بسم الله الرحمن الرحيم

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تم رفع هذه الرسالة بواسطة / سلوي محمود عقل

بقسم التوثيق الإلكتروني بمركز الشبكات وتكنولوجيا المعلومات دون أدنى مسئولية عن محتوى هذه الرسالة.

ملاحظات: لا يوجد

A CASE STUDY OF MATERIAL AND ENERGY BALANCE OF STEEL MAKING IN ELECTRIC ARC FURNACE FROM DRI

By

Ahmed Mohamed Ahmed Ferig

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
MECHANICAL POWER ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

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Title of Thesis:

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Key Words:
Steel Industry; Electric Arc Furnace; Steelmaking; Mass Balance; Energy Balance.

Summary:

The contribution of this thesis is to study the effect of the sponge iron on the energy consumption. DRI is considered one of the most important factors affecting energy. To study that effect, mass and energy balances as well as exergy analysis were implemented in order to deduce the amount of all the energies supplied by electrical or resulting from the combustion of methane or from the oxidation and reduction reactions. Then those energies were described by equations to study its change with the DRI change.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Ahmed Mohamed Ahmed Ferig Date: / / 2022

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Dedication

To my brother and Sister, for the highlights of my childhood, grown-up dreams, and the inspiration of success and keenness—Side by Side, Amr and Basma!

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Table of Contents

List of Tables

List of Figures

Nomenclature

A = Area (m^2)
A_f = cross-section area (cm^2)
Cp = Specific heat at constant pressure ($\frac{J}{mol}K$)
D_f = Shell diameter (m);
D_o = Electrode outer diameter (m);
D_t = Electrode tip diameter (m).
ex^{ch} = chemical exergy ($\frac{J}{mol}$);
ex^{ir} = total irreversibility ($\frac{J}{mol}$);
ex^{phy} = physical exergy ($\frac{J}{mol}$);
F = Shape factor
G_A = weight of Charge (ton)
G_{DRI} = weight of DRI (ton)
G_E = weight of ferrous materials (ton)
G_{HBI} = weight of HBI (ton)
G_{HM} = weight of hot metal (ton)
Gs = Steel weight (ton);
G_{Shr} = weight of shredder (ton)
G_Z = weight of slag formers (ton)
H = enthalpy (J)
h = heat transfer coefficient (W/m^2K)
H_t = Duration (Hours)
I = Electric current (Ampere);
K = thermal conductivity ($\frac{W}{m}K$)
m = mass of substance (kg)
m° = mass flow rate (kg/h)
M_G = specific burner gas (m^3/h)
M_L = specific lance oxygen (m^3/h)
N_V = furnace specific factor
P = Energy ($\frac{kWh}{ton}$)
Pr = Productivity (ton/h).
Q = Heat (MJ)
Q_g = the gas flow rate (cm^3/s)
R_{Gas} = Universal gas constant ($\frac{J}{mol}K$)
S= Entropy ($\frac{J}{K}$)
T = temperature (K)
t = time (min)
T_0 = standard temperature at 298.15° k
T_A = tapping temperature (K)
t_N = power-off time (min)
t_S = power-on time (min)
W_X = Weight of X (ton)
W_R = specific electric energy consumption ($\frac{kWh}{ton}$)
W_s = Side consumption ($\frac{kg}{ton}$);
W_t = Tip consumption (kg/ton);
W_V = energy losses ($\frac{kWh}{ton}$)
W_{Vm} = mean value of W_V
ΔH = Variation in slag height (cm)
ΔV_g^s = superficial gas velocity ($\frac{cm}{s}$)
ϵ = Emissivity
σ = Stefan-Boltzmann Constant ($\frac{W}{m^2}K^4$)
Σ_f = Foaming index
α = thermal diffusivity ($\frac{m^2}{s}$)

Abbreviations

BF - Blast Furnace
BOF - Basic Oxygen Furnace
CFD - Computational Fluid Dynamics
DRI - Direct Reduced Iron
HBI - Hot Briquetted Iron
CDRI – Cold Direct Reduced Iron
HDRI – Hot Direct Reduced Iron
EAF - Electric Arc Furnace
RCB - Refining Combined Burner
UHP - Ultra High Power
HH – Hot Heel

Abstract

The production of steel is an energy intensive process and the Electric Arc Furnace (EAF) is considered the largest electric energy consumer in the industrial sector. With the significant growth of the EAF production, the share of electricity demand in the steel industry is expected to increase from 10% in 2012 to 22% in 2040 [1]. The electric energy consumption in the EAF is about 65% of the total energy supplied, while the reset is produced from the oxy-fuel burners and the chemical energy during melting and refining [2, p. 1].

