Chemical and Process Engineering Research
ISSN 2224-7467 (Paper) ISSN 2225-0913 (Online)
Vol.28, 2014

Process Modeling of Steel refining in Electric Arc Furnace (EAF) for Optimum Performance and Waste Reduction

Aduloju Sunday Christopher*, Ebhota Williams Saturday, Bolarinwa Gabriel Oladeji, Owolabi Oluwasegun Biodun

National Engineering Design Development Institute, PMB 5082, Nnewi, Nigeria.

* E-mail of the corresponding author: chrisaduloju@yahoo.com

Abstract

Studies were carried out on the charge material and energy required by an EAF for production of liquid steel using Heuristic method. Process modeling of the Steel refining operation was performed. The results from the material balance and Energy balance shows 13.38% reduction in the charge materials and 7.38% reduction in the energy required for the furnace steel refining process for a furnace rated for production of 30 tons of liquid steel.

1.0 Introduction

An EAF is a furnace that heats charged material by means of an electric arc. Arc furnaces range in size from small units of approximately one ton capacity used in foundries for producing cast iron products up to about 400 ton units used for secondary steelmaking. Industrial EAF temperatures can be up to 1,800 ℃ (3,272 ℉), while laboratory units can exceed 3,000 ℃ (5,432 ℉). Arc furnaces differ from induction furnaces in that the charge material is directly exposed to an electric arc, and the current in the furnace terminals passes through the charged material [1].

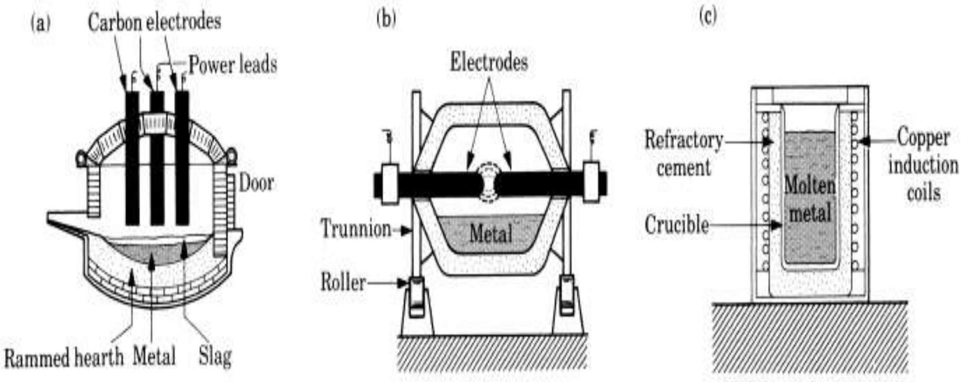
First some history of the direct-arc electric-furnace; Dr. Paul Heroult developed and patented the first AC direct-arc electric-furnace in the late 1800's. Aside from various innovations, developments and refinements in the design of the furnace components, the basic design principle remains the same as it was originally developed and patented. The primary concept for the furnace developed by Dr. Heroult involved the use of two or more electrodes, with the electric current passing from one electrode through an arc to the charge, then flowing through the charge and passing through an arc to the other electrode or electrodes. Accordingly, this type of furnace is often referred to as the "Heroult" type [2].

The steel manufacturing in electric arc furnaces accelerated during the 1930 and 1999 were 33 % of the world production of raw steel produced in EAF. Depending on access to raw material, energy and technical development the scrap based metallurgy vary between different parts of the world. The amount of raw steel produced in EAF increases yearly by 4-5 % and is believed to be about 400 million ton 2005 and answer for more than 50 % of raw steel production 2010. The increase of minimills both in developing countries and the industrialised world contribute to the substantial increase together with investments in the existing steel industry. The cost of investment in electric arc furnaces technique is considerable smaller than for ore-based steel manufacturing.

The Today's EAF

Today's Electric arc furnaces may be categorised into three as direct arc EAF, indirect arc EAF and induction EAF as shown in figure 1. All types of units are suited for the melting of high melting point alloys such as steels and they may be lined with acid or basic refractories. The ordinary EAF consists of a cylindrical furnace room with basic lining [3].

