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Design and Fabrication of Laboratory Size 100kg Charge Bottom Fed Oxygen Steel Converter Shell with Gear Tilting Mechanism

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Abstract Steel industry can successfully spring up and expand starting from small cottage industries which may develop from using transferred technology of steelmaking using different kind of steel converters produced on small scale prior to take off of the Ajaokuta Steel Complex. Having discovered the very wide gap existing between the demand and supply of steels and steel products; the non-availability of steelmaking equipment in the laboratories for practical purpose in the Universities; there is therefore the need to come up with steel making equipment which can be designed and fabricated. It will also expose the students to design and fabrication principles; and enhancing their overall understanding to metallurgy of iron and steel making processes. The present work reports the design and fabrication of a 100 kg capacity bottom fed oxygen steel converter using locally available materials as a step to meeting the need of a steel making in the country. The work is limited to designing and fabrication of the shell of the converter shell and refractory lining, pillow bearing pivot, mild steel stand for support, and the tilting mechanism which containing the gears and driving electric motor. The facility was produced at a cost of ₦759,200:00 ($1,800 USD)

Keywords steel, conversion, refractory, bottom fed oxygen Bessemer, gear tilting mechanism

I. Introduction

Nigeria is naturally endowed with vast number of natural and mineral resources that supposedly improve the economic status internationally [1]. It is famous that iron ores of different grades, coals with diverse metallurgical qualities, limestone, dolomite, and many deposits of clays are available in commercial quantities across the length and breadth of the country. These minerals are the bases for the establishment of iron ore beneficiating plants, steelmaking plant and steel rolling mills in selected regions across the country. However, it is unfortunate that self-sustainable steel production have not been attained for over four decades. The current state of steels industries is horrible and worrisomely devastating. Nigeria imports millions (US$) worth of iron and steel [2, 3]. Ajaokuta Steel Company Ltd. (ASCL) in Kogi State was installed with complete integrated steelmaking production plants: blast furnace, Bessemer oxygen converter and heavy to light sections rolling mills.

At the moment, equipment for refining molten pig iron into steel are seldom available in higher institutions of learning and research centres because of it high cost of procurement and control of the process. It is only available in ASCL which is at industrial scale and neither functioning nor directly accessible to students

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for research and experimental purposes. While efforts should be continuously geared towards resuscitation the nation steel industry to meet up with the ever increasing demand, there is need to make students acquainted with the principle of operations and processibility factors for conversion of liquid pig iron into steel. This is the rationale behind the conceptualization of the study. Hence, for learning and research purposes, the work is conceived to involve the design and fabrication of an easy-to-operate and affordable Bessemer converter for steelmaking processes in laboratories using locally sourced materials.

In the current dispensation the demand for steels are extremely on large-scale and highly integrated. Steel making process involves the production of steel from pig iron and/or scrap by decarbonisation that is, removing excess carbon (most important impurity); and other impurities such as nitrogen, silicon, phosphorus, and sulphur [4;5]. Impurities are removed from the iron ore, while alloying elements such as manganese, nickel, chromium, carbon and vanadium are added to give different grades of steel. Nitrogen and oxygen which are limiting dissolved gases, along aside entrained impurities (termed inclusions) in the steel are also important to be reduced in order to ensure quality products are cast from the liquid steel [6].

Basic Oxygen Steelmaking (BOS), a converter is used to produce approximately 70% of steel worldwide, using supersonic oxygen jet injected through the lance on the surface of the liquid metal; forming CO, FeO, SiO_2, P_2O_5, MnO among many others (except gasses) together with the fluxing agents form a less dense slag layer that floats on top of the liquid metal [7]. The shape of Bessemer converter vessel is a globular bottle, with the blast holes (tuyere) at the bottom, usually movable about 180° through its horizontal axis, but rarely it is fixed [8,9]. The Bessemer process converts pig iron to steel by using air to oxidize the unwanted impurities in molten iron. The oxidation process being exothermic brings about rise in temperature that keeps the iron in molten state. It could be bottom or top blown type through which air or most preferably, oxygen is blown into the converter. Oxidation reactions occurs when oxygen is blown into the melt, which enables removal of impurities found in pig iron, such as silicon, manganese, and carbon in the form of oxides. The oxides can escape either as gas or slags [10-12].

