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ENERGY, EXERGY AND EXERGOECONOMIC ASSESSMENT OF A DRY TYPE ROTARY KILN

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ABSTRACT

This study deals with, energy, exergy, specific energy consumption (SEC) and exergoeconomic assessment of a burner (dry-type) in a currently running cement facility in Şanlıurfa, Turkey. The exergoeconomic analysis of the unit is evaluated. The first and second law analysis including exergy destructions and exergetic cost allotments are analyzed for the unit. The first and second law efficiencies and SEC of the kiln are calculated to be 54%, 29% and 3793 kJ/kg clinker respectively. The specific cost method (SPECO) has been used for the exergoeconomic analysis. The exergetic cost and cost rate and of the clinker product of the rotary kiln are found to be 77.3 $/GJ and 2608 $/h, respectively.

Keywords: Energy, Exergy, Exergoeconomics, Rotary kiln, Cement

1. INTRODUCTION

Cement industry has been consuming high amounts of energy for many years. To produce one ton of cement, a conventional plant consumes about 4GJ of energy. To gain insight of the efficiency and improvement capacity, the energy use for the countries has been analyzed by using exergy analysis [1]. To analyze the energy consumption of a system, the first law of thermodynamics is usually used, but it is very essential to see the quality aspect of the energy. That is where the exergy becomes noticeable. At a specified state, useful work potential of the energy should be defined by using exergy [2]. Exergy is a very prevailing instrument for any unit consuming energy, chiefly when it is joined with exergoeconomic. The costs of a system should be reduced by using exergoeconomic analysis.

Exergoeconomics is the division of engineering that associates exergy analysis with economic restrictions to offer data that cannot be attained by straight energy analysis and monetary estimations [3, 4]. The method gives benefits engineers to find methods to expand the performance of a process in a cost-effective way [5]. There are many studies dealing with the energy and exergoeconomic analyses of different industrial applications. In this paper, the specific exergy costing (SPECO) technique is used [6-16]. The SPECO method disperses a price rate to every exergy component of each material incoming and exiting the components. There are important models of exergoeconomic methodologies in the literature [17-23]. To reduce SEC and escalate the first and second law efficiencies [26, 29], the assessment has been applied on different sections of cement production plants [31, 32, 33].

Schuer et al. [24] considered energy depletion and concentrated on the energy saving procedures for the cement facilities in Germany. They measured electrical and thermal energy saving procedures [25].

Worrell et al. [27] allocated the energy investigation in the industry in United States of America for 27 years (1970-1997). The results show that the CO_2 emission intensity per 1000 kg of cement for the preheating unit process is 5.4 kg CO_2.

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Engin and Ari [28] studied on a rotary kiln in a cement facility in Turkey. They specified that 4 MW of energy could be recovered. Koroneos and Moussiopoulos [30] inspected manufacture of cement in Greece by using exergy investigation. The examination includes calculation of energy and exergy values at each stage of the manufacturing process. They calculated that the 50% of the total exergy is lost during the process.

Kabir and El-Nafaty [34] used a cover surrounding the surface of the kiln. This method help save of 42.9 MWh/year. Madlood et al. [35] motivated on the SEC and energy use categories in the manufacture of cement.

Atmaca et. al [36] have studied on a pyroprocessing tower in Gaziantep, the total heat loss has been reduced from 22.7 MW to 17.3 MW by the use of isolation for the cyclones. Atmaca and Kanoglu [37] considered a farine mill to decrease the total SEC in grinding process. They found the SEC for 1000 kg of farine to be 24.75 kWh. The energy consumption has been decreased by 6.7% by supplying hot gas from the rotary kiln.

The literature review shows that a detailed exergoeconomic investigation of a rotary kiln unit in this study would be a valuable input for the development of the industry. Based on the search in the literature, this paper presents the first detailed analysis for the exergetic and exergoeconomic evaluation of Şanlıurfa Cement cement plant. The main objectives of this study, which applied energy, exergy, and exergoeconomy analyses using the SPECO method to a rotary kiln in clinker production process, are to evaluate the energetic and exergetic efficiencies, SEC and exergoeconomic performance of the unit according to exergetic cost parameters. In this study, balance equations (energy, exergy and mass); first and second law assessments; and cost assessment have been supplied. Using actual operating and charge data, a currently running rotary kiln have been analyzed which is located in Şanlıurfa, Turkey.