It was believed that it would be better from an economical point of view with a DC furnace. A comparison of electrode use between AC and DC furnaces shows that the DC furnace uses 1-1.5 kg/ton steel and the AC furnace 2-3 kg/ton steel (even in some cases lower than 2 kg/ton steel). The difference in the cost of electrodes decreases because AC furnaces use electrodes 600 mm in diameter while DC furnaces use electrodes with 700-750 mm in diameter, which is about 20 % more expensive. The DC furnaces have higher costs for construction and maintenance work since it uses a bottom electrode; this is however in some way compensated by lower cost of electrode material. Both the inner and outer environment is affected by the sound level, when charging and when the power is on the furnace. A DC furnace gives 50-60 % less noise than an AC furnace, but different construction can decrease the difference [5].



a) b) c)

Figure 1: Classification of EAF: a) Direct EAF; b) Indirect EAF; c) Induction EAF

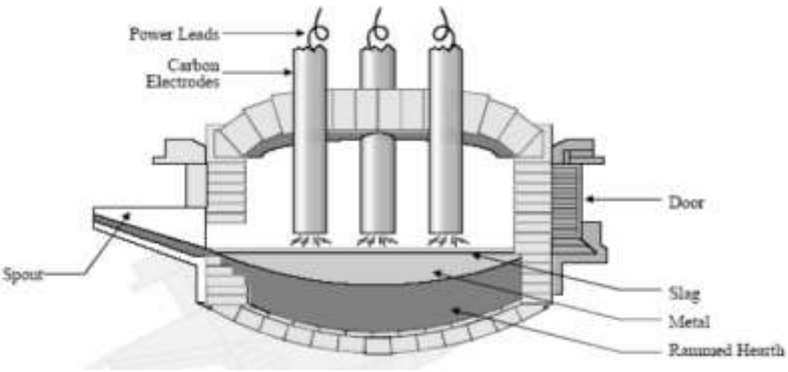


Figure 2: AC EAF with 3 Electrodes

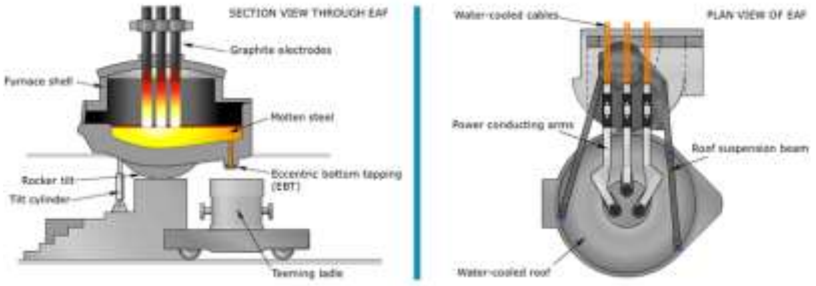


Figure 3: Schematic Diagram of EAF

It was believed that it would be better from an economical point of view with a DC furnace. A comparison of electrode use between AC and DC furnaces shows that the DC furnace uses 1-1.5 kg/ton steel and the AC furnace 2-3 kg/ton steel (even in some cases lower than 2 kg/ton steel). The difference in the cost of electrodes decreases because AC furnaces use electrodes 600 mm in diameter while DC furnaces use electrodes with 700-750 mm in diameter, which is about 20 % more expensive. The DC furnaces have higher costs for construction and maintenance work since it uses a bottom electrode; this is however in some way compensated by lower cost of electrode material.

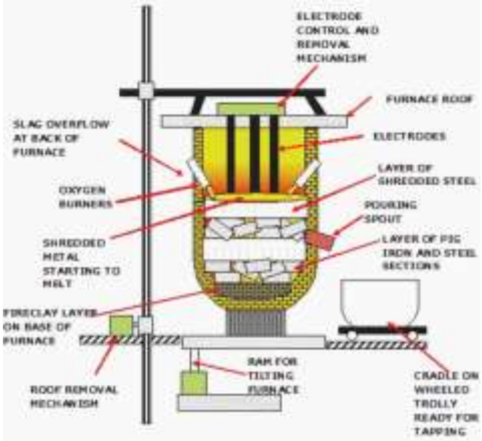


Figure 4: Electric Arc Furnace Design Operation and Working Principle.