Refractory materials are usually resistant to decomposition by heat, pressure, or chemical attack to retain the strength and form/shape at high temperatures [13]. Bessemer converter is usually lined with acidic or basic refractory materials, depending on the slag composition [14]. Refractory linings plays important role in improving the quality of the finished product, increasing its malleability, its ability to withstand rolling and forging at high temperatures and making it more suitable for a vast array of uses [15].

The converter is tilted and molten pig iron is charged directly into it. The converter is then rotated into operational (vertical) position, and air/oxygen blowing begins. The blowing continues for 20-25 minutes [16]**.** The metal charge of bessemer converter is molten pig iron, containing 92 wt.% iron. The oxidation process increases the temperature of the iron mass and enables it to remain in a molten state. Other elemental composition of pig iron includes: Silicon (0.5–0.7 wt.%); Manganese (0.5–0.7 wt.%); Carbon **(**4.2–4.5 wt.%); Phosphorus **(**0.3 wt.% max.): Phosphorus content in pig iron is given by content of P in the blast furnace charge, particularly in iron ore, from which P is completely eliminated during smelting and Sulphur (0.020–0.025 wt.%) [15]

Lump lime and iron ore as the flux and coolant are respectively used in basic oxygen steel making. However, high melting point, poor dissolution property, fines generation tendency and hygroscopic nature of lump lime usually develop problems during operation [17] revealed that a much faster dephosphorization rate and very low phosphorus level can be attained using the pre-fused synthetic flux (PSF) as fluxing material when compared to only lump lime added to the heat. P removal reaction occurs in the slag-metal interface according to equation (1).

$$2[P] + 5(FeO) + 3(CaO) \rightarrow (3CaO{\cdot}P_2O_5) + 5[Fe] \quad (1)$$

Vu *et al.* [18] has well-established the isotherms and kinetics of the adsorption of P to steel-making slag for identifying key removal mechanisms. Experimental data systematically indicate that P removal by steel-making slag is governed by both adsorption and chemical precipitation.

In converters, oxygen is mainly used to increase productivity, while oxygen-steam, oxygen-carbon-dioxide and blowing from the top with ore addition are used to obtain quality steels, comparable to open-hearth steel [19;20]. Once the air is blown, oxidation reaction commences. Even though, the free energy change used in the formation of oxides of iron is much higher than that for SiO_2, MnO and CO. Iron oxidizes first because of its much larger mass. The reactions may be written as shown in equations 2 to 6.

$$Fe + O_2 \rightarrow 2FeO \quad (2)$$

Higher oxides of iron are also formed, but for the sake of simplicity, the state of oxidation is taken as FeO. The FeO, however, reacts immediately with silicon in the metal.

$$2FeO + Si \rightarrow Fe + SiO_2 \quad (3)$$

Mikhail and Turcotte, [21] showed that, at 1300 ^oC under inert atmosphere, a partial reduction of iron oxides occur leaving 20% reducant in the mixture. However, complete metallization of the iron oxides in the dust occur under the same conditions with 50% reducant. In the processes, silicon oxidation occurs first after which manganese reaction starts.

$$Mn + FeO \rightarrow MnO + Fe \quad (4)$$

The SiO_2 reacts with excess FeO and MnO forming a silicate slag according to equations 5.1 and 5.2.

$$SiO_2 + 2FeO \rightarrow 2FeO.SiO_2 \quad (5.1)$$

$$SiO_2 + 2MnO \rightarrow 2MnO.SiO_2 \quad (5.2)$$

Slopping problems occurs whenever layer of foaming slag is formed on the surface of the molten metal exceeds the height of the vessel and overflows, leading to process disruption, metal loss, and environmental pollution. Evestedt and Medvedev [22] proposed an automatic slopping detection method which makeS use of sound signal from a microphone that is located in the off-gas funnel, which is processed to obtain an estimated level of slag level in the converter.