2. CEMENT PRODUCTION

The first Portland cement was made by Joseph Aspdin in the 19th century by burning limestone and clay in a kitchen stove in Leeds England. Today, there are mainly two different processes (dry and wet) are used in cement production. Limestone and marn are the chief raw materials. The primary crushing is the leading stage after quarrying in both procedures. The raw materials are fed through the crushers. The principal crushing reduces the rock to a maximum size of about 10 cm. The pulvarized raw materials are blended, and sent to the homogenization silos before sending the pyroprocessing tower. Finally the farine material is sent through the rotary kiln and the calcination process starts. The precalcined farine heated up to about 1500 ºC in a cylindrical steel rotary kiln. At the end of this stage, a new material called clinker, with different physical and chemical features has been manufactured. The temperature of clinker has been dropped in a cooler. The material is mixed with pozzolans and ground in a cement mill to produce cement. The hot air from the cooler is sent back to the kiln, a process that saves fuel and rises the efficiency of burning stage.

Şanlıurfa plant was selected for the assessment. The facility runs a dry cement process line. 1.5 million tonne of cement have been produced in the facility. A schematic of typical rotary kiln is shown in Fig. 1.

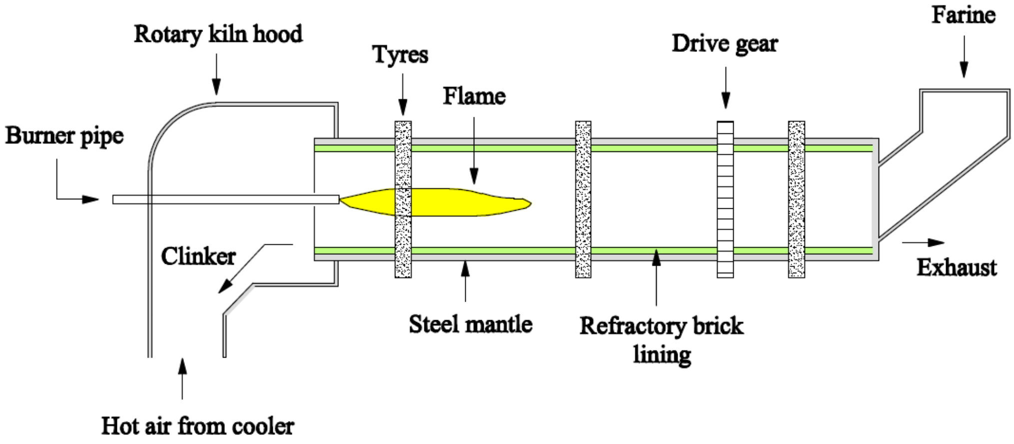

Figure 1. General arrangement of rotary kiln

2.1. Energy and Exergy Analysis

Reference environment is a very important parameter in exergy analyses acting as a system, like a sink or source. In this investigation, June 2015 data is considered. The following assumptions have been made to analyze the kiln system,

- the steady-state operation
- the ideal-gas values are used
- complete combustion in the rotary kiln is assumed
- the kinetic and potential energy variations are ignored
- lower heating value is used
- shaft work is produced by electricity
- the temperature of the system is assumed to be constant.

The mass, energy and exergy balance and the energetic and exergetic efficiencies of the system are expressed as:

$$\sum \dot{m}_{\text{in}} = \sum \dot{m}_{\text{out}} \tag{1}$$

$$\sum \dot{E}_{\text{in}} = \sum \dot{E}_{\text{out}} \tag{2}$$

$$\dot{Q}_{\text{net,in}} - \dot{W}_{\text{net,out}} = \sum \dot{m}_{\text{out}} h_{\text{out}} - \sum \dot{m}_{\text{in}} h_{\text{in}} \tag{3}$$

$$\eta_I = \frac{\sum \dot{E}_{\text{out}}}{\sum \dot{E}_{\text{in}}} \qquad 4)$$

$$\sum \dot{E}x_{\text{in}} - \sum \dot{E}x_{\text{out}} = \sum \dot{E}x_{\text{dest}} \tag{5}$$

$$\sum \left(1 - \frac{T_0}{T_p}\right) \dot{Q}_p - \dot{W}_{\text{net,out}} + \sum \dot{m}_{\text{in}} \psi_{\text{in}} - \sum \dot{m}_{\text{out}} \psi_{\text{out}} = \sum \dot{E}x_{\text{dest}} \tag{6}$$

