Minimization of Energy in Scrap Based Electric Arc Furnace (EAF) Steel Making Through The Use Of Premelter

Oluwole O.O and Fadare O.B
Mechanical Engineering Department, University of Ibadan.

Abstract

An energy minimization route in an all scrap based EAF steel production process is presented in this paper. The attractiveness in flexibility of operation of mini-mills has driven its use by private investors in Nigeria on the upward trend. The situation is not likely to change much as the market demand for steel is not yet met. However, energy utilization is a major consideration in EAF steel making process route. A major energy reduction route and productivity boosting has been through oxygen lancing. However, energy utilization could be cut down even more and productivity boosted by the use of fossil energy in the production process in addition to electrical energy. This would involve the use of fossil fuels directly in pre-melters and burners that are firmly installed in the furnace sidewall panels of EAFs. Thus, primary energy fuel(gas) can be used for heating and pre-melting in a pre-melter before the molten steel is transferred to the EAF for superheating resulting in a minimal use of high cost electricity. A shorter tap-to-tap time is envisaged through spatially separated vessels for heating and superheating of the steel.

Key words: energy minimization, primary energy utilization, pre-melter, EAF

1. Introduction

China is the fastest growing economy in the world today, leading in iron and steel production with an output of 567.8 million metric tones(mmt) in 2009, followed by Japan with a production level of 87.5 mmt, then India with 62.8mmt, Russia with 60mmt and the United States of America with 58.2mmt[1]. Crude steel output of leading African countries in 2009 shows that South Africa occupies the first position with a production capacity of 7.5 million tonnes and is the 20th leading world producer. Egypt is the second highest steel producer in Africa and 27th in the world with a production capacity of 5.5 million tonnes annually. Libya produces 0.94 million metric tonnes and is ranked 49th in the world. Nigeria produces a meagre 300,000 metric tonnes of iron and steel annually [2,3].

The availability and cost of energy in producing steel can not be divulged from the production capacities of different nations. This energy crisis has led to the multiplication of mini-mills which are quite handy to run. This is the case more so in Nigeria. The resultant stifling of the steel sector has led to a low per capita consumption of steel which is an index of the industrialization of the country. The per capita consumption of steel in Nigeria is10kg compared to the world average of 130kg and South Africa's 112kg [2].

The open hearth process was mainly employed in steelmaking until the 3rd quarter of the last century [4-7]. This process employed direct use of fossil fuel i.e. primary energy. More stringent requirements imposed on specialty steels necessitated the increased use of electrical energy and new processes. The flexibility offered by the EAF in producing specialty steels and the use of different mixes of charge has increased its use especially in mini-mills. Today, only small amounts of steel are still produced by the open hearth process mainly in the former East European countries. However, with the use of mini-mills comes the burdening energy cost for EAF operation [8]. This paper presents the energy minimization route offered by the combined use of pre-melter and the EAF.

2.0 Methodology

Initial evaluation of steel production process in Nigeria was done by visitation to steelmaking industries and collation of available data. The commonest process route to steelmaking in Nigeria was found. Thereafter, a process route through the use of primary energy sources was proposed for minimization of energy in the steelmaking process. The development centred on discontinuing with the use of electrical energy for phases of EAF operation that could be done away with and replacing with direct primary energy. To get the fuel to enough temperature to be an effective replacement, the regenerative fuel/air type used in the open hearth process was proposed. Also, to avoid a messy situation, separation of energy phases was considered wise. Calculation of energy savings using the new process route and the EAF was done.

3.0 Results and Discussion

3.1 Results

Table 1 shows steel production capacity in Nigeria, steel manufacturers and the steel making process routes utilised. Actual steel production in 2009 was observed to be less than a quarter of the rated production capacity. It was also observed that only companies using the EAF steel making route produced steel in 2009. Delta

Steel Company, Aladja was the only company using Direct Reduced Iron (DRI) pellets

Figure 1 shows the actual steel plant production in percentages. It was observed that scrap based EAF steel makers produced 54% of all steel produced in 2009 while Delta Steel producing from DRI and scrap mix produced 46%.