The carbon reaction begins immediately after the silicon and manganese have been oxidized away.

$$CO + FeO \rightarrow CO + Fe \quad (6)$$

The Bessemer converter utilizes the carbon-oxygen reaction which is a heterogeneous process. During this process the bath in the form of bubbles helps nitrogen in the air escape [10]. The International Energy Agency, energy-intensive iron and steel industry has been reported to contribute approximately 6.7% of the total CO_2 emission globally; of which the blast furnace emits over 70% of the CO_2 [23].

The top gas recycling oxygen blast furnace (TGR-OBF), is a new iron-making process that appreciably reduce CO_2 emission. Jin *et al.,* [24] established a TGR-OBF model to acquire parameters on the material and energy flows of this process which comprised the top gas removal process, oxygen blast furnace and preheating units. Mantripragada and Sarkar [25] developed a three-dimensional, multi-phase turbulent, transient model to predict the shear stress distribution along the wall in dual plug and bottom purged ladles. The study gave understanding the dependence of wall stresses on various operating parameters like metal bath depth, argon flow rate, slag thickness and on the configuration of the gas injectors.

Pena *et al.* [26] tackled the real-time by-product gas scheduling in an integrated iron-and steel-making industry with uncertainty in by-product gas flows from a rolling horizon algorithm. Adaptive time-series models determined from real data performs forecast for each producer and consumer of by-product gases in main units of the steel-making plant. The endpoint parameters of molten steel, such as the steel temperature and the carbon content, directly affect the quality of the steel production which cannot be online continuously measured in time. In resolving this challenge, Han and Liu [27] proposed an anti-jamming endpoint prediction model to forecast the endpoint parameters of molten steel.

Most literature reported development of oil and gas fired, as well as electric powered crucible melting pot furnaces [28-30], heat treatment muffled furnaces, roasters and ovens [31,32]; whereas none has been reported on indigenous strides taken so far on steel extraction and conversion equipment. The areas of serious challenges have been the optimisation and testing of engineering properties required in the design and fabrication methods of lining refractory ceramic materials. The efficiency of metallurgical reactors is factors of the dynamism of design and flexibility of operation. Charging and discharge mechanisms constitute critical problem to operation time management of most existing indigenous reactors reported. Bulk of these equipment are manually operated thus leading to unnecessary increase in operation time interval existing between two or more stages of metal charging, heating up, soaking, melting and pouring time.

In spite of the occurrence of large deposits of principal raw materials for steel production: iron ore in Kogi State, coal in Enugu, calcareous (limestone, dolomite, gypsum etc) and clays across different geopolitical axes of Nigeria, the indigenous iron and steel processing had suffered serious setback for ages of the national existence [33]. Up to date, there have not been available research reports on the progressive development and technology transfer through indigenous manufacture of fundamental ore processing and extraction equipments for iron and steel making that could have transformed these vast gifts of nature to useful industrial revolution despite the annual increase in the establishment of science, engineering and technology based tertiary institutions and research centers across the nation. With these abundant raw materials in iron and steel making, the nation has not been able to add value to its minerals due to lack of facilities at industrial, pilot and laboratory levels.

The current challenge to be address by this work is to provide means that would ensure proper training of students in this area as it cannot be undertaken without facilities which presently are not available in both higher institutions and research institutes. To bridge the gap, flexible and affordable facilities must be designed, fabricated and made available. It will also make available data for operational principles in laboratory processing of steel making as well adaptable processing factors that can ensure enhanced productivity at industrial scale.