$$\eta_{II} = \frac{\sum \dot{E}x_{\text{out}}}{\sum \dot{E}x_{\text{in}}} \tag{7}$$

where the subscript "in" is used for the input materials and "out" is used for the output materials, $\dot{Q}$ is the rate of heat transfer, $\dot{W}$ is the rate of work (power), $\dot{m}$ is mass flow rate, h is enthalpy, $\dot{Q}_p$ is the heat transfer rate through the boundary at temperature T_p at location p. The dead state of P_0 and T_0 are presented by the subscript zero. The change in "u" and "h" values are presented as:

$$\Delta u = \int_1^2 c(T)\, dT = c_{\text{avg}}\left(T_2 - T_1\right) \tag{8}$$

$$\Delta h = \Delta u + \upsilon\, \Delta P \tag{9}$$

where c_{avg} is average specific heat, υ is specific volume and ΔP is pressure change. The change of enthalpy for solid materials is equal to the change of internal energy. The enthalpies of the ingredients are defined as:

$$\Delta h_{\text{in}} = c_{\text{avg}}\left(T_1 - T_0\right) \tag{10}$$

$$\Delta h_{\text{out}} = c_{\text{avg}}\left(T_2 - T_0\right) \tag{11}$$

where T_1 is the input, T_2 is the output and T_0 is the dead state temperatures. The Δs values for the solids, ideal gases, output and input streams are presented as:

$$s_2 - s_1 = c_{avg} \ln \frac{T_2}{T_0} \tag{12}$$

$$s_2 - s_1 = c_{p,avg} \ln \frac{T_2}{T_0} - R \ln \frac{P_2}{P_0} \tag{13}$$

$$\Delta s_{in} = c_{p,avg} \ln \frac{T_1}{T_0} \tag{14}$$

$$\Delta s_{out} = c_{p,avg} \ln \frac{T_2}{T_0} \tag{15}$$

The Δψ (exergy change) values of input and output constituents are presented by:

$$\Delta \psi_{in} = \Delta h_{in} - T_0 \Delta s_{in} \tag{16}$$

$$\Delta \psi_{out} = \Delta h_{out} - T_0 \Delta s_{out} \tag{17}$$

The energy balance of the system is calculated from Eq. 2. Total energy input ($\Sigma\ \dot{E}_{in}$) contains energy input by input materials, electrical energy and energy obtained from the combustion process. Total energy output ($\Sigma\ \dot{E}_{out}$) involves the energy of constituents and hot gas leaving the component and heat loss from outer surface of the rotary kiln. The mass, energy and exergy values of system materials entering and leaving the dry type rotary kiln system have been presented in more detail in Table 1.

The total amount of energy entering the system has been calculated to be 114.86 MW, while 36.57 MW of this energy has been lost during the formation process of clinker (Table 2). It is found that 32% of the energy is lost during the clinker formation. The total amounts of energy entering and leaving the system have been calculated to be 114.86 MW and 62.17 MW respectively. Some part of the energy has been lost during the formation of clinker and the heat lost is found to be around 16 MW. The 1st law efficiency of the system is found from Eq. 4 to be 54%. First law efficiency has been calculated by (62.12/114.86)x100= 54%. The 2nd law efficiency of the rotary kiln is calculated from Eq. 7 to be 29%. The output contains energy of manufactured clinker, high temperature gas, heat losses, leaking materials, the energy disbursed in the clinker formation. The leading input energy is supplied by the burning process. 32% of the input energy is lost in clinker formation process. Combustion process has the greatest influence on the energy and exergy of the system. The Sankey and Grassmann diagrams of the unit have been presented in Figure 2 and Figure 3 respectively.