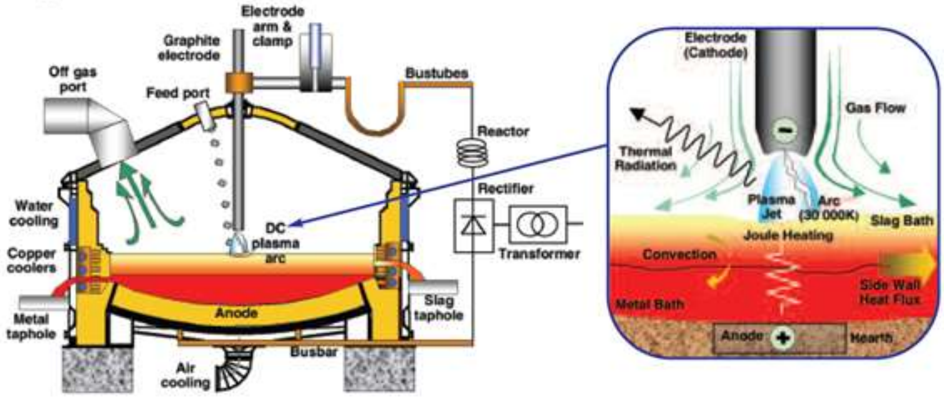


Figure 5: A Typical Schematic of a DC Arc Furnace

Both the inner and outer environment is affected by the sound level, when charging and when the power is on the furnace. A DC furnace gives 50-60 % less noise than an AC furnace, but different construction can decrease the difference [5].

The arc in an EAF is created in similar way as in arc-welding with one electrode. In arc-welding an electric current is passed through an electrode, which is brought close to the metal surface. When they get contact they melt together and when the electrode slowly removes from the metal an arc occurs. The heat from the arc melts the electrode onto the surface of the metal being welded. When an electrode in an EAF gets in contact with the electric leading metal scrap, there will be a current in the circuit and when the electrode rises an arc occurs between the graphite electrode and the scrap. When the electrode has contact with the scrap the contact surface is heated. At high temperatures material is leaving the electrode in the form of charged ions [6].

The arc can be divided in three different parts:

- Cathode-area (negative charge), which is a spot on the cathode where the arc starts.
- Arc, which contains of a conducting plasma
- Anode-area (positive charge), where the arc ends.

In alternating current EAF (AC) the electrode and the scrap changes of being anode and cathode. In a direct current EAF (DC-furnace) is always the electrode cathode and the bottom of the furnace is anode. In a DC-furnace the bottom has to be a conductor.

The heat transfers are mainly radiation from the arc to the scrap. In some part heating radiation comes from the heated ends of the graphite electrodes to the scrap. A convective heat transfer comes also from the arc . The temperature in the middle of the arc is about between 10,000°C and 30,000°C .The melting in an EAF can be divided into 5 different events [7].

i. At start the furnace is filled with scrap and the electrodes have to work in the upper part of the furnace. The arcs are lighted and it is important to stabilize these and lover the points of the electrodes into the scrap.

ii. Relatively soon the electrodes are bored down in the scrap, until they are a bit from the bottom of the furnace. The furnace in now working at medium high effect.
iii. As the electrodes come closer to the bottom of the furnace a melt begins to form.
iv. During the main part of the melting the electrodes are working with the highest possible power. The sides of the furnace are protected by scrap and have water cooled panels. If more than one scrap bucket is charged the first steps is repeated.
v. When the main part of the scrap is melted and the temperature shall rise the power has to be reduced and the arc shortened to protect the furnace. During this time foaming slag can be used, which protects the walls and therefore use longer arc.

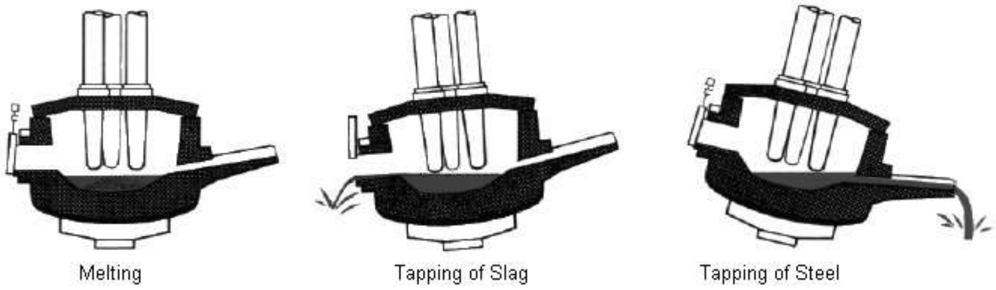


Figure 6. The furnace can be tilted to simplify tapping.

Stirring is of importance to equalize the temperature in the bath, especially in the peripheral parts of the bath. When continuous charging is used it is important to avoid lumps of not yet molten material. A DC-furnace will be electromagnetically stirred when the current is passing the bath, however this is sometime not enough, and other stirring is also used. The stirring can take place through gas injection by nozzles in the bottom of the furnace. An effective stirring is created if coal powder, (or fossil fuels) and oxygen is injected under the surface of the steel bath . Some furnaces are equipped with an inductive stirrer in the bottom of the furnace to for example make it easier tip the slag [8].The furnace can be tilted forwards and backwards to simplify the tapping of steel and slag, see Figure 6.

