International Journal of Thermophysics, Vol. 25, No. 6, November 2004 (© 2004)

Thermodynamic Analysis of Some Industrial Applications with Variable Ambient Conditions

Ünal Çamdali[1, 2] and Murat Tunç[3]

Received December 1, 2003

In this study, the general exergy balance equation of an open system is obtained based on the variable ambient temperature and pressure. Using this result, the mathematical equations regarding both the reversible work given to the system in the electric arc furnace used in steel production and the exergy loss in the rotary burner used in cement production are derived. In obtaining these equations, it is assumed that the ambient temperature has a sinusoidal variation. The effects of varying ambient parameters on calculated exergy values in industrial applications are discussed, and the obtained results are analyzed and demonstrated.

KEY WORDS: electric arc furnace; exergy balance; rotary burner; second law analysis; variable ambient conditions.

1. INTRODUCTION

Because of increasing energy costs, studies on the efficient use of energy are considered to be very important to reduce costs. Moreover, these studies, which are based on exergy analysis, focus on industrial applications. Minimum exergy values required for various sectors are given in the literature [1]. However, the effects of environmental conditions on overall system efficiency are investigated in many studies [2, 3]. Furthermore, problems with transient or periodic changing conditions also pose

---

[1] Development Bank of Turkey, Necatibey Cad., No: 98; Bakanliklar, 06100 Ankara, Turkey.

[2] To whom correspondence should be addressed. E-Mail: u-camdali@tkb.com.tr or ucamdali@yahoo.com

[3] Yeditepe University, Engineering Faculty, 26 Agustos Yerlesimi, Kayisdagi cad., Kayisdagi, 81120 Istanbul, Turkey.

challenges. Variations in ambient conditions may influence the thermal performance of energy conversion systems positively or negatively [4–9]. Obtaining a general exergy balance is necessary from the viewpoint of identifying sources of losses in production processes.

Brodyanskii and Kalinin [10] examined the effects of environmental conditions. Their work is restricted to flow exergy.

In this study, a thermodynamic analysis is carried out under variable ambient conditions. The derived equations are applied to industrial applications. The effects of variable ambient condition parameters on system efficiency are discussed and obtained solutions are analyzed and demonstrated.

2. GENERAL EXERGY BALANCE EQUATION OF A SYSTEM DEPENDING ON VARIABLE AMBIENT TEMPERATURE AND PRESSURE

A general system with matter, heat, and useful work interactions is shown in Fig. 1. A thermodynamic analysis is carried out for this system. In the first step, the first law of thermodynamics is applied to the system with the unusable power, $P_0\ (dV_s/dt)$, subtracted from the total power dW/dt [9]. Then, Eq. (1) can be written as

$$d(Q_i)/dt - d(Q_0)/dt - d(Q_L)/dt + d(W_i)/dt - \{d(W_e/dt - P_0 d(V_s)/dt\} + \{[d(m_i)/dt]h_i - [d(m_e)/dt]h_e\} - [d(m_L)/dt]h_L = d(E_s)/dt + P_0 d(V_s)/dt \tag{1}$$

Here, dQ and dW do not have the meaning of total derivatives. The entropy balance can be written for the system in a similar manner by the following equation:

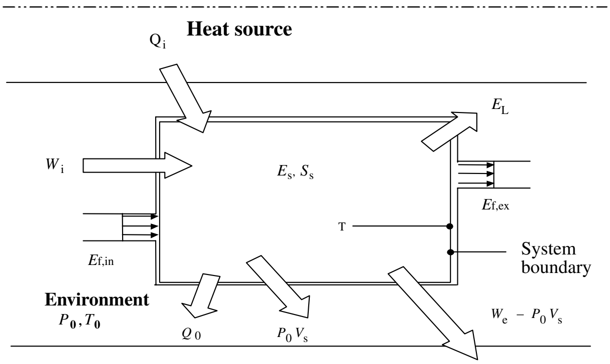

Fig. 1. General view of the system.

$$\begin{gathered}[d(Q_{\mathrm{i}})/dt]/T - [d(Q_0)/dt]/T_0 + \{[d(m_{\mathrm{i}})/dt]s_{\mathrm{i}} - [d(m_{\mathrm{e}})/dt]s_{\mathrm{e}}\} \\ -[d(Q_{\mathrm{L}})/dt]/T - [d(m_{\mathrm{L}})/dt]s_L + d(S_{\mathrm{gen}})/dt = d(S_{\mathrm{s}})/dt\end{gathered} \tag{2}$$