Table 1. Mass, energy and exergy values of system materials

Input material	Content	$\dot{m}$ (kg/h)	c_p (kJ/kgK)	T_0 (K)	T_{in} (K)	Δh (kJ/kg)	Δs (kJ/kgK)	$\Sigma \dot{m} h$ (kW)	$\Sigma \dot{m} \psi$ (kW)
Farine	CaO	75369	0.60	290	1105	489.00	0.80	10237.62	4873.09
	SiO_2	18543	0.69	290	1105	562.35	0.92	2896.57	1378.76
	Al_2O_3	5145	2.01	290	1105	1638.15	2.69	2341.19	1114.40
	Fe_2O_3	2709	4.16	290	1105	3390.40	5.56	2551.28	1214.40
	MgO	1312.50	0.37	290	1105	301.55	0.49	109.94	52.33
	K_2O	901.95	4.31	290	1105	3512.65	5.77	880.07	418.91
	H_2O	739.20	4.18	290	1105	3406.70	5.59	699.51	332.97
	Na_2O	249.90	4.36	290	1105	3553.40	5.83	246.67	117.41
	SO_3	30.45	0.60	290	1105	489.00	0.80	4.14	1.97
Total	-	105000						19.97	9.50
Coal	C_2	4788.00	0.03	290	330	1.62	0.00	2.15	1.50
	Ash	1468.80	1.30	290	330	70.20	0.17	28.64	19.87
	O_2	273.60	0.92	290	330	49.68	0.12	3.78	2.62
	H_2	259.20	14.32	290	330	773.28	1.85	55.68	38.63
	H_2O	201.60	4.18	290	330	225.72	0.54	12.64	8.77
	N_2	115.20	1.04	290	330	56.16	0.13	1.80	1.25
	S_2	93.60	5.64	290	330	304.56	0.73	7.92	5.49
Total	-	7200.00						0.11	0.08
Combustion	-	7200.00	1.15	290	920	30000	1.33	60	59.23
Primary air	N_2	7675.70	1040.00	290	295	5200	17.78	11087.12	10992.63
	O_2	2056.10	0.93	290	295	4.63	0.02	2.64	2.62
	Ar	118.40	4.97	290	295	24.85	0.08	0.82	0.81
	CO_2	3.90	0.85	290	295	4.23	0.01	0.00	0.00
	H_2O	3.00	4180.00	290	295	20900	71.45	17.42	17.27
	Other	8.90	1007.00	290	295	5035	17.21	12.45	12.34
Total	-	9866						11.12	11.03
Secondary air	N_2	69639.6	1.15	290	950	756.36	1.36	14631.3	7628.41
	O_2	18654.1	1.07	290	950	708.84	1.27	3672	1915
	Ar	1074.1	4.97	290	950	3280.2	5.90	978.68	510.26
	CO_2	35.8	1.21	290	950	798.6	1.44	7.94	4.14
	H_2O	26.9	2.40	290	950	1584	2.85	11.84	6.17
	Other	80.6	1.18	290	950	776.82	1.4	17.39	9.07
Total	-	89511.10						19.32	10.07
Electrical								4.34	4.34
TOTAL								114.86 (MW)	94.25 (MW)

