

Design and Prototype Development of a Mini-Electric Arc Furnace

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ABSTRACT

Electric arc furnaces (EAF) have the capabilities required for furnaces used for metallurgical research. An electric arc furnace was designed and constructed to melt approximately 5kg of steel/cast iron scraps, using locally produced Soderberg electrodes. Tests carried out showed that it required about 60 minutes to heat up the furnace to the melting temperature of cast iron (1150C – 1400C). It took about 95 minutes to melt the first charge of 2kg resulting in a melting rate of 21.05g/minute. The average electrode consumption rate was 0.0467cm/minute. A transformer efficiency of about 83% was also achieved.

(Keywords: electric arc furnace, melting rate, electrode consumption rate, transformer efficiency)

INTRODUCTION

In an EAF, electric arcs are used to provide heat for melting and for smelting. The few EAFs in the study country (Nigeria) are located in the integrated steel plant, the Delta Steel Company, and other large industrial plants. They are so complicated in design and so expensive that even national universities cannot afford to buy prototypes for experimental purposes.

EAFs have numerous advantages required in furnaces for metallurgical research. Such features include close temperature and heat control, accurate analysis of melt, definite metal refining sequence, high thermal efficiency (as high as 70%), and production of steel directly from pig iron and steel scrap.

The objective of this research work is to design and develop an electric arc furnace for melting steel/cast iron scraps using locally available materials.

Although information relating to the design and fabrication of an electric arc furnace of such a small size as that fabricated through this research, was not readily available in literature, the available information relating to the giant sized electric arc furnaces were used as a guide in the design of this prototype.

DESIGN THEORY AND CALCULATIONS

An electric arc furnace should have a powerful transformer, high thermal and electrical efficiency, and a lining made of high-grade refractory [Edneral, 1979].

Shape and dimensions of the bath

The bath is usually conical-spherical with the banks inclined at an angle of 45°. This form ensures quick melting. One tonne of molten steel occupies 0.145m³. The mass ratio of slag for acid-lined furnaces may be taken equal to 0.03 – 0.04. [Edneral, 1979].

The diameter-to-depth ratio of the bath operating by the basic process is usually taken as:

$$D = 5H \quad \text{..... (1)}$$

where D = bath diameter, and H = total depth of the bath.

In existing furnaces, the height (h₁), of the spherical portion is roughly 1/5 of the total bath depth:

$$h_1 = 0.2H \quad \text{..... (2)}$$

and the depth of the conical portion:

$$h_2 = 0.8H \quad \text{..... (3)}$$

The total volume of the bath, V_b , is the sum of the volumes of the truncated cone and that of the spherical segment. By virtue of the relationships given above:

$$V_b = 0.0968 D^3 \text{ (m}^3\text{)} \quad (4)$$

Dimensions of the reaction chamber

The banks of a furnace are usually made 100 to 200 mm above the door sill level or the bath surface, to ensure that the slag does not contact the brickwork or reach the joint between the wall blocks and banks. The diameter of the reaction chamber is:

$$D_{rc} = D + 200 \text{ (mm)} \quad (5)$$

It is recommended that the following relationship be used in determining the height of the reaction chamber (H_1) [Edneral, 1979]:

$$H_1 = (0.04 - 0.6) D_{rc} \quad (6)$$

the lower value relating to large-capacity furnaces.

The camber of the roof (h_3) is:

$$h_3 = 0.15 D_r \quad (7)$$

where D_r is roughly taken 1000 mm wider than D_{rc} .

$$\begin{aligned} D_r &= D_{rc} + 1000 \\ h_3 &= 0.15 (D_{rc} + 1000) \end{aligned} \quad (8)$$

The total height of the roof above the bath level is given as:

$$H_2 = H_1 + h_3 \quad (9)$$

The recommended slope (S) for the inclination of the wall is roughly 10% of the height from the line of banks to roof skewbacks:

$$S = \frac{H_1 - 100}{10} \quad (10)$$

The diameter of the reaction chamber at the level of the roof skewbacks (i.e. at the level of the upper edge of the furnace shell) is:

$$D_1 = D_{rc} + S \quad (11)$$

The thickness of the lining is found by thermal analysis from the condition that the furnace shell should not be heated above 200°C at the end of the furnace campaign. With the refractory lining δ mm thick, the furnace will have the following inside diameter of the shell:

$$D_{i,sh} = D_{rc} + 2 \delta \quad (12)$$

The steel shell varies in thickness and may range from $\frac{1}{4}$ inch (6mm) thick for small furnaces and up to $1\frac{1}{4}$ in (32 mm) thick on 80 to 100 ton furnaces [Robiette, 1972].