Figure 2 shows electrical energy production process for use in a EAF melt shop. The different processes involved in the transformation of primary energy to electricity are shown. Losses incurred in the different phases are also shown. Energy losses were incurred during transformation of primary energy to heat, during transformation of thermal energy to electrical energy and during transport of electrical energy to the melt shop.

Figure 3 shows the direct use of primary energy in a melting operation. It shows the whole cost of electricity generation is bypassed and primary energy is used directly for melting. Energy losses are drastically reduced.

Figure 4 shows present energy utilization in electric arc furnaces using electrical energy. It shows that seventy one percent (71%) of energy utilization in a EAF is for heating while 19% is for melting and the remaining 10% is needed for superheating.

Figure 5 shows the proposed use of energy in electric arc furnace steelmaking using primary energy sources for heating and melting.

Figure 6 shows the proposed EAF –premelter set-up with the regenerative heat supply to the premelter for heating and melting after which the molten steel is transferred to the EAF for additives, corrections and refining.

3.2 Discussion

3.2.1 Importance of EAFs in the steel sector

Steel production in 2009 by mini-mills in Nigeria account for over 50% of steel production in Nigeria (Table 1). This shows the importance of mini-mills in the steel sector. All the mini-mills are scrap-based mills. It also shows that the EAF steelmaking route is the only route being used in Nigeria at the moment. Delta Steel Company making use of DRI and scraps account for 46% steel production in the country (Fig.1).

TABLE 1: The Steel Industry In Nigeria Today Showing Contribution of mini-mills

Manufacturers	Rated Capacity (mt/yr)	Capacity (mt/month)	Actual Production 2009(mt/month)	Process Route
Mayor Group	240,000	20,000	8,000	EAF
Universal Steel	60,000	5,000	4,000	EAF
Federated Steel	60,000	5,000	4,000	EAF
Sunflag Group	60,000	5,000	3,500	EAF
Phoenix Steel	24,000	2,000	2,000	EAF
General Steel(GSM steel)	36,000	3,000	2,000	EAF
African Steel	60,000	5,000	3,000	EAF
Ajaokuta Steel Company Limited(AJSCL)	1,300,000	108,000	0	BF-BOF
Delta Steel Company(DSC)	1,000,000	83,000	25,000	DR-EAF
Others	60,000	5,000	2,000	EAF
Total Domestic Availability	2,900,000	241,700	53,500	

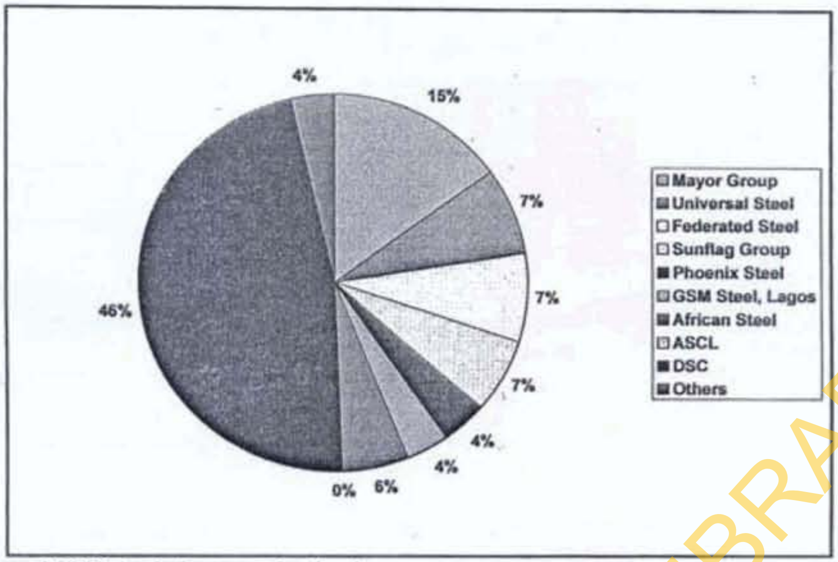

Fig.1: Actual 2009 steel plants production in percentages

3.2.2 Energy utilization in EAF steelmaking

Effective utilization of primary energy in the EAF is limited to a short melt-down phase during which scrap column still exists [9]. Important aspects such as the saving of resources and cost efficiency are resulting in a reconsideration of the relationship between electrical energy and primary energy in steelmaking. This is especially true because the electrical energy needed by the EAF today is still mainly generated from primary energy.