Output material	Content		ṁ (kg/h)	c_p (kJ/kgK)	T_0 (K)	T_{in} (K)	Δh (kJ/kg)	Δs (kJ/kgK)	Σ ṁ h (kW)	Σ ṁ ψ (kW)
Clinker	C_4AF	4CaO	1956	0.62	290	1550	778.68	1.04	423.08	163.22
		Al_2O_3	1434.4	2.17	290	1550	2730.42	3.63	1087.92	419.69
		Fe_2O_3	2934	4.43	290	1550	5576.76	7.42	4545.06	1753.37
	C_2S	2CaO	6520	0.62	290	1550	778.68	1.04	1410.28	544.05
		SiO_2	7824	0.74	290	1550	936.18	1.25	2034.63	784.91
	C_3A	3CaO	3260	0.62	290	1550	778.68	1.04	705.14	272.03
		Al_2O_3	3390.4	2.17	290	1550	2730.42	3.63	2571.45	992
	C_3S	3CaO	23472	0.62	290	1550	778.68	1.04	5076.99	1958.58
		SiO_2	11084	0.74	290	1550	936.18	1.25	2882.39	1111.96
	K_2O		1304	4.78	290	1550	6021.54	8.01	2181.14	841.43
	SO_3		652	0.89	290	1550	1117.62	1.49	202.41	78.09
	MgO		717.2	0.39	290	1550	493.92	0.66	98.40	37.96
	Na_2O		652	4.71	290	1550	5935.86	7.90	1075.05	414.73
Total	-		65200	-	-	-			24.29	9.37
Hot gas	N_2		91975	1.08	290	1120	898.89	1.46	22965.64	10842.24
	CO_2		30035	1.09	290	1120	907.19	1.48	7568.91	3573.34
	H_2O		7742.54	2.05	290	1120	1698.18	2.76	3652.28	1724.27
	O_2		1468.41	1.01	290	1120	839.96	1.37	342.61	161.75
	Ar		1334.92	4.97	290	1120	4125.1	6.72	1529.63	722.15
	SO_2		734.21	0.71	290	1120	589.3	0.96	120.19	56.74
	Other		200.24	1.05	290	1120	871.5	1.42	48.47	22.89
Total	-		133492		-	-			36.23	17.10
Dust and ash	C_4AF	4CaO	463.86	0.71	290	710	296.1	0.63	38.15	23.59
		Al_2O_3	180.39	2.60	290	710	1091.16	2.33	54.68	33.80
		Fe_2O_3	309.24	5.30	290	710	2226	4.75	191.21	118.22
	C_2S	2CaO	1713.71	0.71	290	710	296.1	0.63	140.95	87.14
		SiO_2	927.72	0.92	290	710	388.08	0.83	100.01	61.83
	C_3A	3CaO	734.45	0.71	290	710	296.1	0.63	60.41	37.35
		Al_2O_3	438.09	2.60	290	710	1091.16	2.33	132.79	82.09
	C_3S	3CaO	4329.36	0.71	290	710	296.1	0.63	356.09	220.15
		SiO_2	1546.2	0.92	290	710	388.08	0.83	166.68	103.05
	Ash		2241,99	1.3	290	710	546	1.16	340.03	0,72
Total	-		12885	-	-	-	-	-	1.64	0.78
TOTAL	-			-	-	-	-	-	62.17 (MW)	27.25 (MW)

Table 2. Energy and mass balance of the system

Entering stream	**ṁ (kg/h)**	**Σ $\dot{E}_{in}$ (MW)**
Farine	105000	19.97
Coal	7200	0.11
Air (primary)	9866	11.12
Air (secondary)	89511.1	19.32
Work (electrical)	-	4.34
Combustion process	-	60
Total	211577.1	114.86
Exiting stream	**ṁ (kg/h)**	**Σ $\dot{E}_{out}$ (MW)**
Clinker formation	-	36.57
Clinker	65200	24.29
Hot gas	133492	36.23
Dust and ash	12885	1.64
Heat transfer	-	16.12
Total	211577	114.86