Transformer power and furnace productivity

Table 1 contains some recommendations on transformer power for furnaces of different size, which are based on experiences in many countries.

By analogy with the existing furnaces (using Table 1), the transformer power may be taken as P_{ap} (MVA). Noting the inevitable switching off of the furnace during melting required to push the scrap from the banks, partial operation of the furnace at a reduced voltage when the arcs are open and radiation of much heat onto the walls and roof, the average power consumed during the melting period can be found by using a factor of 0.8 – 0.9:

$$P_{av} = 0.8 P_{ap} \text{ (KVA)} \quad (13)$$

Useful power consumed during the melting period (power consumed for the melting proper) is represented as:

$$P_u = P_{av} \cos \varphi_{el} \text{ (KW)} \quad (14)$$

Voltage taps

The upper voltage tap of the secondary voltage for small furnaces can be selected by using the following empirical formulae [Edneral, 1979]:
For basic furnaces

$$V = 15 \sqrt[3]{P_{AP}} \quad (15)$$

For acid furnaces:

$$V = 70 + 15 \sqrt[3]{P_{AP}} \quad (16)$$

Table 1: Recommended Transformer Power for Furnaces of Different Sizes.

Furnace Capacity (t) Transformer Power (MVA) for Making Various Steels	25	50	75	100	150	200	250	400
(i) Alloy steels	5-18	20-25	-	30-35	-	55-70	-	-
(ii) Carbon steels	18-22	28-32	30-45	40-50	45-60	60-80	90	120
Transformer power of super powerful furnaces of the future	-	40	-	60	-	125	-	200

(Source: *Electrometallurgy and Ferro-alloys*, 1979)

Electrode diameter

The diameter of electrodes can be found by the formula:

$$d = \sqrt[3]{\frac{0.406I^2\delta}{K}} \text{ (cm)} \dots\dots\dots (17)$$

Where I = linear current, (A)

$$I = \frac{P_{ap} 10^3}{V_{max} \sqrt{3}},$$

δ = electrode resistivity at 500°C (for graphitized electrodes δ = 10 ohm. Mm²/m), and

K = coefficient (for graphitized electrodes K = 2.1 W/cm²).

The diameter of electrodes can also be found by the allowable current density (A/cm²).

Electrode spacing

The recommended ratio of the electrode spacing diameter to the bath diameter is 0.45 for small furnaces, 0.35 for medium sized and large furnaces, and still lower for super powerful furnaces (Edneral, 1979).

Energy distribution

The energy required for melting of metal scrap is

$$Q = mc(\theta_2 - \theta_1) + mL \dots\dots\dots (18)$$

where, m = mass to be melted (kg),

c = specific heat capacity of metal to be melted (KJ/Kg°C),

θ_2 = melting point of the metal (°C),

θ_1 = room temperature (°C), and

L = latent heat of fusion of the metal

MATERIAL AND METHODS

The electric arc furnace comprises two Soderbeg self baking electrodes (Afolabi, 2004); an electrode support and sliding mechanism; a tiltable crucible lined with refractory silica brick in which melting takes place; the roof also lined with silica brick, which is removable for charging and for pouring; and the support frame which carries the other parts. The crucible and roof were constructed using 4mm thick mild steel sheet. The furnace is shown schematically in Figure 1 and pictorially in Figure 2.

The furnace is supplied at 50Hz using a tapped power transformer with a high current secondary, the connections between the transformer and the electrodes is a length of flexible cable which allows the electrodes to be moved vertically and also for the complete roof assembly to be lifted and moved horizontally.

Melting is achieved by the heat generated by the electric arc drawn between the electrodes tips and the scrap metals. The transformer is oil cooled.