An EAF has about 150 tonnes in each melt, which takes around 90 minutes. Steel making with electric arc furnace is also relatively economical compared to the Basic Oxygen (BOS) route. Every tonne of electric arc furnace steel uses about 7.4 GJ of energy compared with about 16.2 GJ for every tonne of BOS steel. However, 7.4 GJ is still equal to the power consumption of a town of 100,000 populations! [10]. Oxygen lancing has been used effectively to reduce energy by about 20% [9]. Also, dynamic optimal control of the EAF steel-making process is another method of reducing time and electricity cost [11]. Specific electrical energy requirement in EAFs have also been computed based on input materials and a regression equation developed for required energy and actual energy used [12].

3.2.3 The generation of electrical energy

To generate electricity from primary energy, the chemical energy of the energy source (e.g., oil) must first be transformed into heat (Fig.2). From the heat generated electrical energy is produced in a further step. These two transformations lead to energy losses. The amount of these losses is determined by the efficiency of the power station. In state-of-the-art power stations this efficiency is not higher than 40 to 42% [13].

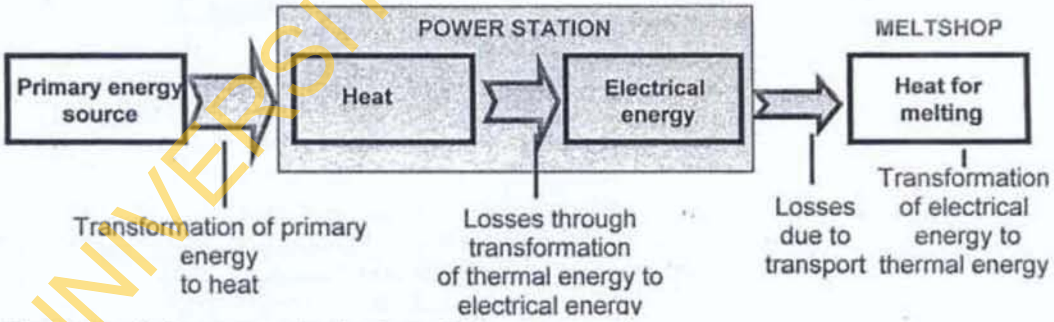

Fig. 2: Electrical energy production for meltshop energy needs

Further energy losses are caused by the transport of the electrical energy produced to the melt shop. In the melt shop the electricity is transformed to thermal and radiation energy for steelmaking. On this route almost two thirds of the original primary energy produced is lost before they are used in the melt shop [8, 10, 14]. Direct use of primary energy in steelmaking will cut off these energy wastes (Fig. 3).

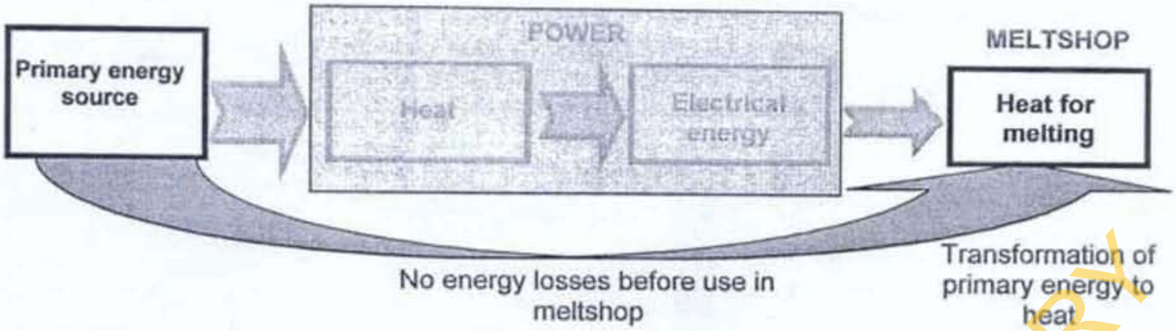

Fig. 3: Proposed use of primary energy in the meltshop

3.2.4 Direct use of primary energy in the electric arc furnace steelmaking process

The theoretical energy requirement in scrap-based steelmaking is split up in three subsequent steps; heating up to melting, melting and superheating (Fig.4).