2.0 Existing Refining Method in the Plant

The furnace is rated for production of 30 tons of liquid steel. It has an inner diameter of 9.4m. the plant is designed for direct three phase connections of 30KV high voltage mains. The roof can be swung open to enhance charging of the scrap and for slag removal. Feeding of sponge non-pelet and removal of the slag is effected through the charging door opposite the spout the door is operated by an electric motor. Oxygen gas is lanced with pipe through the charging door into the melt. The roof with structure is designed to permit the water-cooled pipe nozzle required for fume extraction to be fitted For tapping and slag removal , the furnace shell is tilted hydraulically in the direction of the tapping spout or the slag door.

After tapping a heat, the roof is moved away , and the hearth is inspected and where necessary, repaired. An overhead crane then charges the furnace with scrap from a cylindrical bucket that is open on the top for loading and fitted with a drop bottom for quick discharging. Scrap buckets are loaded in such a manner as to assure a cushioning of heavy scraps when the load drops onto the hearth in order to obtain good electrical conductivity in the charge, low risk of the electrode breakage and good furnace wall protection during melt down. Coke and Slag formers are added to the charge to prevent over oxidation of the steel and to quicken slag formation. After charging one bucket, the roof is moved back to the furnace and the electrodes lowered.

Figure 7: The EAF used in the plant

After tapping a heat, the roof is moved away , and the hearth is inspected and where necessary, repaired. An overhead crane then charges the furnace with scrap from a cylindrical bucket that is open on the top for loading and fitted with a drop bottom for quick discharging. Scrap buckets are loaded in such a manner as to assure a cushioning of heavy scraps when the load drops onto the hearth in order to obtain good electrical conductivity in the charge, low risk of the electrode breakage and good furnace wall protection during melt down. Coke and Slag formers are added to the charge to prevent over oxidation of the steel and to quicken slag formation. After charging one bucket, the roof is moved back to the furnace and the electrodes lowered.

Melting begins with a low power setting until the electrodes have burned themselves into the light scrap on top of the charge, protecting the side walls from over heating during high-power melt down. Leaving some scraps un-melted at the furnace wall for its protection, a second bucket is charged and the same melt down procedure is followed.

After meltdown, the carbon level in the steel is about 0.25% above the final tap level , which prevents the oxidation of the melt. By this time a basic slag is formed , typically consisting of 55%Mn, 15% Silica and 15-20% iron oxide. Injection of the lime-coke mixture , which reacts with iron oxide in the slag to produce carbon monoxide gas, generates slag foaming. This foams shields the sidewalls and permits a higher power setting. If the carbon content in the steel is high , then oxygen lanced into the melt and if low , additional coke is added. Samples are taken, the temperature of the bath is checked and the result will determine whether additional heat energy needs to be supplied in order to achieve the required tapping temperature (1650-1700^{0}C) depending on the steel grade.

When all the required conditions have been achieved, the furnace is tapped by tilting it forward so that liquid flows over the spout onto an already prepared ladle. When slag appears, a quick back tilt is applied and the slag is poured through the charging door of the furnace into a slag pot. The total heat time is usually two-three hours depending on the steel grade. The data recorded for one heat operation is shown in Table 2

Table 2: The data recorded for one heat operation

Material/Energy	**Value**	**Unit**
Scrap	4.61	tons
DRI	21.82	tons
Liquid Steel in the furnace	1.82	tons
Lime	1.27	tons
FeMn	0.15	tons
FeSi	0.10	tons
Coke	0.01	tons
Volume of Oxygen Injected	130	Nm^{-2}
Total Material input	27.96	tons
Total energy Used		MWhr
Working Temperature	1650	^0C

3.0 Material balance

One of the major accomplishment of the theory of relativity is the formation of the principle that the total mass and energy of a system is conserved .The general conservation of any process system can be written as :

Material out= material in + Generation –Consumption –Accumulation

For a steady state process the accumulation term is Zero.

Material Out = Material in

The Simplification of the material balance problem leads to a system of linear equations , where each of the equation represents a stream. The number of the system of linear equation is a function of a number of streams. The model was built on a simultaneous solution strategy using Gaussian elimination method

$$\begin{pmatrix} a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n = b_1 \\ a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n = b_2 \\ \ldots \\ \ldots \\ a_{n1}x_1 + a_{n2}x_2 + \ldots + a_{nn}x_n = b_n \end{pmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