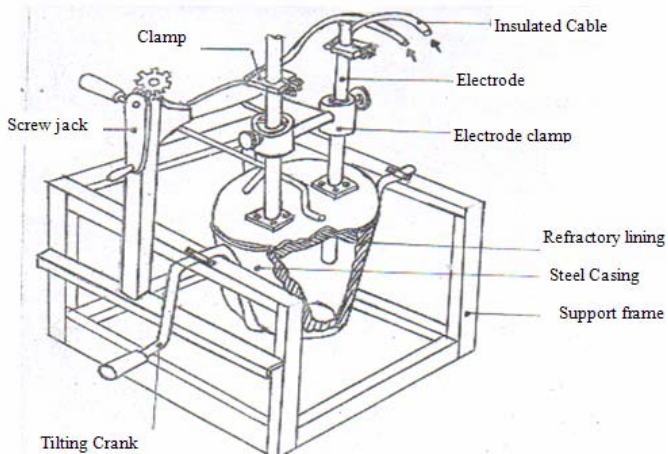


Figure 1: Schematic of the Electric Arc Furnace.

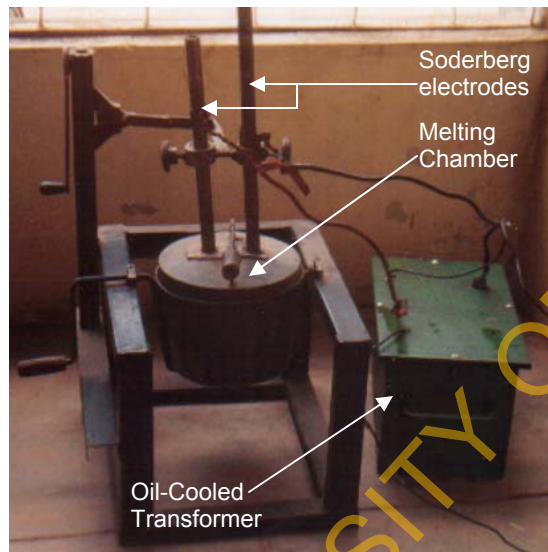


Figure 1: Prototype Electric Arc Furnace.

RESULTS AND DISCUSSION

Tests were carried out on the EAF to assess its operation and evaluate its performance. Table 2 and Table 3 show the test results. The EAF performance was evaluated in terms of heating and melting rate, transformer efficiency, Soderberg electrode consumption rate, and insulation resulting.

The result shows that it required about 60 minutes to heat up the furnace to the melting point of cast iron (1150°C – 1400°C).

Table 2: Test Data.

Test	Mass of charge (kg)	Time of Operation (min)	Electrode Consumption (cm)	
			1	2
1	2	102	1.0	3.0
2	2	89	1.0	3.0
3	2	94	1.0	3.0
4	3	128	2.0	4.0
5	3	130	2.0	4.0
6	3	123	2.0	4.0

$$V_p = 220V, V_o = 62V, I_p = 30.5A, I_o = 90A$$

Table 2: Average Melting Rate and Electrode Consumption.

Mass of charge (Kg)	Average time of melting (min.)	Average total electrode consumption (cm)	Electrode Consumption ratio	Average melting rate (g/min)	Average electrode consumption rate, (cm/min.)	Transformer efficiency, η	Melting temperature (C)
2	95	4.0	1:3	21.05	0.042	83	1150-1400
3	127	6.0	1:2	23.62	0.047	83	1150-1400

It took about 95 minutes to melt the first charge of 2kg resulting in a melting rate of 21.05g/minute. A higher melting rate of 23.62g/minute was however achieved when the charge was increased to 3kg. The average total electrode consumption rate was 0.0467cm/minute in the ratio 1:1.5 a transformer efficiency of about 83% was also achieved. The refractory material used also showed high insulation and thermal stability. Throughout the tests, no crack was observed in the refractory lining.

CONCLUSION

An electric arc furnace has been produced capable of producing small quantities of melted steel for research. The tests show that the performance is satisfactory. The heating rate, melting rate, and electrode consumption rate are comparable to existing standard furnaces attaining a temperature of well over 1000 C within an hour and melting the first charge in about 95 minutes.

Tests carried out with Soderberg electrodes specifically produced locally for this project gave satisfactory performance thus allaying fears of inadequate electrode supply.

RECOMMENDATIONS

Based on the study carried out in this project, there is a need to produce an effective and efficient furnace transformer in Nigeria which can withstand the high current surges normally experienced in the operation.

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