JESTECH, 15(2), 77-83, (2012)

JESTECH

OPTIMUM CHARGING MATERIALS FOR ELECTRIC ARC FURNACE (EAF) AND LADLE FURNACE (LF) SYSTEM: A SAMPLE CASE

Yasar Yetisken[*], **Unal Camdali**[**] **and Ismail Ekmekci**[***]
[*]Karabük University, Engineering Faculty, Mechanical Engineering Department, Karabuk, Turkey
[**]Abant Izzet Baysal University, Engineering and Architecture Faculty, Mechanical Engineering Department, Golkoy Campus, Bolu, Turkey
[***]Istanbul Commerce University Faculty of Engineering and Design, Istanbul, Turkey

Abstract

In this study, the thermo-economic optimization is accomplished on a steel production plant depending on the electric arc furnace (EAF) and ladle furnace (LF) used in a firm in Turkey. EAF and LF are taken as a system and mass balance is made by using literatures and firm catalogs. Cost functions based on energy and exergy were made for optimization.

Keywords: Electric arc furnace (EAF), ladle furnace (LF), exergy optimization, steel making

Notation

C_{ELT}	Cost of electricity (=0.057 $/kWh)
C_{ex}	Cost in exergy base ($)
E	Reaction energy (kJ/kg)
EAF	Electric arc furnace
E_{x-R}	Reaction exergy (kJ)
LF	Ladle furnace
m	Mass (kg)
MKE	Mechanical and Chemical Industry Corporation in Turkey

Subscript

AL	Aluminum
Al_2O_3	Aluminum oxide
AR	Argon
CAR	Carbon
COK	Coke
CW	Cooling water
DEOX	Deoxidization material
DKP	Scrap (scrap type used in the firm)
e	Energy
ex	Exergy
ELD	Electrodes
ELD(EAF)	Electrode for EAF
ELD(LF)	Electrode for LF
ELT	Electric
FBO	Ferro boron
FCR-HC	Ferro chrome with high carbon
FCR-LC	Ferro Chrome with low carbon
FLS	Fluspat
FLX	Fluxes

Corresponded Author; camdali_u@ibu.edu.tr

FMN	Ferro manganese
FMO	Ferro molybdenum
FSI	Ferro silica
HMS	Heavy melting scraps
LIM	Lime
MGO	Magnesium oxide
MMN	Metalic manganese
NG	Natural gas
NI	Nickel
OXY	Oxygen
PIG	Pig iron
PW	Production waste scraps
SFMN	Silica ferro manganese
SS	Scrap shredder
SULP	Sulphur

1. Introduction

In Turkey, approximately 70% of total steel are produced by EAF. This presents that about 20 million tones steel are produced by EAF method [1].

Using scrap steel as a raw material at the EAF steel production processes is the main advantage of EAF+LF system and due to this fact EAF production method is preferred to other steel production methods worldwide and also in Turkey. Because of this reason, steel production amounts by using EAF have also been increasing recently in Turkey. One of the important reasons for the increase of EAF steel production ratio is that the investment cost for each ton of raw steel production capacity for EAF processes is much lower than that of other steel production methods likely integrated production facilities [2].

Optimization techniques applied for EAF are available in the literature [3,4]. First paper gives a new strategy to control the elements of oxidation as well as to increase the oxygen efficiency. Second paper presents actions aiming at indicating the optimal demand for electric energy in the process of steel production in EAF [5].

2. Steel Making By EAF and LF

A real steel-making process involves many complex physical and chemical coupled phenomena such as oxidation, decarburization, dephosphorization, and slag formation [2]. Before the melting and heating operations start, the furnace is charged with recycled steel scrap using a scrap basket that has been carefully loaded at the scrap yard. After scrap charging, the roof is closed and the electrodes can be lowered towards the scrap within the furnace using a specific regulator and mechanical drive for each electrode. The electrodes are connected to the furnace transformers [6]. The electrical power is switched on and on contact electrical power is transformed into heat as arcing takes place between the electrodes and the solid feedstock. After about 80-90 minutes, the temperature is raised to about 1600°C, then the molten steel is tapped into the ladle and transferred to the ladle furnace (LF) [2,3,7,8].