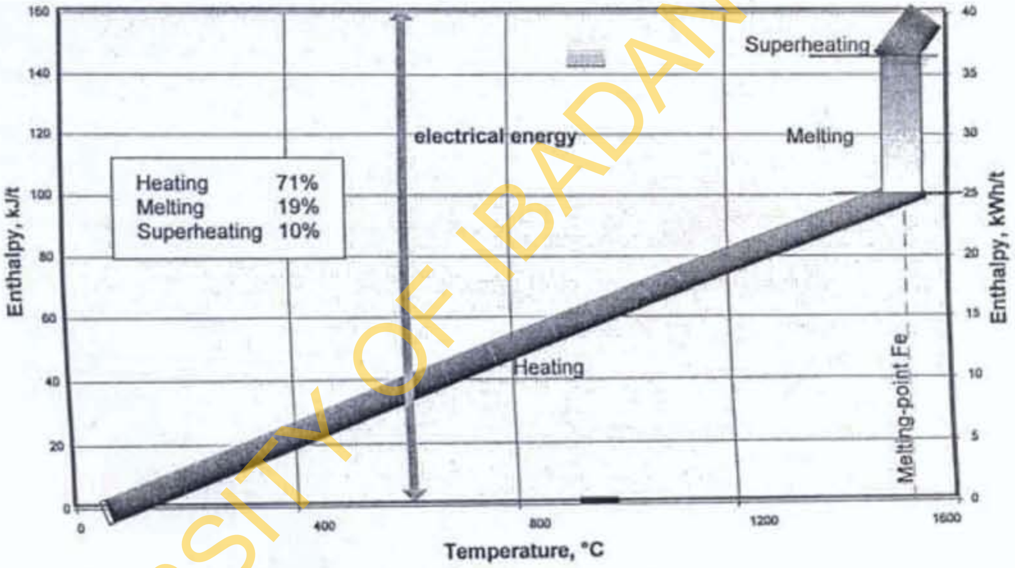

Fig.4: Present energy utilization in electric arc furnace

A large part of the energy (~71%) is needed in the first step in which the scrap is still solid [8-10] and presents a very large surface for the transfer of heat (Figs 4 and.5). This is the most important prerequisite for the use of primary energy. Where this condition is fulfilled, fossil energy can be admitted to the scrap to be molten down better than the comparable electrical energy of an electric arc (Fig.5).

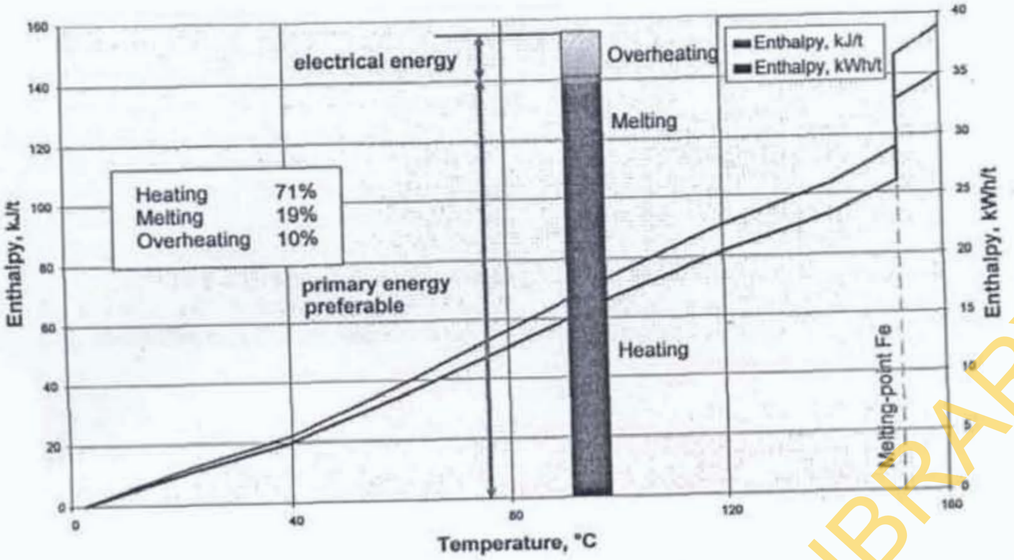

Fig.5: Proposed use of energy in electric arc furnace steelmaking

The prerequisite for efficient use of different types of energy in an all scrap based EAF hence, is a combination of electrical energy and primary energy with a separation of the melting phases.