The equation can be represented in the matrix form or notation

$$A.\,x = b \quad \ldots\ldots\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \ldots 2$$

$$\begin{pmatrix} a_{11}, a_{12}, \ldots, a_{1n} \\ a_{21}, a_{22}, \ldots. a_{2n} \\ \ldots \\ \ldots \\ a_{n1}, a_{n2}, \ldots. a_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ . \\ . \\ x_n \end{pmatrix} = \begin{pmatrix} b_1 \\ b_2 \\ . \\ . \\ b_n \end{pmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Given n,a,b

Set a = a_{ij}, b = b_i, i.i=1(1)n …………………………………………………………………… …....4

For

r = 2, 3,……….,n

i = 1, 2,………..,n-1

k = i+1,………,n

Set $r, M_{ki} = \frac{r-1}{a_{ki}} \Big/ \frac{r-1}{a_{ii}}$ ……………………………………………………….………5

For j = i +1…….,n

Set $a_{ki}^{(r-1)} - M_{ki}^{(r-1)} a_{ij}$ ……………………………………………………………………6

$$r = b_1^{(r-1)} - M_{ki}^{(r-1)} b_i$$

By backward Substitution

$x_n = \frac{b_n^{(n)}}{a_{nn}}$ ……………………………………………………………….……… …....7

$x_i = \frac{b_1^{(n)} - \sum_{i=1}^{(n)} a_{ij} x_i}{a_{ii}^{(n)}}$ ………………………………………………………….… ...…..8

$$i = n - 1(-1)1$$

$$i \neq j$$

.

Table 2: The Actual composition of the charge

Composition Charge Material	Amount in Charge (Kg)			
	Mn	Si	C	P
Scrap (x_1)	156.71	322.81	77.32	1.55
DRI (x_2)	0.00	933.63	398.20	48.32
FeMn (x_3)	14497.50	0.00	0.00	0.00
FeSi (x_4)	0.00	14497.50	0.00	0.00

From the above algorithm , a matlab program was developed for the material balance of the electric arc furnace.

Material balance were done for furnace with Steel grade material of Nst 42/50 12 NIS 1990 for a targeted steel analysis of 0.42%C, 0.19%Si, 0.36%Mn, 0.01%P and 0.23%. The liquid steel tapped was 19330kg. The initial Input composition used for validating the model is show below:

FeMn: 25.00%Fe, 75.00%Mn

FeSi: 25.00%Fe, 75.00%Si

Scrap: 0.40%C, 1.6%Si,0.81%Mn,0.0085P and 0.006%S

DRI: 2.06%C, 4.83%Si,0.25%P and 0.1%S

Table 2 shows the actual composition of the charge and table 2 shows the amount of element in the melt

Table 3: The amount of the element in the melt

Element	Value	Unit
Manganese (Mn)	262.88	Kg
Silicon (Si)	36.72	Kg
Carbon	81.18	Kg
Phosphorus	1.93	Kg

4.0 Energy balance

The usefulness of thermochemistry cannot be overestimated in energy balance problems in metallurgical plants operation. Thermochemistry deals with heat transfer in volume in chemical reaction occurring irreversibly in calorimeters. Electric furnace is a good example and the first law of thermodynamics applies.

For a system to be steady from energy balance point of view, it is required that temperature and pressure at each point do not vary. An Electric furnace is an example of an unsteady state open system, however, for simplicity, it is assumed to be steady. For calculation purposes, we have selected an arbitrary reference value for energy of the system at 25^0C (278K) and $2*10^5$ to be equal to zero. The first law was used to calculate the final energy of the system at any other state in terms of heat and work required to reach that state. Thus,

$E_2 = E_1 + Q - W$ ……………………………………………………….……………………………………...9

Where E_2 = Final energy state of the system

E_1 = Initial energy state of the system

Q = Amount of heat transferred to the system

W = Work done by the system to the surrounding

When W= 0 , we have

$E_2 = E_1 + Q$ ………………………………………………………………..……..…………..………..…..10

The above equation is a practical equation upon which energy balance in EAFoperation is based. It is an illustration of an open system in which heat is supplied to the system.

Equation 10 can be evaluated using Hess's law and kirchoff's equation. We apply the Hess's law to find the energy of the system E_1 at standard states of 298K, while E_2 is finally determined as the energy of the furnace at working temperature by adding Q, which is determined using Kirchoff's equation. From Hess's law,

$E_1 = H_{298} = H_{f_{product}} - H_{f_{reactant}}$ ……………………………..…………………….....……….11

Where H_{298} = Enthalpy at standard state

H_f = Heat of formation

From Kirchoff's equation,

$Q = \int \Delta C_p dT$……………………………………………………………..…………………….....…12

Where ΔCp = Change in heat capacity

Then the change in Heat capacity can be expressed as

$\Delta C_p = C_{p_{product}} - C_{p_{reactant}}$ ……………………………………………………….……...…………13