If Eq. (2) is multiplied by T_0, the following equation is obtained:

$$\begin{gathered}\{[d(Q_{\mathrm{i}})/dt]/T]\}T_0 - \{[d(Q_0)/dt]/T_0\}T_0 + T_0\{[d(m_{\mathrm{i}})/dt]s_{\mathrm{i}} - [d(m_{\mathrm{e}})/dt]s_{\mathrm{e}}\} \\ -\{[d(Q_{\mathrm{L}})/dt]/T\}T_0 - T_0[(dm_{\mathrm{L}})/dt]S_{\mathrm{L}} + T_0[d(S_{\mathrm{gen}})/dt] = T_0[d(S_{\mathrm{s}})/dt]\end{gathered} \tag{3}$$

Subtracting Eq. (3) from Eq. (1) and rearranging, one obtains

$$\begin{gathered}\{d(W_{\mathrm{i}})/dt - d(W_{\mathrm{e}})/dt - P_0(V_{\mathrm{s}})/dt\} + \{[d(Q_{\mathrm{i}})/dt](1-T_0/T) - [d(Q_{\mathrm{L}})/dt](1-T_0/T)\} \\ + \{[d(m_{\mathrm{i}})/dt](h_{\mathrm{i}}-T_0s_{\mathrm{i}}) - [d(m_{\mathrm{e}})/dt](h_{\mathrm{e}}-T_0s_{\mathrm{e}})\} - \{[d(m_{\mathrm{L}})/dt](h_{\mathrm{L}}-T_0s_{\mathrm{L}})\} \\ -T_0[d(S_{\mathrm{gen}})/dt] = d(E_{\mathrm{s}}+P_0V_{\mathrm{s}}-T_0S_{\mathrm{s}})/dt - V_{\mathrm{s}}dP_0/dt + S_{\mathrm{s}}dT_0/dt\end{gathered} \tag{4}$$

After adding and subtracting $N\ \mu_{\mathrm{i}0}$ and $N\mu_{\mathrm{i}00}$ from flow and system exergy terms, Eq. (4) can be expressed as

$$\dot{E}_{\mathrm{w}} + \dot{E}_{\mathrm{q}} + (\dot{\boldsymbol{m}}_{\mathrm{i}}e_{\mathrm{fi}}) - (\dot{\boldsymbol{m}}_{\mathrm{e}}e_{\mathrm{fe}}) - \dot{E}_{\mathrm{L}} - \dot{E}_{\mathrm{d}} = \dot{E}_{\mathrm{s}} + \dot{E}_{\mathrm{c}} \tag{5}$$

All of the terms in Eq (5) are integrated over a process between t_1 and t_2; they are defined as

$$E_{\mathrm{w}} = \int_{t_1}^{t_2} [\dot{W}_{\mathrm{i}} - (\dot{W}_{\mathrm{e}} - P_0\dot{V}_{\mathrm{s}})]dt \tag{6}$$

$$E_{\mathrm{q}} = \int_{t_1}^{t_2} \{[\dot{Q}_{\mathrm{i}} - \dot{Q}_{\mathrm{L}}](1 - T_0/T_{\mathrm{b}})\}dt \tag{7}$$

$$e_{\mathrm{f}} = e_{\mathrm{f}}^{\mathrm{TM}} + e_{\mathrm{f}}^{\mathrm{CH}} \tag{8}$$

$$e_{\mathrm{f}}^{\mathrm{TM}} = (h_{\mathrm{t}} - T_0s) - \sum_i (\dot{N}_{\mathrm{f}}/\dot{m}_{\mathrm{f}})_{\mathrm{i}}\mu_{\mathrm{i}0} \tag{8a}$$

$$e_{\mathrm{f}}^{\mathrm{CH}} = \sum_i (\dot{N}_{\mathrm{f}}/\dot{m}_{\mathrm{f}})_{\mathrm{i}}(\mu_{\mathrm{i}0} - \mu_{\mathrm{i}00}) \tag{8b}$$

$$E_{\mathrm{L}} = \int_{t_1}^{t_2} (dm_{\mathrm{L}}/dt)(e_{\mathrm{L}}^{\mathrm{TM}} + e_{\mathrm{L}}^{\mathrm{CH}})dt \tag{9}$$

$$e_{\mathrm{L}}^{\mathrm{TM}} = (h_{\mathrm{L}} - T_0 s_{\mathrm{L}}) - (h_{\mathrm{L0}} - T_0 S_{\mathrm{L0}}) \tag{9a}$$