II. Materials and Method

A. Conceptualisation

A new or better machine and its component are more economical in the overall cost of production and operation. Parts of the machine were selected with good durability consideration and due to the nature of the expected operation at high temperature.

From the study of existing ones, a new one was conceived and developed [34,35]. The idea was studied, minding its commercialization and fund and required materials for the execution of the innovative idea to an actuality Designing of drawings preparation, care was taken with attractive shape in the design drawing. In the respect to the availability of resources, that is, a machine component is essentially principled on the fundamentals of mathematical theories, engineering drawing, strength of materials, theories of machines and basic workshop practices [1,36]. The conceptualization stage answers some basic questions such as: what size and volumetric capacity? By what mechanism does it rotate about its axis? What means and method is oxygen fed, agitated and slag discharged? What could the maximum attainable temperature be? How best to solve the problems arising from the material selection? And what combination of refractory lining will be more appropriate?

B. Design calculations

i. Volumetric capacity design calculations based on equations 7 to 18.

The converter is a pear-like shaped steel shell that is divided into five sections (the sprue, hemispherical frustum, big cylindrical shell, inverted frustum base, and small cylindrical base) as shown in Figures 1a-d.

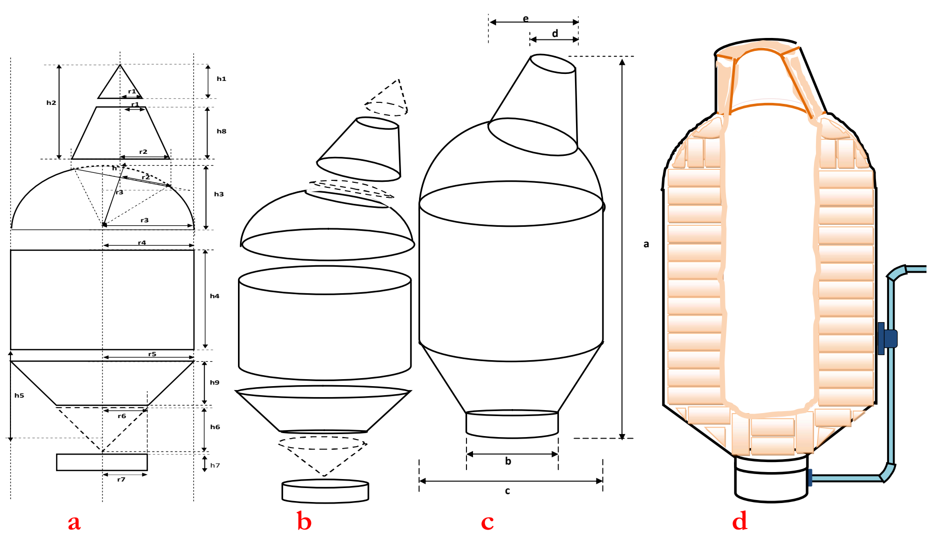
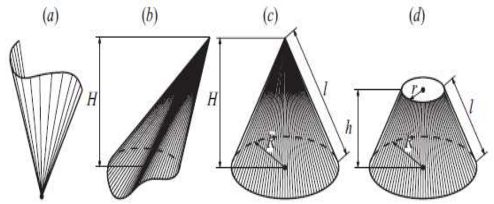


Figure 1: (a) calculating dimensions, (b) dismounting, (c) assembly and (d) refractory lining

a. Volume of converter sprue

The volume of the sprue is calculated from the frustum of a cone



The volume of an arbitrary cone is given by

$V = 1/3HS_{base}$, (7)

Where H is the height of the cone and S_{base} is the base area [37]

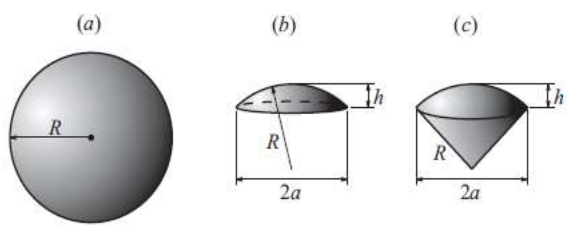
Volume of the conical frustum (sprue) = volume of big cone – volume of small cone (in Figure 1a);