3.2.5 Pre-melter Concept

The Pre-melter concept (Fig.6) would provide for a more efficient use of primary energy in the heating and melting stages by using a counter-current reactor. In this type of reactor the material to be molten down (scrap) would be continuously or quasi-continuously charged from above and made to become liquid roughly above the liquidus temperature through the use of primary-energy oxygen burners. The pre-molten metal and the arising slag can be immediately transferred to a second vessel in which it is superheated by electrical energy in the electric arc. A shorter tap-to-tap time is envisaged through spatially separated vessels for heating and superheating of the steel.

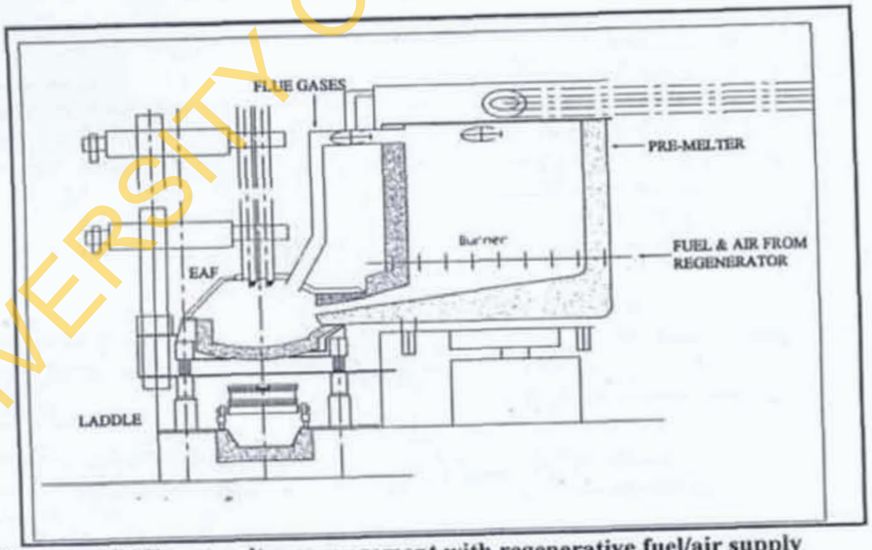

Fig.6: Proposed EAF-pre-melter arrangement with regenerative fuel/air supply

Proposed characteristics of the pre-melter are:

- proposed operation based on regenerative fuel/air supply
- Capacity should be bigger than EAF so that there is always liquid metal left in premelter for next melting process in a continuous production facility
- Natural gas proposed for fuel

Coaxial arrangement of tapping from the melting vessel with the axis of rotation of the superheating vessel. The process for scrap-based steelmaking with the use mainly of primary energy will represent an interesting alternative to the electric arc furnace, which would lead to a major reduction of CO_2 emissions and a clear reduction of the cost of energy.

3.2.6. EAF and Premelter Route Energy and Productivity analyses

3.2.6.1 EAF Energy analysis

Energy requirement for electric arc furnace [EAF] is estimated at about

440 KW hr/t = 1320 KJ/t [Heat Energy] with 67% Energy losses [14]

For an all scrap charge= 0.34MWhr/t= 1020KJ/t[8]

3.2.6.2 Pre-melter-EAF Process route

Energy requirement for Pre- melter + EAF process route

Natural gas consumption based on the open hearth estimation is about 60Nm^3/t [14]

Energy estimation for a pre–melter for heating and melting using the open hearth energy consumption is about 530 KJ/t[14].