$$e_{\mathrm{L}}^{\mathrm{CH}} = \sum_i (\dot{N}_{\mathrm{f}}/\dot{m}_{\mathrm{f}})_{\mathrm{i}}(\mu_{\mathrm{i0}} - \mu_{\mathrm{i00}}) \tag{9b}$$

$$E_{\mathrm{d}} = \int_{t_1}^{t_2} T_0\{[d(S_{\mathrm{gen}})/dt]\}dt \tag{10}$$

$$\Delta E_{\mathrm{s}} = \int_{t_1}^{t_2} \left\{ d\{E^{\mathrm{TM}} + E^{\mathrm{CH}}\}/dt \right\} dt \tag{11}$$

$$E^{\mathrm{TM}} = (E_{\mathrm{ts}} + P_0 V_{\mathrm{s}} - T_0 S_{\mathrm{s}}) - (U_{\mathrm{s0}} + P_0 V_{\mathrm{s0}} - T_0 S_{\mathrm{s0}}) \tag{11a}$$

$$E^{\mathrm{CH}} = \sum_i N_{\mathrm{is}}\, \mu_{\mathrm{is0}} - \sum_i N_{\mathrm{is}}\, \mu_{\mathrm{i00}} \tag{11b}$$

$$\Delta E_{\mathrm{c}} = \int_{t_1}^{t_2} \Bigg\{ S_{\mathrm{s}}(dT_0/dt) - V_{\mathrm{s}}(dP_0/dt) - \left(\sum_i \dot{N}_{\mathrm{i}}\mu_{i00}\right)_{\mathrm{in}} + \left(\sum_i \dot{N}_{\mathrm{i}}\mu_{\mathrm{i00}}\right)_{\mathrm{ex}} + \sum_i \left(\dot{N}_{\mathrm{iL}}\mu_{\mathrm{i00}}\right)_L + d\left(\sum_i N_{\mathrm{is}}\mu_{\mathrm{i00}}\right)_s /dt \Bigg\} dt \tag{12}$$

Now, using mass balance one may write [5,8,9]:

$$\sum_i (d(N_{\mathrm{is}})/dt\mu_{\mathrm{i00}})_s = \left(\sum_i \dot{N}_{\mathrm{i}}\mu_{\mathrm{i00}}\right)_{\mathrm{in}} - \left(\sum_i \dot{N}_{\mathrm{i}}\mu_{\mathrm{i00}}\right)_{\mathrm{ex}} - \sum_i \left(\dot{N}_{\mathrm{iL}}\mu_{\mathrm{i00}}\right)_L ; \;\; i = 1, 2, \ldots k \tag{13}$$

In that case, the correction term is

$$\Delta E_{\mathrm{c}} = \int_{t_1}^{t_2} \left\{ S_{\mathrm{s}}(dT_0/dt) - V_{\mathrm{s}}(dP_0/dt) + \sum_i N_{\mathrm{is}} d(\mu_{\mathrm{i00}})s/dt \right\} \tag{14}$$

3. APPLICATIONS

Thermodynamic analysis is applied to electric arc furnace (EAF) and rotary burner (RB) by using Eq. (5). The assumptions in this analysis are presented as follows:

- Heat losses from the system, exergy of coal going into the system (RB) and Δh, Δs of materials going into and out of the system are assumed to be constant.
- The variation of chemical exergy is neglected.
- Calculations are made according to mean values of production.
- Values of EAF for one casting and values of RB for 1 h production are taken into consideration.
- Required inputs for EAF are taken from Ref. 11 and for RB are taken from Ref. 12.
- Both systems are assumed to be open systems.
- $dP_0/dt \approx 0$; $E_\mathrm{d} = \int_{t_1}^{t_2} T_0\{[d(S_\mathrm{gen})/dt]\}\,dt \approx 0$
- The ambient temperatures of EAF and RB are assumed to vary harmonically such as $T_0 = T_{0\mathrm{m}} + T_{0\mathrm{a}} \sin[(2\pi/24)t)]$ [2].

3.1. Electric Arc Furnace (EAF)

The production of steel of a desired composition is realized as a result of bringing the concentrations of some of the elements to desired amounts after many chemical reactions occurring at different velocities between elements or compounds at high temperatures and adding alloy materials for the other elements needed in the composition. The mass balance of EAF depends on chemical reactions taking place in the EAF (Fig. 2). This balance is given in Table I and these reactions can also be found in Ref. 13.