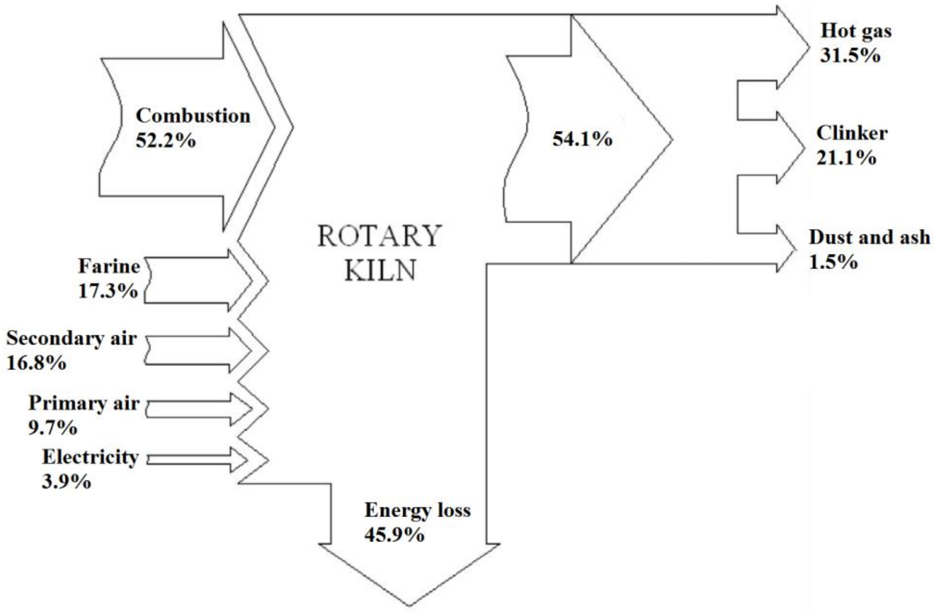

Figure 2. The Sankey diagram of the rotary kiln

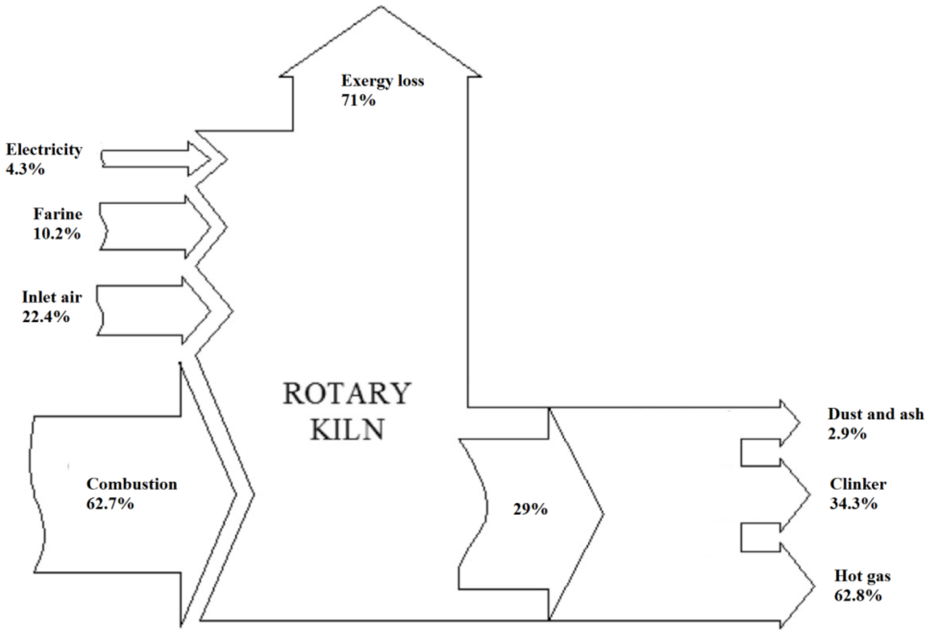

Figure 3. The Grassmann diagram of the rotary kiln

2.2. Specific Energy Consumption of the Rotary Kiln System

The specific energy consumption of the system is found by observing the statistics from the facility during one year of manufacturing and indicated in Table 3. The facility consumes electricity and energy by the burning of coal to produce clinker. The SEC value is found from the data is 3793 kJ/kg clinker.

Table 3. SEC of the kiln system

Date (2009)	Coal consumption (kg/month)	Electricity consumption (kWh/month)	Clinker production (kg/month)	SEC (kJ/kg clinker)
January	5366	3330095	44821	3711
February	4855	2895852	38522	3907
March	5666	319221	42566	4126
April	5100	3100522	41089	3847
May	5388	3135578	44688	3737
June	5125	3136785	42008	3782
July	5366	3239887	46055	3611
August	5422	3454788	45102	3726
September	5189	3327870	42998	3741
October	5366	3438871	43698	3806
November	5291	3289957	43568	3764
December	5568	3358765	45855	3764
Average				3793

3. EXERGOECONOMIC ASSESSMENT

Exergoeconomics, in other words thermoeconomics associates exergy analysis and financial values to offer the designer with valuable information to plan a cost effective structure. This approach points out how resources are used successfully. The data about carrying, fuel, and operating and maintenance (O&M) costs are the basic essential inputs for the economic analysis. These monetary values diverge considerably within the economic life. That is why, the levelized annual value are important in the financial evaluations.

The levelized cost is calculate by using the following equation:

$$CRF = \frac{i(i+1)^n}{(i+1)^n - 1} \tag{18}$$

where i is the interest rate and n is the payment period. The cost rate related with the capital, O&M and total expenses for the kiln are:

$$\dot{Z}_{CI} = \frac{CRF}{t_{op}} \ x \ PEC \tag{19}$$

$$\dot{Z}_{OM} = \dot{Z}_{CI} \ x \ \varphi \tag{20}$$

$$\dot{Z}_T = \dot{Z}_{CI} + \dot{Z}_{OM} \tag{21}$$

where top is the time of operation, PEC is the purchased equipment cost and φ is the factor of O&M. To find the financial flows of the kiln, all the monetary data are acquired from the company considering the kiln's entire economic life (30 years). These prices are changed by using average nominal escalation (ANE) rate of the equivalent costs. ANE is taken as the average general inflation rate within the plant entire economic life, which is 6% in US dollars [38].