3.2.6.3 Energy for Superheating

Electrical energy consumption for superheating in the EAF is about 150 KJ/t[14]

***Total Energy requirement for Pre- melter + EAF Process* route** = [530 + 150]KJ/t = 680 KJ/t

3.2.6.4 Energy cost analysis

Let the cost of Primary energy [Natural gas] = NX_1 per ₭J

($12.5/GJ) = $0.0000125/KJ[8]

Let the cost of Electrical energy = NX_2 per ₭J

($90/MWh) = $0.27/KJ[8]

Considering two Steel Plants Plant A and Plant B

PLANT A [Electric Arc furnace]

Energy requirement for EAF =1020 KJ/t

Hence cost of energy per ton of Steel = ₦ [1020 x$0.27] = ₦1020X = $275.4/t

PLANT B [Pre-melter + EAF process route]

Energy requirement for Pre- melter + EAF process route = 530*$0.0000125+150*0.27 = $40.51

Hence cost of energy per ton of Steel = ₦ [680 x X] = $40.51/t

It can be seen from above that for all values of energy cost X (low or high) Plant A spends more on energy than Plant B.

3.2.6.5 Productivity analysis

Considering two steel plant that have equal monthly budget for energy cost = $Y

Plant A [Electric Arc furnace]

Monthly budget for energy cost = $Y

Cost of energy per ton of Steel = $275.4

Hence, production capacity = $\dfrac{\$Y}{\$275.4}$

Plant B [Pre- melter + EAF process route]

Monthly budget for energy cost = $Y

Cost of energy per ton of Steel = $40.51

Hence, production capacity = $Y/40.51

From the analysis above it is evident that for all values of energy cost X and budget for energy cost Y (low or high) Plant B has higher productivity than plant A to the tune of about 7 times(700%). Hence, it is more economical and profitable to operate a plant based on Pre-melter + Electric furnace process route.

4.0 Conclusion

Steel production in Nigeria is dominated by all scrap based mini-mills. EAF operation requires high consumption of electrical energy, natural gas, reheating fuel and lubricants. The extremely high energy cost is a major contributory factor to high cost of local production of steel. For instance at Delta Steel Company, Aladja, the cost of electrical energy and natural gas is close to 15% of the cost of production[3].

However, in scrap- based EAFs, the possibility of drastic reduction in energy costs and dramatic increases in productivity can be achieved by efficient use of a combination of electrical energy and primary energy with a separation of the melting phases. This will require a pre-melter for heating and melting phases of the steelmaking process while the last stage of super heating to adjust elemental composition could be done by electric power.

References

[1] World Steel Association (2010) 'World Steel in Figures 2010' http://www.worldsteel.org/?action=newsdetail&id=302

[2] World Steel Association (Assessed Aug.2010) 'Crude Steel statistics Total 2009

http://www.worldsteel.org/?action=stats&type=steel&period=latest&month=13&year=2009

[3] Omoh. G and Lukat B. (2008) 'Nigeria: How Realistic is Vision 2020 Without a Functional Iron and Steel Plant' Vanguard Newspaper http://allafrica.com/stories/200808110096.html .Assessed Aug.2010

[4]Wikipedia (Assessed Aug.2010) 'Open Hearth Furnace' en.wikipedia.org/wiki/Open_hearth_furnace

[5] Britannica (Assessed Aug.2010) Open Hearth Furnace' britannica.com/EBchecked/topic/429660/open-hearth-furnace

[6]Chemie lexicon(Assessed Aug. 2010) 'Open Hearth Furnace' www.chemie.de/lexikon/e/Open_hearth_furnace

[7] Science (Assessed Aug. 2010)'How Stuff Work' www.science.howstuffworks.com/iron4.htm

[8] Steelonthenet(assessed 2010) 'Electric Arc Furnace Steelmaking Costs 2010 http://www.steelonthenet.com/steel_cost_eaf.html

[9] A. A.Mottahedi and S.Amani(2009) 'Using Oxygen Reaction as Electricity Saving in Electric Arc Furnace Steel Making'International Journal of ChemTech Research, 1(1)62-70

[10] EGS CELIK (2010) 'Steel making with electric arc furnace'http://www.arcfurnace.com/electric_arc_furnaces.html

[11] (1970) 'Dynamic optimization of a steel-making process in electric arc furnace'Automatica,6(6),767-778

[12] R. Pierre (assessed Aug.2010) 'Regression equation for specific energy requirement in EAF'http://www.bfi.de/en/fields_of_activity/process_automation_steelmaking/electric_arc_furnace_energy_consumption.htm

[13] Britannica (Assessed Aug.2010) Open Hearth Furnace'britannica.com/EBchecked/topic/429660/open-hearth-furnace

[14] International Iron and Steel Institute www.worldsteel.org