The reversible work given to the EAF, which is based on ambient temperature, is obtained by using Eq. (5). Applying this equation to the EAF, the following equation is found for work exergy:

$$\dot{E}_\mathrm{W} = \dot{E}_\mathrm{q} + (\dot{m}_\mathrm{e} e_\mathrm{e}) - (\dot{m}_\mathrm{i} e_\mathrm{i}) + \dot{E}_\mathrm{L} + \dot{E}_\mathrm{d} + \dot{E}_\mathrm{s} + \dot{E}_\mathrm{c} \tag{15}$$

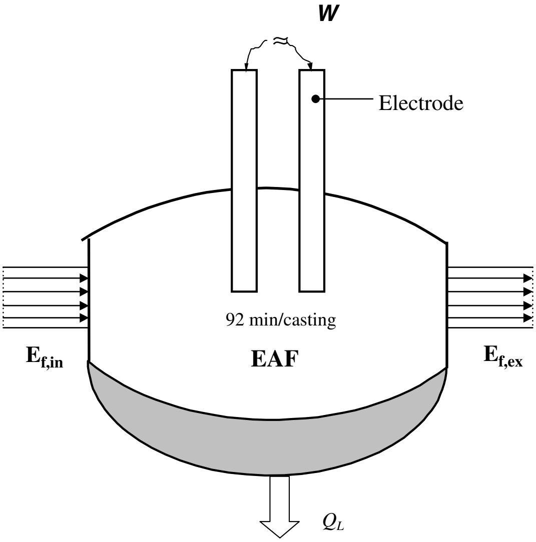

Fig. 2. Electric arc furnace and energy balance.

Table I. Mass Balance of EAF

Materials	(kg)
Materials Entering EAF	
Scrap	50800
Pig	7400
Fluxes	2100
Coke	900
Deoxidation materials	340
Electrode	150
Natural gas	160
Oxygen	3580
Total	65430
Materials Exiting EAF	
Liquid steel	55750
Slag	4150
Dust	790
Stack gases	4440
Steel in slag	300
Total	65430

The terms in Eq. (15) are given by the following equations in term of T_0:

$$\dot{E}_{\mathrm{q}} = 16310 - 11.7\mathrm{T}_0 \ \text{(MJ) (loss)} \tag{15a}$$

$$\dot{E}_{\mathrm{f}} = (\dot{m}_{\mathrm{e}} e_{\mathrm{e}}) - (\dot{m}_{\mathrm{i}} e_{\mathrm{i}}) = 62205 - 124\mathrm{T}_0 \ (\mathrm{MJ, T_0(K)}) \tag{15b}$$

$$\dot{E}_{\mathrm{L}} = 415 - 0.3\mathrm{T}_0 \quad (\mathrm{MJ, T_0(K)}),\ \text{(steel in slug)} \tag{15c}$$

$$\dot{E}_{\mathrm{d}} = 0 \ \text{(MJ)} \tag{15d}$$

$$\dot{E}_{\mathrm{s}} = -0.63\cos([2\pi/24]t) \ \text{(MJ)} \tag{15e}$$

$$\begin{aligned} \dot{E}_{\mathrm{c}} &= \Delta S_{\mathrm{s}}(dT/dt) = (\Delta S_{\mathrm{ms}} + \Delta S_{\mathrm{cmb}} + \Delta S_{\mathrm{fb}} + \Delta S_{\mathrm{ss}})6\,(2\pi/24\cos[(2\pi/24)t] \\ &= 0.4\{6(2\pi/24)\cos[(2\pi/24)t] = 0.63\cos[(2\pi/24)t]\,(\mathrm{MJ}) \end{aligned} \tag{15f}$$

where

$$\Delta S_{\mathrm{s}} = \int_{T_1}^{T_2} N(\bar{c}_p/T)dT = \int_{T_1}^{T_2} N[(a + bT + cT^{-2})/T]dT \tag{15g}$$

$$\begin{aligned} &= N_{\mathrm{ms}}\{a\ln(T_2/T_1) - b(T_2 - T_1) - 0.5c(T_2^{-2} - T_1^{-2})\} \\ &\quad + N_{\mathrm{cmb}}\{a\ln(T_2/T_1) - b(T_2 - T_1) \\ &- 0.5c(T_2^{-2} - T_1^{-2})\} + N_{\mathrm{fb}}\{a\ln(T_2 - T_1) \\ &- b(T_2 - T_1) - 0.5c(T_2^{-2} - T_1^{-2})\} \\ &+ N_{\mathrm{ss}}\{a\ln(T_2/T_1) - b(T_2 - T_1) \\ &- 0.5c(T_2^{-2} - T_1^{-2})\} = 0.4 \quad (\mathrm{MJ}\cdot K^{-1}) \end{aligned} \tag{15h}$$

$$T_0 = 24 + 6\sin[(2\pi/24)t] \quad (^{\circ}\mathrm{C}) \tag{15i}$$

$$T_0 = 297 + 6\sin[(2\pi/24)t] \ \text{(K) (for a day)} \tag{15j}$$

$$dT_0/dt = 6(2\pi/24)\cos[(2\pi/24)t] \tag{15k}$$

$$\dot{E}_{\mathrm{W}} = 78930 - 136\,T_0 \quad (\mathrm{MJ}, T_0(\mathrm{K})) \tag{15l}$$