LF process is often used for the secondary refining of alloy steel. In the steel-making processes strong heat fluxes can be offered at LF furnace then it permits to add desired amount of different kinds of alloy elements and also precise temperature controlling can be enabled. It also provides outstanding desulfurization with the treatment at high temperature by reducing fluxes and the removing deoxidation products [9].
Secondary steelmaking has become an integral feature of modern steel plants and continuous casting process can be succeeded with this very advantageous feature of EAF+LF process and required more stringent quality control can be enabled.

As known, the production of steel with a desired composition can be accomplished with many chemical reactions between materials charged into the furnace and elements and compounds forming the liquid steel in the LF. For this reason, a mass analysis must first be made. For this analysis the mass amounts of each raw and semi raw material ingoing to the LF and of each material outgoing from the LF, is determined for a casting capacity of 55 tons [7,9].

3. Cost Analysis of the Materials

Cost amounts of the materials are given in Tables 1 and 2 for April 2003. These amounts were obtained from MKE as well as from market and the purchasing contracts of the firm as well as.

Table 1. Prices of inlet and outlet materials of EAF

Inlet to EAF	**Mass Amount (ton)**	**Mass Amount (ton) (for 1ton liquid steels**	**Mass Amount (kg) (for 1ton liquid steels)**	**Unit Price ($/ton)**	**Price (for 1 ton liquid steels) ($/ton)**	**Total Price ($)**
Scrap (production waste)	17.500	0.318	318.182	111.000	35.318	1942.500
Scrap (heavy melting scraps)	10.000	0.182	181.818	111.000	20.182	1110.000
Scrap (Shredder)	12.500	0.227	227.273	111.000	25.227	1387.500
Scrap (DKP)	10.000	0.182	181.818	111.000	20.182	1110.000
Pig iron	7.500	0.136	136.364	120.000	16.364	900.000
Coke	1.000	0.018	18.182	99.000	1.800	99.000
Lime	1.500	0.027	27.273	240.000	6.545	360.000
Limestone	1.000	0.018	18.182	30.400	0.553	30.400
Aldexo	0.200	0.004	3.636	896.000	3.258	179.200
Silica ferro manganese	0.350	0.006	6.364	470.000	2.991	164.500
Aluminum	0.050	0.001	0.909	1400.000	1.273	70.000
Electrode	0.150	0.003	2.727	1890.000	5.155	283.500
Natural gas	0.131	0.002	2.386	240.000	0.573	31.495
Oxygen(Net)	3.510	0.064	63.821	76.000	4.850	266.770
Cooling water	600.000	10.909	1,0909.091	0.300	3.273	180.000
Total	665.391	12.098	12,098.025	5,905.700	147.543	8114.864
Outlet From EAF	**Mass Amount (ton)**	**Mass Amount (ton) (For 1ton Liquid steels**	**Mass Amount (kg) (For 1ton Liquid steels)**	**Unit Price ($/ton)**	**Price For 1 ton liquid steel ($/ton)**	**Total Price ($)**
Liquid steel	55.000	1.000	1,000.000	157.000	157.000	8635.000
Steel in slag	0.300	0.005	5.455	0.000	0.000	0.000
Dusts	3.116	0.057	56.654	2.170	0.123	6.762
Slag	2.741	0.050	49.842	0.000	0.000	0.000
Stack gases	4.234	0.077	76.983	0.000	0.000	0.000
Cooling water	600.000	10.909	10,909.091	0.600	6.545	360.000
Total	665.391	12.098	12,098.025	159.770	163.668	9001.762

Note: Purchasing agreements at the firm for row and auxiliary materials. Prices are valid for April 2003.