Substituting the equations (10) and (11) into equation (10), we have

$E_2 = H_{298} + \int \Delta C_p dT$……………………………………………………………….………….………14

Equation (14) gives the energy content when there is no transformation. Where there transformation occurs in EAF equation 14 is modified as

$E_2 = \Delta H_{298} + \int_{T_1}^{T'} \Delta C_p I dT + \Delta L_f + \int_{T'}^{T''} \Delta C_p II dT + \Delta L_v + \int_{T''}^{T_2} \Delta C_p III dT$………………......15

Where ΔLf = Latent heat of fussion

ΔLv=Latent heat of vaporization

T' and T" = Melting and Boiling temperatures, such that $T_2 > T'' > T' > T_1$

ΔCp(I,II,III) = Heat capacities at the elevated temperatures

Table 4: Thermochemical Data [9]

Elements and Components	Heat of Formation ΔH_f at298K (KJ/mol)	Latent Heat of Fussion, L_f (KJ/mol)	Latent Heat of Vaporisation, L_v (KJ/mol)
Fe	0.00	14.952	35.532
O_2	0.00	0.00	0.00
C	0.00	16.20	0.00
Si	0.00	38.51	0.00
Mn	0.00	14.49	231.62
P	0.00	2.58	52.58
S	0.00	9.28	0.00
FeO	-271.40	0.00	0.00
CO	-110.97	0.00	0.00
SiO_2	-851.00	0.00	0.00
MnO	-386.57	0.00	0.00
P_2O_5	-1512.00	0.00	0.00
CaO	-637.14	0.00	0.00
CaS	-480.06	0.00	0.00

$< Fe > + {}^{1}/_{2}\,(O_2) \rightarrow < FeO >$ ……………………………………………………………………16

To calculate the ΔH at 1923, Kirchoff's equation is modified to :

$E_1 = \Delta H_{1923} = \Delta H_{298} + \int_{298}^{1041} \Delta C_p I dT + L_{f(Fe)} + \int_{1041}^{1179} \Delta C_p II dT + L_{v(Fe)} + \int_{1179}^{1923} \Delta C_p III dT$………....17

Where $\Delta H_{298} = H_{f<FeO>} - \{H_{f<Fe>} + {}^{1}/_{2}\, H_{f(O_2)}\}$

$\Delta C_p I = C_{p<FeO>} - \{C_{p<Fe\alpha>} + {}^{1}/_{2}\, C_{p(O_2)}\}$

$\Delta C_p II = C_{p<FeO>} - \{C_{p<Fe\beta>} + {}^{1}/_{2}\, C_{p(O_2)}\}$

$\Delta C_p III = C_{p<FeO>} - \{C_{p\{Fe\alpha\}} + {}^{1}/_{2}\, C_{p(O_2)}\}$

$< C > + {}^{1}/_{2}\,(O_2) \rightarrow (CO)$ ………………………………………………………………..…18

To calculate the ΔH at 1923K

$E_2 = \Delta H_{1923} = \Delta H_{298} + \int_{298}^{1200} \Delta C_p I dT + L_{f(C)} + \int_{1200}^{1373} \Delta C_p II dT + L_{v(C)} + \int_{1373}^{1923} \Delta C_p III dT$…..……...19

Where $\Delta H_{298} = H_{f(CO)} - \{H_{f<C>} + {}^{1}/_{2}\, H_{f(O_2)}\}$

$\Delta C_p I = C_{p(CO)} - \{C_{p<C>} + {}^{1}/_{2}\, C_{p(O_2)}\}$

$\Delta C_p II = C_{p(CO)} - \{C_{p\{C\}} + {}^{1}/_{2}\, C_{p(O_2)}\}$

$\Delta C_p III = C_{p(CO)} - \{C_{p(C)} + {}^{1}/_{2}\, C_{p(O_2)}\}$

$< Si > + (O_2) \rightarrow < SiO_2 >$ ……………………………………………………………….…20

Table 5: heat Capacities of elements and Compounds [9]