Mole numbers (N) and $\bar{c_p}$ functions depending on T[14] for EAF bottom materials are given in Tables II and III, respectively. These equations vs. time for a day are depicted in Figs. 3–7.

3.2. Rotary Burner (RB) with Pre-calcinations in Cement Production

The rotary burner (Fig. 8) used in cement production supplies farine, which comes from the pre-heater system, to be transformed into cement clinkers by using heat. The mass balance of RB is presented in Table IV.

Using Eq. (5), the exergy balance for RB can be given as follows:

$$\dot{E}_{\mathrm{d}} = \dot{E}_{\mathrm{w}} - \dot{E}_{\mathrm{q}} + (\dot{m}_{\mathrm{i}} e_{\mathrm{i}}) - (\dot{m}_{\mathrm{e}} e_{\mathrm{e}}) - \dot{E}_{\mathrm{L}} - \dot{E}_{\mathrm{s}} - \dot{E}_{\mathrm{c}} \tag{16}$$

Table II. Chemical Components and Number of Moles of EAF Bottom Materials

Materials	m (%)	N (kmol)
Magnesite Stamp		
MgO	100	195
Chromium–Magnesite bricks		
MgO	42	145
Cr_2O_3	26	24
Fe_2O_3	15	13
Al_2O_3	12	16
SiO2	5	12
Firebricks		
SiO_2	50	27
Al_2O_3	45	14
Fe_2O_3	5	1
Steel sheet		
Fe	100	89

Table III. Isobaric Specific Heat of Substances used in the EAF Bottom [14]

	$\bar{c_p} = a + bT + cT^{-2}$ (kcal·kmol^{-1}·K^{-1})			
Substance	a	b	c	T
MgO	10.7	2.4×10^{-3}	-2.3×10^5	$T > 298$
Cr_2O_3	28.5	2.2×10^{-3}	-3.7×10^5	$T > 298$
Fe_2O_3	23.5	18.6×10^{-3}	-3.5×10^5	$298 < T < 950$
Al_2O_3	25.5	4.25×10^{-3}	-6.8×10^5	$T > 298$
SiO_2	11.2	8.2×10^{-3}	-2.7×10^5	$298 < T < 848$
Fe	4.2	5.9×10^{-3}	0	$273 < T < 1033$

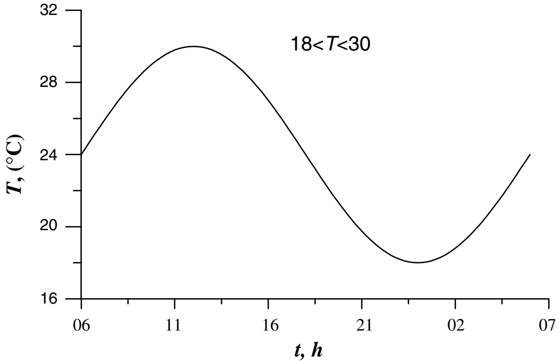

Fig. 3. Variation of the ambient air temperature of the EAF within a day.

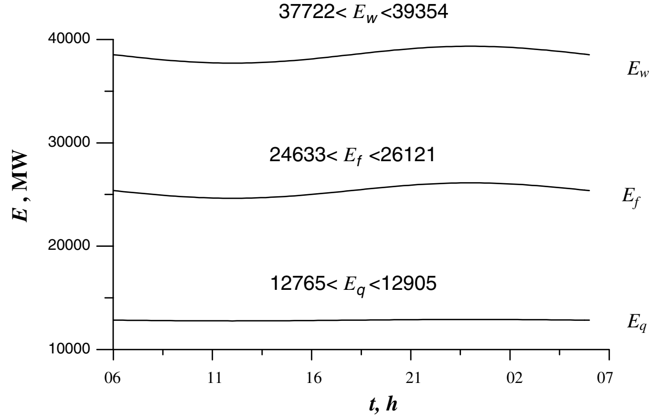

Fig. 4. Variations of E_{w}, E_{f}, and E_{q} for EAF within a day.