$V_1 = \pi r_2^2 h_2 - \pi r_1^2 h_1$ (7.1)

Where, r_2 is radius of big cone, r_1 is the radius of small cone, h_2 is the height of the big cone, h_1 is the height of the small cone, and h_8 is the height of the frustum.

b. Volume of hemispherical frustum

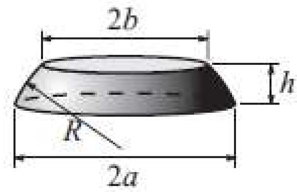
To find the volume of a spherical segment from a sphere (a), a spherical cap (b), and a spherical sector (c) using equations (8) to (8.2).



The volume V of a spherical cap is given by

$$V = \frac{\pi h}{6}(3a^2 + h^2) = \frac{\pi h^2}{3}(3R - h), \quad (8.1)$$

For a spherical segment of the shell;



The volume V of a spherical segment is given by;

$$V = \frac{\pi h}{6}(3a^2 + 3b^2 + h^2). \quad (8.1)$$

Volume of hemispherical frustum is the difference between volume of big hemisphere and the volume of spherical cap.[37].

The volume of hemispherical frustum (in Figure 1a and 1b) is therefore:

$V_2 = ⅓\pi(r_3)^3 - ⅓\pi h^2(3r_3-h)$ (8.2)

Where, r_3 is radius of big hemisphere, h is the height of the spherical cap

c. Volume of big cylindrical shell

$V_3 = \pi r_4^2 h_4$ (9)

Where, r_4 is the radius of the cylindrical shell of the converter, and h_4 is the height of the cylindrical part of the converter

d. Volume of inverted frustum base

Volume of inverted frustum base = volume of big inverted cone – volume of small inverted cone (in Figure 1a)

$V_4 = \pi r_5^2 h_5 - \pi r_6^2 h_6$ (10)

Where: r_5 is radius of big cone, r_6 is the radius of small cone, h_5 is the height of the big cone, h_6 is the height of the small cone, and h_9 is the height of the frustum.

e. Volume of small cylindrical base

$V_5 = \pi r_7^2 h_7$ (11)

Where: r_4 is the radius of the base, and h_4 is the height of the base.

f. Total height of the converter shell (h_t)

$$h_t = h_3+h_4+h_7+h_8+h_9 \quad (12)$$

g. Total width of the converter

$$(c) = 2r_4 \quad (13)$$

h. Total volume of converter shell

$$Vs= V_3+V_4+V_5 \quad (14)$$

For a close end cylindrical hollow lining;

i. Volumetric capacity of converter

Vc = Vol. of shell (Vs) – Vol. of refractory lining (Vr) (in Figure 1a)

$$Vc = (Vs) - (Vr) \quad (15)$$

Taking

$$hc = (h_{10}+h_4+(h_9)/2) \quad (16)$$

Vol. of cylindrical hollow

$$(Vc) = \pi r_4(h_{10}+h_4+(h_9)/2) \quad (17)$$

$$Vc = \pi r_4 hc \quad (18)$$

C. **Power drive, gears and shaft design calculations**

i. Power drive and Tilting mechanism design

a. Weight of converter shell on suspension

Weight of converter shell	= 100kg
Weight of refractory lining = 240 x 1.5kg	= 360kg
Weight of mortal cement (1.5bags x 50kg)	= 75kg
Weight of driven gear A	= 20kg
Weight of pinion gear B	= 15kg
Weight of two shaft	= 5kg
Total	**= 575kg**

ii. Total weight of full iron charged Iron converter on suspension

Weight of empty converter	= 575kg
Weight of feed (iron, coke, scrap) charge	= 100kg
Total	**= 675kg**

iii. Tilting mechanism

The tilting mechanism (Figure 2) consists of the hollow shaft, set of gears and bearing sets. Pillow block bearings and flanged cartridges are used to connect the two pieces of hollow shafts on both sides of the converter shell and the gears. Equations 19 to 21 were used to determine the values.