The Direct Reduced Iron (DRI) percentage in the charge is a very important factor influencing the EAF productivity, yield, as well as operating costs. A brief comparison between the most significant EAF parameters with the variation of DRI percentage is presented to investigate the effect of the DRI on them. Such parameters are Electric energy demand, Carbon combustion, Oxy-Fuel burner energy, HDRI Energy, and Power on time. To fully define the EAF parameters, mass and energy balance of the EAF were implemented on 160 tones tapping capacity EAF charged with DRI and Scrap. An exergy analysis is implemented as well to determine the EAF potential and to estimate the maximum available work that the EAF benefit from it.

Due to the presence of FeO in the DRI, which absorbs additional heat since the reaction is endothermic, the electric energy consumption increases appropriately with the increase of the DRI. The electric energy consumption for 100% scrap heats was 431.15 kWh/t and it increased to a maximum value of 565 kWh/t at around 70% DRI. The role of the HDRI in reducing the electric energy arises when its quantity increases with the increase of the DRI percentage through supplying heat resulting electric energy consumption of 539.30 kWh/t at 100% DRI since it is charged with temperatures ranging from 400°C to 600°C. Similarly, the power on time has a quite relation with the DRI percentage. scrap heats have a shorter power on time than DRI heats because the process of reducing the FeO in the DRI takes more time.

The carbon content of the DRI has a considerable influence on the chemical energy use since it aids in the reduction of FeO. The greater the quantity of carbon in the DRI than the amount required to lower the FeO in the DRI, the greater the necessity for the addition of oxygen, resulting in a more increase in chemical energy. As the cases in this study has a positive equivalent carbon, the carbon injection was a positive factor for the energy. The increase of the energy supplied through the combustion of carbon by means of the positive equivalent carbon is typically from 20.68 kWh/t at 0% DRI to 67.73 kWh/t at 100%. The oxy-fuel burners energy on the other hand has a reverse affect with DRI fraction, it ranges from 30 kWh/t at 100% Scrap to 22 kWh/t at 100% DRI.

Chapter 1 : Introduction

1.1. Overview and Research Contest

1,911.9 million tons of crude steel produced worldwide in 2021 with increase 3.6% from 2020 [3] and This increase forces the steel manufactures to reduce the energy consumption as possible as it is the most factor influence the production cost. The energy intensity per ton of steel produced has decayed by 61% since the 1960s and the consumption reached 18.9 GJ/ton in 2019 [4]. above and beyond the electric energy consumption is subjected to be lower in the future.

With a cumulative production of 10.3 million tons in 2021 with increase 25.1% from 2020 [3], Egypt is the second-largest steel producer in the Middle East and North Africa, however its production capacity is 14 million tons per year and the iron and steel sector consumed 8604.79 GWh in 2014 in Egypt with share 20.44% [5]

Electric Arc Furnace is the route of producing steel by recycling metal scrap; however, the Electric Arc Furnace can be charged with DRI. In MIDREX® Processes (MIDREX direct reduction ironmaking), The iron ore is first charged in a shaft furnace and reduced using reducing gases generated in a gas reformer from natural gas then the reduced iron is discharged to be fed into the Electric arc furnace. DRI is charged either hot using a hot transport conveyor for energy saving or cold [6].

The study is implemented in an integrated Steel Plant in Egypt with one DRI plant, 2 steel melt Shops, and one section mill. One of the melt shops is integrated with the DRI plant by a hot charge conveyer that directly discharge the DRI to the EAF. The Electric Arc Furnace of the melt shop is 3 phase AC type with 160 tones taping capacity equipped by an eccentric bottom tapping system. The energy supplied to the EAF by:

- 3 graphite electrodes connected to a 140 MVA apparent power transformer.
- 4 refining combined burners (RCBs), consists of oxy-fuel burner and a Laval nozzle for supersonic oxygen jet for the refining process.

The high electrical energy costs lead to a significant movement to increase the chemical energy share in the electric arc furnace at the expense of the electrical energy. A modern electric arc furnace consumes 350 kWh/t of energy for 100% scrap operations. About 65% of the total energy is electrical, while the rest produced from the exothermic reactions and from the oxy-fuel burners [2, p. 1], [7, p. 273]. The temperature around the arc generated from the 3 graphite electrodes reaches 5000°C, this makes the melting power is maximum at the center of the furnace, while the temperature near the side walls is not hot enough. To overcome this issue, burners are installed in the cold spots around the furnace to make the temperature homogeneous near the wall.

Refining combined burners (RCBs) developed by siemens VAI are used to make the temperature distribution inside the furnace homogenies during melting; as well as, producing a supersonic oxygen lance that works along with a carbon injection stream located beside it. The oxygen and carbon injection boost the exothermic reactions in the bath and form the foamy slag that increases the energy efficiency and stabilize the arc.