary air	11.55	14215.82	8191.35
Electrical work	-	13454	13454
Total		95727.56	77549.35
Output			
Clinker	23.32	32428.55	19773.88
Clinker formation	-	39879.75	-
Hot gas	17.18	18305.98	9784.87
Dust & ash	1.00	370.65	133.94
Kiln shell	-	4300	1743.52
Unaccounted loss	-	442.63	-
Total		95727.56	31436.21

CONCLUSION

The objective of this study is to evaluate and assess exergy utilization, exergy balance and their irreversibility in Messebo cement factory. Mass, energy and exergy analysis of the whole process and recovery process has been performed using the actual operational data of the plant. Exergy analysis is an important tool, which is used to carefully analyze the design and assess the performance of the system that related with energy. By recovering heat the volume of exhaust gas and emissions to the atmosphere can be reduced. From heat recovery there is direct savings in case of reducing fuel consumption and indirect savings in case of decreasing environmental impact. It also facilitates smaller and more economic furnaces.

In this study the kiln shell is used as a furnace to supply heat to the generator by natural means (convective mode of heat transfer) in vapor absorption refrigeration system for cooling effect production in the evaporator and by using duct system the cooling effect can be distributed to the rooms which requires cooling effect or conditioned air.

It is recommended for various cement industry to use technical ways to reduce energy and exergy loss and also exergy destruction using by pass. It should be given great concern to increase thermal efficiency of the system by considering different affecting operation factors and recovery of waste heat from the cement plant.

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Persian Abstract

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چکیده

هدف اصلی از این مطالعه استفاده از گرمای زباله سوز جهت تولید اثر خنک‌کننده از پوسته کوره دوار سیمان با استفاده از سیستم تبرید جذب بخار است. این کارخانه برای تولید ۲۰۰۰ تن کلینکر در روز کارایی دارد. تجزیه و تحلیل انرژی و انرژی برای ارزیابی کارایی قانون اول و دوم انجام شده است و از کوره دوار به عنوان یک حجم کنترل در کارخانه سیمان نوع خشک استفاده گردید. نتایج نشان می‌دهد که حدود ۴/۳ مگاوات انرژی از پوسته کوره اتلاف می‌شود. از این تجزیه و تحلیل، در صورت پیش تنظیم و گرم کردن مواد اولیه، ماده انرژی کل ۳۱/۳ درصد به محیط اطراف هدر می‌رود. نتیجه کلی برای تجزیه و تحلیل انرژی کوره نشان می‌دهد ۵۹/۴۶ درصد از برگشت‌ناپذیری و همچنین راندمان قانون اول و دوم کوره دوار به ترتیب ۳۹/۳۹ درصد و ۴۰/۵۴ درصد است. با استفاده از حالت همرفتی انتقال گرما، حدود ۱۱ درصد انرژی توسط تولیدکننده برای تولید اثر خنک‌کننده که از پوسته کوره تلف می‌شود، استخراج می‌گردد. حدوداً ۳۰۰ کیلو وات اثر خنک‌کننده با استفاده از چرخه جذب با عملکرد سیستم ۰/۶۷ و بازده ضروری ۸۷ درصد در تبخیرکننده ایجاد می‌شود. صرفه‌جویی مستقیم انرژی با کاهش مصرف سوخت و صرفه‌جویی غیرمستقیم آن از طریق کاهش اثرات محیطی، بازیابی گرما را به دنبال خواهد داشت. از این رو، استفاده از گرمای زباله منجر به کاهش آلودگی حرارتی و مصرف انرژی در تجهیزات کمکی می‌شود.