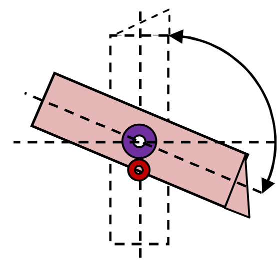


Figure 2: Tilting Mechanism of the Converter

In the vertical position of the converter shell

$$F = mg \quad (19)$$

To tilt the machine through an angle (θ) ranging from 112.5° ~120°

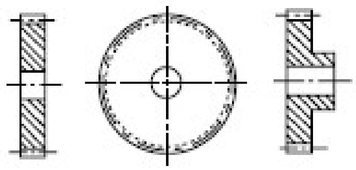
$$F = mg\cos\theta \quad (20)$$

$$\text{Kinetic energy, } E = \tfrac{1}{2}mv^2 \quad (21)$$

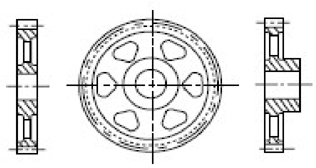
where: F is force, m is mass of shell plus lining, θ is tilting angle, g is acceleration due to gravity, E is kinetic energy, v is velocity of tilt.

D. Gears and shafts design

The gear and shaft system is an essential mode of energy transmission and tilting mechanism of the converter. It facilitates the speed reduction from the prime mover to the driven parts by using two meeting gears in a rotating machine [34-36]. A spur gear, pinion and hollow shaft was incorporated into the design. A spur gear (Figure 3a & b) is cylindrical in shape, with teeth on the outer circumference that are straight and parallel to the axis (hole). There are number of variations of the basic spur gear, including pinion wire, stem pinions, rack and internal gears. In this work, a plain spur gear is used as the pinion (Figure 4a), and spoked spur gear as driven gear (Figures 4b & 5).



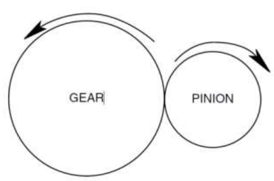
(a)



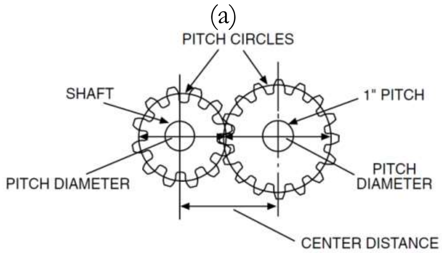
(b)

Figure 3: (a) Plain Spur Gear and (b) Spoked Spur Gear (bostongear.com)

Center distance (CD) is the distance between the center of the shaft of one spur gear to the center of the shaft of the other spur gear (Figure 4b).



(a)



(b)

Figure 4: The Pinion and Gear rotate in opposite directions [38].

Gear ratio is the mathematical ratio of a pair of spur gears (equation 22) obtained as:

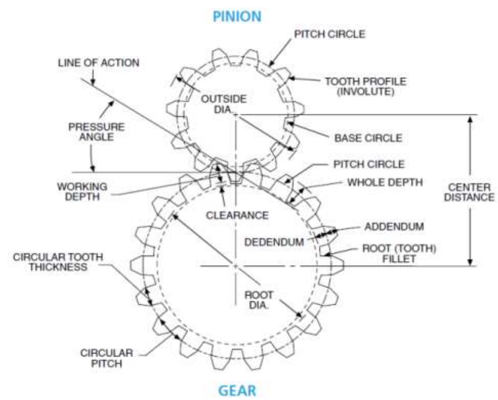
Gr = number of teeth on the larger gear/the number of teeth on the pinion.