In this study, the annual nominal discount rate is predicted as 10%. The levelized cost values of the carrying charges and payments of the system are presented below. The annual total revenue requirement (TRR) is calculated by adding the carrying charges (CC), fuel (electricity and coal) and O&M costs [39].

$$\text{TRR} = \text{CC+Fuel+O\&M} \tag{22}$$
$$\text{TRR} = 580.000 + 7.614.000 + 125.000 = 8.319.000\ \$$$

Table 4 shows the cost of equipment, O&M costs, the hourly levelized costs of capital investment, and the total costs of the components of the kiln.

Table 4. The cost rates of the kiln unit

Unit	PEC (x10^3 \$)	$\dot{Z}_{CI}$ (\$/h)	$\dot{Z}_{OM}$ (\$/h)	$\dot{Z}_{T}$ (\$/h)
Rotary kiln	35.000	897.9	143.6	1041.5

This paper uses SPECO method to evaluate the cost formation arrangement of the facility. According to this approach, fuels and products are defined by systematically registering exergy additions to and removals from each material and energy stream. This method consists of three main steps: (1) identification of exergy streams, (2) definition of fuel and product for each system component, and (3) allocation of cost-balance equations. In exergy costing, a cost is associated with each exergy stream. The specific exergy and costs, 2nd law efficiency, and the costing equations for the kiln have been investigated. The exergy is transferred by the input and exit streams, by power and by heat. The following equations are developed for each stream:

$$\dot{C}_i = c_i \dot{E}x_i = c_i(\dot{m}_i \psi_i) \tag{23}$$

$$\dot{C}_e = c_e \dot{E}x_e = c_e(\dot{m}_e \psi_e) \tag{24}$$

$$\dot{C}_w = c_w \dot{E}x_w \qquad 25)$$

$$\dot{C}_q = c_q \dot{E}x_q \tag{26}$$

The rotary kiln system, receives electrical work and transfers heat from the surface, the exergoeconomic balance equation [16] is stated as:

$$\sum_i (c_i \dot{E}x_i) + c_w \dot{E}x_w + \dot{Z}_k = \sum_e (c_e \dot{E}x_e) + c_q \dot{E}x_q \tag{27}$$

The cost rates and the unit exergetic costs connected with each input and output stream of the kiln system in the facility have been obtained by using exergetic cost rate balance equations (Table 5).
The exergetic cost rate balance equation for the kiln is stated as:

$$c_{frn} \dot{E}x_{frn} + c_a \dot{E}x_a + c_w \dot{E}x_w + c_f \dot{E}x_f + \dot{Z}_k = c_c \dot{E}x_c + c_d \dot{E}x_d + c_q \dot{E}x_q + c_{ex} \dot{E}x_{ex} \text{ or;} \tag{28}$$

where $c_a = c_f = c_q = c_{ex}$

Table 5. The exergy and cost flow rates, and the unit exergy costs

Component	$\dot{E}x$ (MW)	$\dot{C}$ ($/h)	c ($/GJ)
Farine	9.50	787.50	23.02
Primary and secondary air	21.10	364.35	4.80
Electrical work	4.34	361.79	23.15
Fuel	62.54	1080.00	4.80
Clinker	9.37	2608.00	77.30
Dust and ash	0.78	515.40	184.25
Surface heat transfer	16.12	278.38	4.80
Hot gas exhaust	17.10	295.36	4.80

Exergetic cost rate balance equation is formulated for the kiln of Şanlıurfa Cement Plant. The cost data of the facility is used to find the flow rates through the kiln related with the exergy loss. This is provided by the exergoeconomic factor f_k, and it is defined as:

$$f_k = \frac{\dot{Z}_k}{\dot{Z}_k + c_{f,k}\dot{E}_{D,k}} \tag{29}$$

where $c_{f,k}$ is the unit exergetic cost of the fuel of kiln and $\dot{E}_{D,k}$ is the corresponding exergy destruction of the unit. The relative cost difference is a very important parameter used for the exergoeconomic assessment. The factor gives an idea about the relative increase in the average cost per exergy unit between fuel and product of the system. For the kiln it is defined as:

$$r_k = \frac{c_{p,k} - c_{f,k}}{c_{f,k}} \tag{30}$$

where cp,k is the unit exergetic cost of the clinker of the kiln. The cost rate of exergy destruction is stated as:

$$\dot{D}_{D,k} = c_{f,k}\dot{E}x_{D,k} \tag{31}$$

The unit exergetic costs, the change of relative exergetic cost, exergoeconomic factor, cost rate of exergy destruction, and cost rate of investment for the kiln are stated in Table 6.