Table 2. Prices of inlet and outlet materials of LF

Inlet to LF	**Mass Amount (ton)**	**Mass Amount (ton) (For 1ton Liquid steels**	**Mass Amount (kg) (For 1ton Liquid steels)**	**Unit Price ($/ton)**	**Price For 1 ton liquid steel ($/ton)**	**Total Price ($)**
Liquid steel from EAF	55.000	1.000	1000.000	157.000	157.000	8635.000
Ferro Manganese	0.800	0.015	14.545	470.000	6.836	376.000
Ferro Silica	0.120	0.002	2.182	419.000	0.914	50.280
Aluminum	0.050	0.001	0.909	1400.000	1.273	70.000
Ferro Boron	0.010	0.000	0.182	1290.000	0.235	12.900
Carbon	0.150	0.003	2.727	96.000	0.262	14.400
Lime	0.350	0.006	6.364	240.000	1.527	84.000
Fluspat	0.030	0.001	0.545	92.000	0.050	2.760
Magnesium oxide	0.100	0.002	1.818	160.000	0.291	16.000
Al_2O_3	0.100	0.002	1.818	0.400	0.001	0.040
Electrode	0.030	0.001	0.545	1890.000	1.031	56.700
Argon	6.600	0.120	120.000	375.000	45.000	2475.000
Oxygen (Net)	0.677	0.012	12.300	76.000	0.935	51.414
Total	64.017	1.164	1163.936	6665.400	215.354	11844.494
Outlet From LF	**Mass Amount (ton)**	**Mass Amount (ton) (For 1ton Liquid steels**	**Mass Amount (kg) (For 1ton Liquid steels)**	**Unit Price ($/ton)**	**Price For 1 ton liquid steel ($/ton)**	**Total Price ($)**
Liquid steel	55.000	1.000	1000.000	157.000	157.000	8635.000
Dusts	1.216	0.022	22.109	2.000	0.044	2.432

Slag	0.869	0.016	15.793	0.000	0.000	0.000
Stack gases	0.332	0.006	6.035	0.000	0.000	0.000
Argon	6.600	0.120	120.000	375.000	45.000	2475.000
Total	64.017	1.164	1163.936	534.000	202.044	11112.432

Note: Purchasing agreements at the firm for row and auxiliary materials. Prices are valid for April 2003.

4. Determination of Thermo-Economic Cost Function In Exergy Base

The total cost function for EAF and LF can be written as follows by taking into consideration all the materials and exergy of chemical energy. So, the cost function for the EAF and LF system as seen in Fig. 1 depending on exergies for every materials and energies can be written as follows in Eq. (1).

$$C_{ex}= C_{ex\text{-}PW} * m_{PW} + C_{ex\text{-}HMS} * m_{HMS} + C_{ex\text{-}SS} * m_{SS} + C_{ex\text{-}DKP} * m_{DKP} + C_{ex\text{-}PIG} * m_{PIG} + C_{e\,x\text{-}COK} * m_{COK} + C_{e\,x\text{-}FLX} * m_{FLX} + C_{ex\text{-}DEOX} * m_{DEOX} + C_{ex\text{-}ELD(EAF)} * m_{ELD(EAF)} + C_{ex\text{-}NG} * m_{NG} + C_{ex\text{-}OXY} * m_{OXY} + C_{ex\text{-}CW} * m_{CW} + C_{ex\text{-}FMN} * m_{FMN} + C_{ex\text{-}MMN} * m_{MMN} + C_{ex\text{-}SFMN} * m_{SFMN} + C_{ex\text{-}FSI} * m_{FSI} + C_{ex\text{-}FCR\text{-}HC} * m_{FCR\text{-}HC} + C_{ex\text{-}FCR\text{-}LC} * m_{FCR\text{-}LC} + C_{ex\text{-}FMO} * m_{FMO} + C_{ex\text{-}NI} * m_{NI} + C_{ex\text{-}AL} * m_{AL} + C_{ex\text{-}FBO} * m_{FBO} + C_{ex\text{-}SULP} * m_{SULP} + C_{ex\text{-}CAR} * m_{CAR} + C_{ex\text{-}LIM} * m_{LIM} + C_{ex\text{-}FLS} * m_{FLS} + C_{ex\text{-}MGO} * m_{MGO} + C_{ex\text{-}Al2O3} * m_{Al2O3} + C_{ex\text{-}ELD(LF)} * m_{ELD(LF)} + C_{ex\text{-}ELT} *(E_{ELT}^{EAF} + E_{ELT}^{LF}) + C_{ex\text{-}AR} * m_{AR} - (E_{x\text{-}R1} + E_{x\text{-}R2} + E_{x\text{-}R3} + E_{x\text{-}R4} + E_{x\text{-}R\text{-}5} + E_{x\text{-}R6} + E_{x\text{-}R7} + E_{x\text{-}R8} + E_{x\text{-}R9} + E_{x\text{-}R10} + E_{x\text{-}R11} + E_{x\text{-}R12} + E_{x\text{-}R13}) *(1/3600)* C_{ex\text{-}ELT} \quad (1)$$