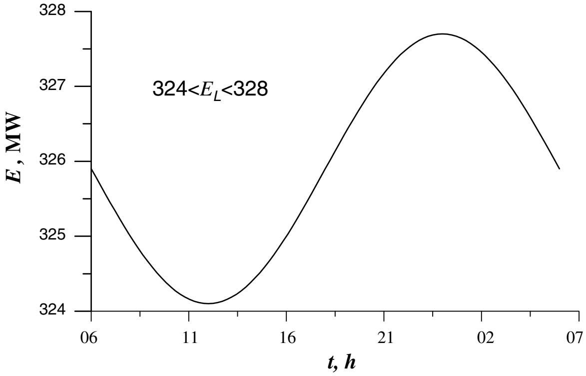

Fig. 5. Variation of E_{L} for EAF within a day.

The terms in Eq. (16) are given by the following equations in term of T_0:

$$\dot{E}_{\mathrm{w}} = 0 \ \text{(MJ)}$$

$$\dot{E}_{\mathrm{q}} = 50141 - 30\,T_0 \quad (\text{MJ}, T_0(\text{K})) \tag{16a}$$

$$\dot{E}_{\mathrm{f}} = (\dot{m}_{\mathrm{i}} e_{\mathrm{i}}) - (\dot{m}_{\mathrm{e}} e_{\mathrm{e}}) = 130984 + 89\,T_0 \quad (\text{MJ}, T_0(\text{K})) \tag{16b}$$

$$\dot{E}_{\mathrm{L}} = 0 \ \text{(MJ)} \tag{16c}$$

$$\dot{E}_{\mathrm{s}} = 0 \ \text{(MJ)} \tag{16d}$$

$$\dot{E}_{\mathrm{c}} = 0 \ \text{(MJ)} \tag{16e}$$

$$\dot{E}_{\mathrm{d}} = 80843 + 119\,\mathrm{T}_0 \qquad (\text{MJ}, \mathrm{T}_0(\text{K})) \tag{16f}$$

$$T_0 = 12 + 6\sin[(2\pi/24)t] \quad (^{\circ}\text{C})(\text{for a day}) \tag{16g}$$

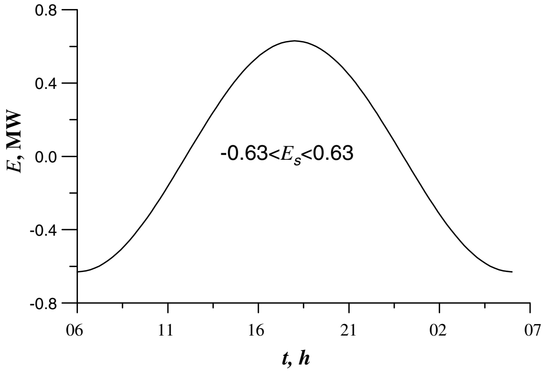

Fig. 6. Variation of E_s for EAF within a day.

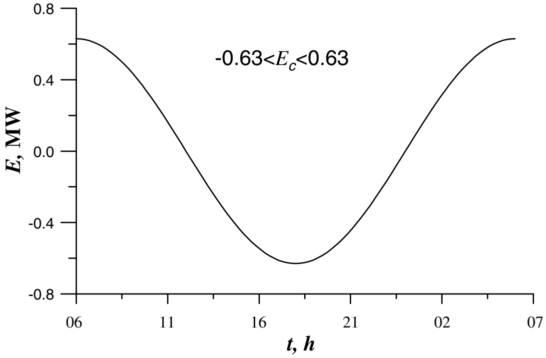

Fig. 7. Variation of E_c for EAF within a day.

These equations vs. time for a day are depicted in Figs. 9 and 10.

4. DISCUSSION

4.1. Electric Arc Furnace (EAF)

The values of exergies for EAF are given below when the ambient temperature is constant, which is reference environment temperature $T_0 = 25°C = 298\,K$: $E_w = 38402\,MJ$, $E_f = 25253\,MJ$, $E_q = 12823\,MJ$, $E_L = 325.6\,MJ$, $E_s = 0$, $E_c = 0$.