Element and Compounds	Heat capacity, Cp (Kg/mol)	Temperature Range (K)
<Feα>	$17.489 + 24.769 \times 10^{-3}T$	298 – 1041
<Feβ>	$26.610 + 6.276 \times 10^{-3}T$	1041 – 1179
{Fe}	$35.400 + 3.745 \times 10^{-3}T$	1179 – 1923
<FeO>	$51.798 + 6.778 \times 10^{-3}T – 1.590 \times 10^{5}T^{-2}$	298 – 1173
(O_2)	$29.957 + 4.184 \times 10^{-3}T – 1.674 \times 10^{5}T^{-2}$	300 – 5000
<C>	$17.154 + 4.268 \times 10^{-3}T – 8.786 \times 10^{5}T^{-2}$	273-1373
{C}	-	-
(C)	20.92	-
(CO)	$28.407 + 4.100 \times 10^{-3}T – 0.460 \times 10^{5}T^{-2}$	-
<Si>	$23.933 + 2.469 \times 10^{-3}T -4.142 \times 10^{5}T^{-2}$	298 – 386
{Si}	$45.990 + 0.0231T$	386 – 848
$<SiO_2>$	$46.945 + 34.309 \times 10^{-3}T – 11.297 \times 10^{5}T^{-2}$	273 – 8480
<Mn>	$15.792 + 0.03137T$	298-1108
{Mn}	$21.252 + 0.01659T$	1108-1317
(Mn)	$20.16 + 0.01772T$	1317-1923
<MnO>	$31.206 + 0.04359T – 0.0000152T^{-2}$	-
<P>	23.10	298-317
{P}	27.72	317 – 378
(P)	27.90	378 – 1923
$<P_2O_5>$	$66.024 + 0.45864T$	273 – 631
<CaO>	$49.622 + 4.519 \times 10^{-3}T – 6.945 \times 10^{5}T^{-2}$	273 – 631
<S>	$14.811 + 24.058 \times 10^{-3}T – 4.142 \times 10^{5}T^{-2}$	298 – 368
{S}	$18.396 + 0.01848T$	368 – 392
(S)	$18.396 + 0.00126T$	300 – 2500
<CaS>	$24.187 + 7.740 \times 10^{-3}T$	273 – 1000

At 1923K, the ΔH will be

$$E_3 = \Delta H_{1923} = \Delta H_{298} + \int_{298}^{386} \Delta C_p I dT + L_{f(Si)} + \int_{386}^{848} \Delta C_p II dT + L_{v(Si)} + \int_{848}^{1923} \Delta C_p III dT \ldots\ldots\ldots\ldots\ldots 21$$

Where $\Delta H_{298} = H_{f<SiO_2>} - \{H_{f<Si>} + {}^1/_2 H_{f(O_2)}\}$

$$\Delta C_p I = C_{p<SiO_2>} - \{C_{p<Si>} + {}^1/_2 C_{p(O_2)}\}$$

$$\Delta C_p II = C_{p<SiO_2>} - \{C_{p\{Si\}} + {}^1/_2 C_{p(O_2)}\}$$

$$\Delta C_p III = C_{p<SiO_2>} - \{C_{p(si)} + {}^1/_2 C_{p(O_2)}\}$$

$$< Mn > + {}^1/_2 (O_2) \rightarrow < MnO > \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 22$$

At 1923K, the ΔH will be

$$E_4 = \Delta H_{1923} = \Delta H_{298} + \int_{298}^{1108} \Delta C_p I dT + L_{f(Mn)} + \int_{1108}^{1317} \Delta C_p II dT + L_{v(Mn)} + \int_{1317}^{1923} \Delta C_p III dT \ldots\ldots\ldots\ldots 23$$

Where $\Delta H_{298} = H_{f<MnO>} - \{H_{f<Mn>} + {}^1/_2 H_{f(O_2)}\}$

$$\Delta C_p I = C_{p<MnO>} - \{C_{p<Mn>} + {}^1/_2 C_{p(O_2)}\}$$

$$\Delta C_p II = C_{p<MnO>} - \{C_{p\{Mn\}} + {}^1/_2 C_{p(O_2)}\}$$

$$\Delta C_p III = C_{p<MnO>} - \{C_{p(Mn)} + {}^{1}/_{2}\, C_{p(O_2)}\}$$

$$2 < P > + {}^{5}/_{2}\,(O_2) \rightarrow < P_2O_5 > \quad \text{...24}$$

At 1923K, the ΔH will be given by:

$$E_5 = \Delta H_{1923} = \Delta H_{298} + \int_{298}^{317} \Delta C_p I dT + L_{f(Mn)} + \int_{317}^{378} \Delta C_p II dT + L_{v(Mn)} + \int_{378}^{1923} \Delta C_p III dT \quad \text{...........25}$$