Where, 1/3600 is a coefficient to transform kJ into kWh.

C_{ex} and m are obtained by using Tables 1 and 2 for materials for EAF and LF system. $E_{x\text{-}R1}$… $E_{x\text{-}R13}$ represent the exergy by exothermic and endothermic chemical reactions occurred into the system [10].

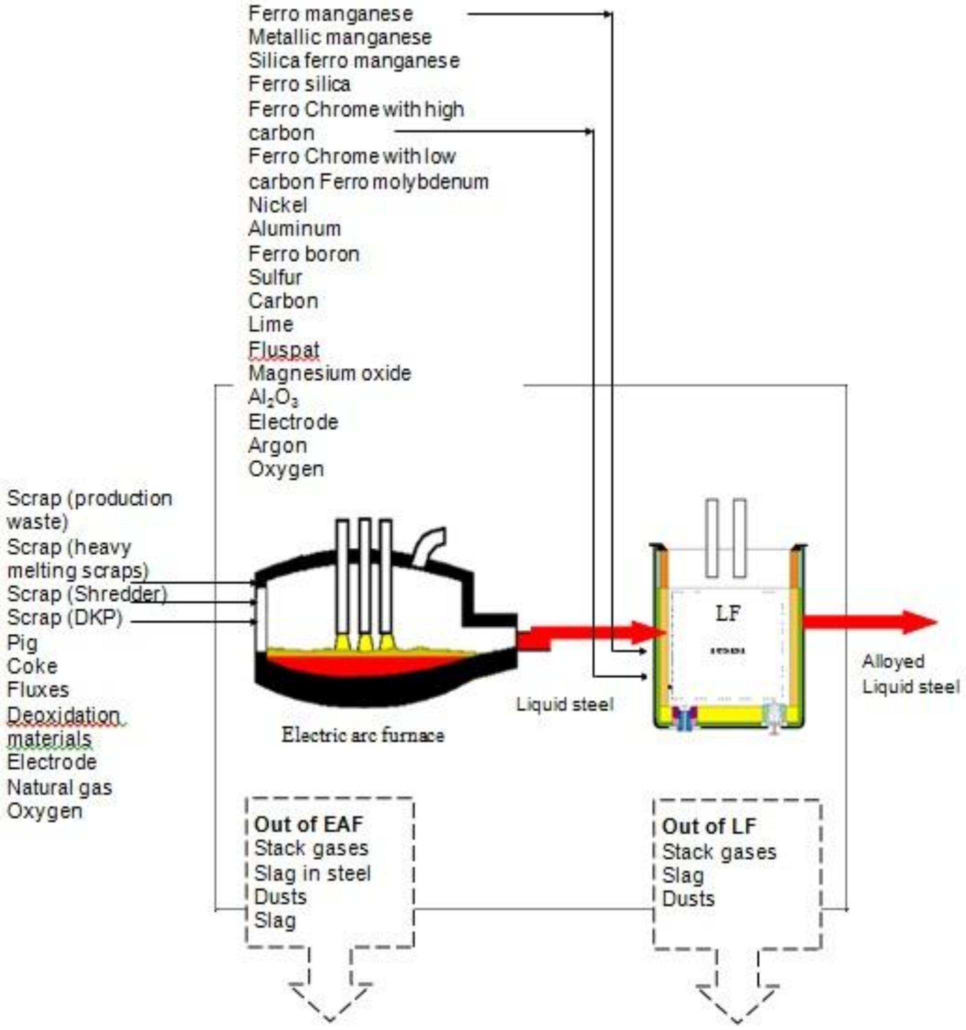

Figure 1. Inlet and outlet materials for the EAF and LF [2,10]