In Fig. 3 the typical variation of ambient temperature between 18 and 30°C is shown. Corresponding exergy values are depicted in Fig. 4. The exergy values are fluctuating between $37722\,MJ \leqslant E_w \leqslant 39354\,MJ$, $24633\,MJ \leqslant E_f \leqslant 26121\,MJ$, $12765\,MJ \leqslant E_q \leqslant 12905\,MJ$, as shown in this

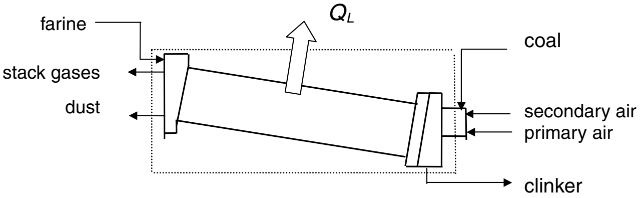

Fig. 8. Materials going into and out from RB.

figure. The variation of lost exergy for the EAF is depicted in Fig. 5. The exergy loss is varying between 324 and 328 MW during the 24 h cycle. As expected, the loss term is inversely proportional to ambient temperature. Taking industrial applications into consideration, the maximum reversible work (exergy of work) given to EAF is 39354 MJ whereas the minimum reversible work (exergy of work) is 37722 MJ. The difference between them is 1632 MJ per casting. The variations of E_S and E_C are depicted in Figs. 6 and 7, respectively.

4.2. Rotary Burner (RB)

Schematically a rotary burner is shown in Fig. 8. Materials entering and exiting the process are shown in this figure. The values of exergies for EAF are given below when the ambient temperature is constant, which is a reference standard environment temperature $T_0 = 25°C = 298\,K$: $E_q = 41201\,MJ$, $E_f = 157506\,MJ$ and $E_d = 116305\,MJ$.

Table IV. Mass Balance of RB

Materials	($kg{\cdot}h^{-1}$)
Materials Entering RB	
Farine	120540
Coal	10250
Air (primary and secondary)	243049
Total	373839
Materials Exiting RB	
Clinker	93000
Dust	8578
Stack gases	47497
Waste air	224764
Total	373839

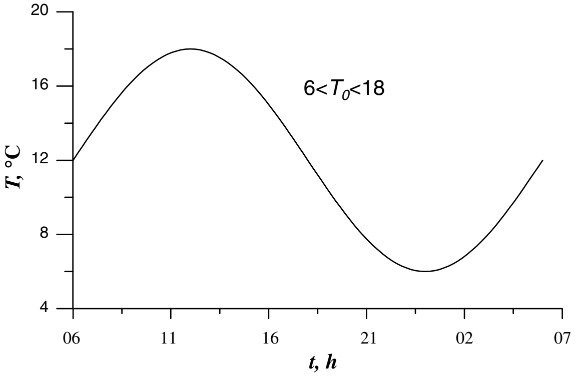

Fig. 9. Variation of the ambient temperature of the RB within a day.

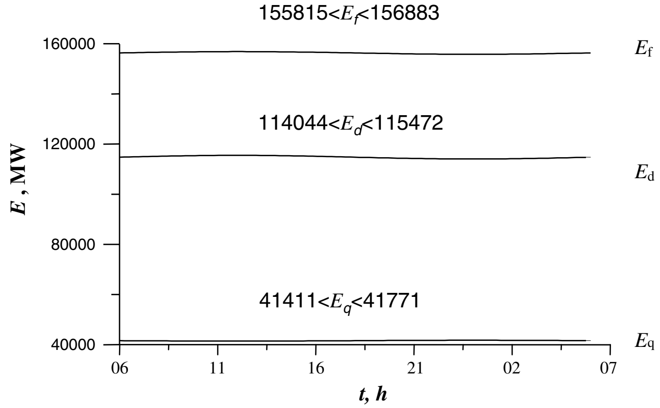

Fig. 10. Variations of E_f, E_d, and E_q for RB within a day.

In Fig. 9, the typical variation of ambient temperature between 6 and 18°C is shown. Corresponding exergy values are depicted in Fig. 10. As can be seen from this figure the exergy values are varying between the limits shown below: $155815\,\text{MJ} \leqslant E_f \leqslant 156883\,\text{MJ}$, $114044\,\text{MJ} \leqslant E_d \leqslant 115472\,\text{MJ}$, $41411\,\text{MJ} \leqslant E_q \leqslant 41771\,\text{MJ}$.