Where $\Delta H_{298} = H_{f<P_2O_5>} - \{2H_{f<P>} + {}^{5}/_{2}\, H_{f(O_2)}\}$

$$\Delta C_p I = C_{p<P_2O_5>} - \{2C_{p<P>} + {}^{5}/_{2}\, C_{p(O_2)}\}$$

$$\Delta C_p II = C_{p<P_2O_5>} - \{2C_{p\{P\}} + {}^{5}/_{2}\, C_{p(O_2)}\}$$

$$\Delta C_p III = C_{p<P_2O_5>} - \{2C_{p(P)} + {}^{5}/_{2}\, C_{p(O_2)}\}$$

5.0 Result and Discussion

Table 6 shows the waste reduction of materials as a result of the process modeling of the EAF for steel refining. The result from the material balance shows that 27.96 ton of charge materials will be required to produce 19.330 ton of Nst 42/50 12 NIS 1990 for a targeted steel analysis of 0.42%C, 0.19%Si, 0.36%Mn, 0.01%P and 0.23%. trial by error method has always been used in this plant and 32.28ton of charge materials were used to obtain the same result.

Table 6: The waste reduction of materials as result of the process modelling

Materials	Amount (ton)
Steel Scrap	4.61
DRI	21.82
Fe-Mn	0.15
Fe-Si	0.10
Others	1.28
Total (Material Balance)	27.96
Total (Heuristic method)	32.28
Material Wasted	4.32

The incorporation of process modeling of the EAF for the production of steel has reduced material waste by 4.32ton. this represent 13.38% reduction in the charge materials required for the furnace steel refining process.Table 7 shows the Energy reduction of materials as a result of the process modeling of the EAF for refining of steel. The result from the Energy balance shows a total of 119.64MWhr is required for the refining of the steel. Previously, it was observed the total energy used for refining of steel in the plant is 129.17MWhr. This shows a process modeling incorporation into the refining process has saved about 9.53MWhr of Energy.This account for 7.38% reduction in the energy used for refining of steel in the plant.

Table 7: The Energy reduction of materials as result of the process modelling

Energy	Value (MWhr)
E_1	19.74
E_2	9.90
E_3	53.22
E_4	24.72
E_5	11.34
E_6	0.72
Total (Energy Balance)	119.64
Total (Heuristics Method)	129.17
Energy Wasted	9.53

6.0 Conclusion

We have shown that process modeling is a good tool for reduction of Waste of materials and Energy in Engineering Process and Plant. The principle of Material balance and Energy balance has been applied to the refining of steel in the furnace rated for production of 30 tons of liquid steel and it was observed that there was material waste reduction of 4.32ton and about 9.53MWhr of Energy was saved. The results from the material balance and Energy balance shows 13.38% reduction in the charge materials and 7.38% reduction in the energy required for the furnace steel refining process.

References

1. Wikipedia (2014, November 3). EAF. Retrieved from http:// en.wikipedia.org/wiki/Electric_arc_furnace
2. Valchev, A. Y., Ninov, E. P., Peev, V. G., Velev, V. T., Visokomogilski, G. A., & Krestenyakov, Y. I. (1974). *U.S. Patent No. 3,835,230*. Washington, DC: U.S. Patent and Trademark Office. Lankford, W. T. (Ed.). (1985). *The Making, Shaping, and Treating of Steel*. Association of Iron & Steel Engineers.
3. Li, J., Provatas, N., & Brooks, G. (2005). Kinetics of scrap melting in liquid steel. *Metallurgical and materials transactions B*, *36*(2), 293-302.
4. Li, J., Brooks, G. A., & Provatas, N. (2004). Phase-Field Modeling Of Steel Scrap Melting In A Liquid Steel Bath. In *Aistech-Conference Proceedings-* (Vol. 1, P. 833). Association For Iron & Steel Technology.
5. Heikkinen, E. P., & Fabritius, T. (2012). Modelling of the Refining Processes in the Production of Ferrochrome and Stainless Steel. *Recent Researches in Metallurgical Engineering-From Extraction to Forming. InTech*, *186*, 65-88.
6. Alexis, J., Ramirez, M., Trapaga, G., & Jönsson, P. (2000). Modeling of a DC Electric arc furnace: Heat transfer from the arc. *ISIJ international*, *40*(11), 1089-1097.
7. Gerhardt, B. J., Keith, C. I., & Christiaan, P. P. (1999). Modeling and simulation of an EAFprocess. *ISIJ international*, *39*(1), 23-32.
8. Väinölä, R. V., Holappa, L. E. K., & Karvonen, P. H. J. (1995). Modern steelmaking technology for special steels. *Journal of materials processing technology*, *53*(1), 453-465.
9. Wagman, D.D. (1993). Selected Values of Chemical Thermodynamic Properties. *National Bureau of Standards Technical Notes*, 270-3,270-4,270-5,270-6 and 270-7. Washinton D.C.