4.1. Objective Function in Exergy Base

Objective function depending on mass in exergy base used in the system can be written by the following equation:

$$
\begin{aligned}
C_{ex} = \quad & (0.1007718) * m_{PW} + (0.101466) \; *m_{HMS} + (0.104835) *m_{SS} \\
& + (0.1046802) *m_{DKP} + (0.093624) *m_{PIG} + (-0.237088)*m_{COK} \\
& + (0.253121) \; *m_{FLX} + (0.302449) \; *m_{DEOX} + (-0.385005)*m_{ELD(EAF)} \\
& + 0.24 *m_{NG} + 0.076 *m_{OXY} + 0.0003*m_{CW} + (0.372668) *m_{FMN} \\
& + (0.727801) *m_{MMN} + (0.279963)*m_{SFMN} + (-0.17901) \; *m_{FSI} \\
& + (0.911897)*m_{FCR\text{-}HC} + (0.93731)*m_{FCR\text{-}LC} + (0.457507)*m_{FMO} \\
& + (8.899619)*m_{NI} + (0.557062)*m_{AL} + (1.24504)*m_{FBO} \\
& + (0.12108) \; *m_{SULP} + (-0.27819) *m_{CAR} + (0.03)*m_{LIM} \\
& + (0.095087)*m_{FLS} + (0.16) *m_{MGO} + (0.4)*m_{Al2O3} \\
& + (-0.385005)*m_{ELD(LF)} + (0.057)* E_{ELT}^{EAF} + (0.057)* E_{ELT}^{LF} + 0.375*m_{AR}
\end{aligned}
\tag{2}
$$

5. Solution of The Modelling by Linear Programing Method

We used the linear programming method in order to solve the Eq. (3). Linear programming is an optimization method applicable where both the objective function and the constraints can be expressed as linear combinations of the variables [11,12]. The objective function F is the sum of multiplications of C_n (constant) and X_n (decision variables) as expressed by the following formula:

$$F=C_1X_1 + C_2X_2 + ...+ C_nX_n \tag{3}$$

The next step is to determine the constraints. The general formula for constraints is as follows:

$$A_{i1}X_1 + A_{i2}X_2 + \ldots + A_{in}X_n \leq, =, \geq B_i, \; i= 1, 2,\ldots, n \tag{4}$$

Where, A_{in} and B_i are given constants and X_n are the decision variables. The values of A may be positive, negative, or zero whereas B is always positive in our study.
In order to form cost function for EAF and LF system as seen in Fig. 1, we consider the costs of materials and energies which are going in and leaving the system [5].

5.1. Constraint Functions for some Steels Productions

In order to solve optimization problem, maximum and minimum amounts are defined by using computer program. There are 33 variables for optimization problem. Objective functions and constraints for types of steels are given in detail in [10].

6. Results

Physical and chemical properties of scraps and the auxiliary materials affect the chemical properties, energy requirement and production time of the liquid steel produced both EAF and LF.

Optimum values of materials entering the system and electric energies for EAF and LF are taken by running the WINQSB optimization program. The results are given in Table 3. In this study, there is considered two types of steel which are coded as 25CrMo4-1.7218 and 38Cr2-1.7003 in the firm. This study is suitable to extend the other types of steel.