The maximum exergy destruction value for 1 h production at RB is 115472 MJ and the minimum exergy value is 114044 MJ. The difference between them is 1428 MJ. As the ambient temperature of RB increases, $\dot{E}_q$ decreases. In contrast, when the temperature decreases, the exergy value increases. Both $\dot{E}_f$ and $\dot{E}_d$ increase with increasing temperatures. Indeed, assuming the inlet and outlet conditions of the system are constant, as the

NOMENCLATURE

a, b, c	constants of $\bar{c_p}$
$\bar{c_p}$	constant pressure specific heat (kcal·kmol^{-1}·K^{-1}; kJ·kmol^{-1}·K^{-1})
E	exergy (MJ)
E_c	correction of system exergy (MJ)
E_d	exergy destruction (MJ)
E_f	flow exergy (MJ)
E_L	loss exergy (MJ)
E_q	exergy of heat (MJ)
E_s	exergy of system (MJ)
E_w	exergy or work (MJ)
EAF	electric arc furnace
e	specific exergy (kJ·kg^{-1})
g	Gibbs function (kJ·kg^{-1})
h	enthalpy (kJ·kg^{-1})
m	mass (kg)
N	mumber of kmol
P_0	ambient pressure (kPa)
Q	heat (kJ)
RB	rotary burner
s	entropy (kJ·kg^{-1}·K^{-1})
T	temperature (°C, K)
t	time (h)
T_0	ambient temperature (°C, K)
W	work (kJ)
μ	chemical potential (kJ·kmole^{-1})

ambient temperature increases, the exergy of the materials entering and exiting RB decreases. The difference between them ($\dot{E}_d$) increases. Therefore, if the total capacities of iron–steel and cement plants are considered, the importance of precise predictions is clear. The ambient temperature is a variable which affects the system exergy as shown in this work.

5. CONCLUSION

The main objective of exergy analysis is to detect and evaluate the causes of the thermodynamic inefficiencies in thermal and chemical processes. Exergy analysis gives us clues for improving system performance. This potential is proportional to the ambient temperature. So, the effects of fluctuating ambient temperature on system exergy are determined and the obtained results are analyzed and discussed for two separate industrial applications.

Subscripts

a	amplitude
f	flow
cmb	chromium-magnesite bricks
d	destruction
e	exit
c	correction term for system
f	flow
fb	fire bricks
i	inlet or *i*th component
L	loss
q	relating with heat
m	mean
ms	magnesite stamp
s	system
ss	steel sheet
t	total
gen	generation
0	properties at ambient conditions
00	standard state including chemical equilibrium
w	relating with work

Superscripts

CH	chemical
TM	thermo mechanical
.	rate of change of property
-	molar property

REFERENCES

1. A. Sergio and I. Jose, *Energy* **15**:1023 (1990).
2. Y. Göğüş and Ö. E. Ataer, in *Thermodynamic Optimization of Complex Energy Systems*, A. Bejan and E. Mamut, eds.,(Kluwer Academic Publishers, Dordtrecht, Netherlands, 1999), pp. 231–240.
3. Ü. Çamdalı, *Turk. J. Eng. Environ. Sci.* **25**:537 (2001) [in Turkish].
4. Y. Göğüş, Ö. E. Ataer, and A.İleri, in *Proc. Energy Systems and Ecology Conf. (ENSEC '93)*, G. Tsatsaronis, J. S. Szargut, Z. Kolenda, and Z. Ziebik, eds. (Cracow 1993), pp. 857–866.
5. Y. Göğüş and Ü. Çamdalı, *J. Therm. Sci Techno.*, **21**:33 (2001) [in Turkish].
6. J. Szargut, D. R. Morris, and F. R. Steward, *Exergy Analysis of Thermal, Chemical and Metallurgical Process* (Hemisphere, New York, 1976), pp. 7–71.
7. Y. Göğüş and Ö. E. Ataer, in *Advanced Thermodynamic Analysis of Complex Systems*, A. Bejan, ed. (Kluwer, New York, 1999), pp. 231–240.
8. Y. Göğüş and Ü. Çamdalı, in *Proc. Energy Systems and Ecology Conf.* (ECOS) (2000), pp. 1117–1130.
9. Y. Göğüş, Ü. Çamdalı, and M. Ş. Kavsaoğlu, *Energy* **27**:625 (2002).

10. V. M. Brodyanskii and N. V. Kalinin, Inzhenerno-Fizicheskii Zhurnal, (1966) [in Russian]; in *The Exergy Method of Energy Systems Analysis*, B. App and J. E. Ahern, eds. (John Wiley, New York, 1980) [Eng. Trans].
11. Ü. Çamdalı and M. Tunç, *Appl. Therm. Eng*. **23**:2255 (2003).
12. Ü. Çamdalı, F. Çelen, and A. Erişen, *Thermodyn. J*. **88**:71 (1999) [in Turkish].
13. Ü. Çamdalı, M. Tunç, and A. Karakaş, *Energy Convers. Manage*. **44**:961 (2003).
14. O. Kubaschewski, E. L. Evans, and C. B. Alcock, *Metallurgical Thermo-Chemistry* (Pergamon Press, New York, 1967), pp. 268–356.