Table 6. The exergetic cost parameters of the kiln

Component	$c_{f,k}$ ($/GJ)	$c_{p,k}$ ($/GJ)	r (%)	f (%)	$\dot{D}_{D,k}$ ($/h)
Rotary kiln	4.8	77.3	15	53	934.4

4. RESULTS AND DISCUSSION

Cement industry has been consuming large amounts of energy since 1900's. The current processes which have been used should be revised to decrease the energy consumption. There are no considerable improvements in processing techniques and that makes the cement industry one of the top two manufacturing industry sources of greenhouse gases.

After the calculations, the exergy input to the kiln is found to be 89.48 MW. The total exergy input of fuel is found to be 97.4 MW. The 54.1 MW of exergy input is lost (56% of total exergy entering the system). The 2nd law efficiency of the burner is calculated to be 29%. The exergy destruction is commonly due to the highly irreversible combustion and heat losses from the surface of the kiln.

The followings exergoeconomic results have been drawn from the study;

- The exergetic cost rate and the specific unit exergetic cost of the fuel are found to be 1080 $/h and 4.8 $/GJ, respectively.

- The capital investment cost, the O&M costs, and the total cost of the unit are calculated to be 897.9 $/h, 143.6 $/h and 1041.5 $/h, respectively (See Table 4).

- The specific unit exergetic costs and the exergetic cost rate of the hot gas output of the kiln are found to be 4.8 $/GJ and 295.3 $/h and, respectively.

-The exergoeconomic factor of the unit is found to be 53%. Although we see an increase in the investment costs, the decrease in exergy destruction will be cost effective. Cost effectiveness for the rotary kiln should be accomplished by decreasing the destruction of exergy.

- It is very important to select high quality and right type of the refractories used inside the kiln. The amount of energy loss in the system is inevitable; however, this should be reduced by using high quality refractories. In addition to this the scheduled maintenance is also an important parameter affecting the performance of the rotary kiln.

- The specific unit exergetic costs and the exergy cost rates of other cement factories show important differences in literature. For example, the cost rate associated with first capital investment and O&M costs for the kiln in Gaziantep Cement factory is calculated to be 457.7 $/h in another study [40,41,42] while the same value is calculated to be 1041.5 $/h in this study. The difference here is mostly related to the old technology used in Şanlıurfa Cement factory.

5. CONCLUSIONS

The exergoeconomic analysis contains economic assessment and exergy analysis of a system. By exergoeconomic analysis, the cost rate of exergy consumption and the exergoeconomic performance limitations (i.e. relative cost difference and the exergoeconomic factors) of a system are calculated. The exergoeconomic analysis of a system helps to point out how resources are used more successfully to save them. Assessing the cost of the flow streams and processes in a cement facility helps to comprehend the procedure of cost formation, from the input resources to final products.

In this study, the exergoeconomic evaluation of an existing cement factory in Şanlıurfa has been performed using real statistics. The results offer significant information about exergetic performance of the kiln. It is clear that there is a noteworthy potential for increasing exergy efficiency of the system. First of all, a strategic work to create an energy management structure in the facility is very important. The exergy consumption of the kiln is calculated to be 54 MW and the exergoeconomic factor of the kiln is found to be 53%. Total investment cost of the unit is about 35 million $. The total cost rate of the unit is found to be 1041.5 $/h.

The results based on the exergoeconomic study indicates that it is needed to improve exergy utilization especially in the rotary kiln system of a cement plant. Small improvements in system operation can provide better developments in plant performance compared to large improvements in other components. In general, better plant performance can be achieved by reducing exergy destruction through better insulation and operation as well as by reducing investment and exergetic destruction costs. In general, better kiln performance should be attained by decreasing exergy destruction through better operation and design (by using effective insulation) as well as by reducing investment and exergetic destruction costs. Further studies may concentrate on the selection of a suitable isolation material for the kiln. The analyses reported here will offer the facilities with important information about how effectively the rotary kiln units in cement industry use the energy resources.

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