Table 3. Optimum values obtained after running program for steel types

Raw materials going into system	**Unit**	**25CrMo4 1.7218**	**38Cr2 1.7003**
Production waste	Kg	55000	909.74
HMS Scraps	Kg	0	20664.75
Shredder Scraps	Kg	0	0
DKP Scraps	Kg	0	0
Pig	Kg	0	33425.51

Coke	Kg	1000	1000
Fluxes	Kg	0	0
Deoxidation	Kg	0	0
Electrode (EAF)	Kg	150	150
Natural gas	Kg	121	121
Oxygen	Kg	4000	4000
Cooling Water	Kg	590000	590000
Ferro Manganese	Kg	0	0
Metallic Manganese	Kg	0	0
Silica Ferro Manganese	Kg	412.35	131.09
Ferro Silica	Kg	120	120
Ferro Chrome with high carbon	Kg	99.31	0
Ferro Chrome with low carbon	Kg	160	0
Ferro Molybdenum	Kg	0	0
Nickel	Kg	0	0
Aluminum	Kg	95	95
Ferro Boron	Kg	9	9
Sulphur	Kg	0	0
Carbon	Kg	150	150
Lime	Kg	1750	1750
Fluspat	Kg	28	28
Magnesium Oxide	Kg	95	95
Al_2O_3	Kg	95	95
Electrode (LF)	Kg	30	30
Electric (EAF)	kWh	22000	22000
Electric (LF)	kWh	7250	7250
Argon	Kg	6500	6500
Liquid Steel	Kg	52460.53	51618.09

7. Conclusion

Iron and steel industry as one of the main sectors is an intensive energy using sector for many countries. So, firstly system process parameters can be changed and new technologies can be used in order to save energy. Thus, it is aimed that secondary energy can be saved by optimization applying new technology and process parameters.

Alloying steel demand and consumption are on the rise in developing and developed countries. This causes the increasing of prices of raw and auxiliary materials of EAF and energy. All of the these issues lead to the decreasing the production duration and increasing production speed naturally by using new methods such as optimization and new techniques.

References

1. Tunc, M., Camdali, U. and Arasil, G., Mass analysis of an electric arc furnace (EAF) at a steel company in Turkey, *Submitted an Int. J.*
2. Ekmekci, I., Yetisken, Y. and Camdali; U., Mass Balance Modeling for Electric Arc Furnace and Ladle Furnace System in Steelmaking Facility in Turkey, Iron and Steel Res, Int., **14**(5), 1-6, 55, 2007.
3. Risonarta, V.Y., Voj, L., Pfeifer, H., et al., Optimization of electric arc furnace process at Deutsche Edelstahlwerke, *Archives of Metallurgy and Materials*, **53**(2), 551-557, 2008.
4. Czapla, M; Karbowniczek, M; Michaliszyn, A The optimisation of electric energy consumption in the electric arc furnace, *Archives of Metallurgy and Materials*, **53**(2), 559-565, 2008.
5. Camdali, U., Yetisken, Y. and Ekmekci, I., Determination of the Optimum Cost Function for an Electric Arc Furnace and Ladle Furnace System by Using Energy Balance, Energy Sources, Part B, (in Press).
6. Hocine, L., et al., Improvement of electrical arc furnace operation with an appropriate model, Energy, 34, 1207–1214, 2009.

7. Camdali, U. and Tunc, M., Computer Aided Mass Balance Analysis for AC Electric Arc Furnace, *Journal of Iron and Steel Research*, 12(3), 11-13, 2005.
8. Araslı, G. and Özdemir, M., Electric Arc Furnace System Analysis, Bachelor Thesis, Yeditepe University, System Engineering Department, 2010.
9. Camdali, U., Tunc, M and Karakas, A. Second law analysis of thermodynamics in the electric arc furnace at a steel producing company. Energy Convers Manage, 44, 961–73, 2003.
10. Yetisken, Y., Thermo-economic Optimization of a Steel Producing Facility, PhD Thesis, Sakarya University Institute of Science and Technology, 2005 (in Turkish).
11. Kuester J.L. and Mize J.H., Optimization Techniques with Fortran. Mc Graw-Hill Book Company, 1973.
12. Stoecker, W.F., Design of Thermal Systems, Third edition, McGraw-Hill Inc., 1989.