The Gear ratio, $Gr = N_1/ N_2$ (22)

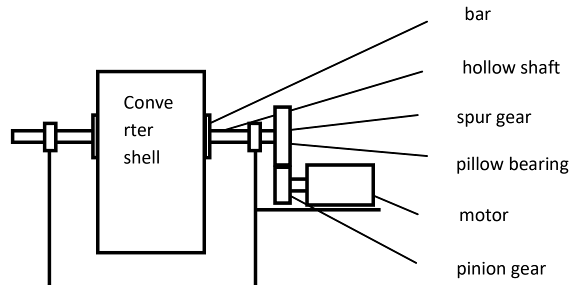
where, N_1 is the number of teeth for the driven gear and N_2 is the number of teeth for the driver gear.

Velocity or speed is the distance any point on the circumference of a pitch circle will travel in a given period of time (equation 23).

Velocity = pitch diameter (PD) x 0.262 x revolutions of the gear (in rpm) (23)



(a)



(b)

Figure 5: (a) Description of the Dimensions of Gear Teeth (bostongear.com) and (b) Calculating Torque [34-36].

i. Spur Gear Design

To design gear and shaft system to power driven machine with a 3 horse power (2.28 Kilowatt), 1440 rpm motor under the assumption that hollow shaft in the system transmits 3 hp. The system is to consist of spur gear driven input, hollow shaft connected to the pinion gear on motor.

To calculate the pinion speed and torque based on the gear coupled to the motor pinion, equations 24 to 35 are used [39,40].

$$n_2 = \frac{n_{motor}R_{motor}}{R_2} \quad (24)$$

$$n_2 = n_P \quad (24.1)$$

$$T_1 = \frac{P}{n_2} \quad (25)$$

$$T_1 = T_P \quad (25.1)$$

To solve for transmitted power in the equation 26

$$P = 3.0 \text{ hp x } K_o \quad (26)$$

To solve for the diameter of pinion A, D_P using Equation (27), choosing the number of teeth from gear standard Table (Robert and Mott, 2014,) to be greater than 16, thus making the calculations easy N_P = 50 teeth.

$$D_P = \frac{N_p}{P_{dAB}} \quad (27)$$

By using the velocity ratio (VR) to calculate the diameter of Gear B (Equation 28-29)

$$N_G = VR.N_A \quad (28)$$

$$D_G = \frac{N_G}{P_{dAB}} \quad (29)$$

To calculate the gear speed and torque (Equation 30-31)

$$n_G = \frac{npN_p}{N_G} \quad (30)$$

$$T_G = \frac{P}{nG} \quad (31)$$

To solve for center distance and pitch line speed. (Equation 32-33)

$$C = \frac{N_pN_G}{2P_{dAB}} \quad (32)$$

$$v_{tAB} = \frac{\pi D_{PnP}}{12} \quad (33)$$

To calculate the face width for Gears A and B and transmitted load, Wt. (Equation 34-35)

$$F = \frac{12}{P_{dAB}} \quad (34)$$

$$W_{tAB} = 33000 \text{ x} \frac{P}{V_t} \quad (35)$$

ii. Shaft design

In the present work, the shafts serve different functions such as: (i) carrying the total weight of the converter suspended on the pillow bearing; (ii) transfer energy from the gears and prime mover to rotate the converter shell and; (iii) a channel through which the oxygen pipe is conveyed to the tuyere and rotates simultaneously with the body shell. Therefore, a thick circular hollow shaft type of mild steel [41] material was selected for use (Figure 6).

iii. Torsion of circular shafts

To determine the angle of twist, Θ (Equation 36)

$$\Theta = \frac{TL}{GJ} \quad (36)$$

Where: Θ = the angle of twist (rad), T = the applied torque (m-kg.), L = shaft length (m.), J = polar moment on inertia of the shaft cross section (m^4), G = shear modulus of elasticity of the shaft material (kg/m^2) as in Equation (36)

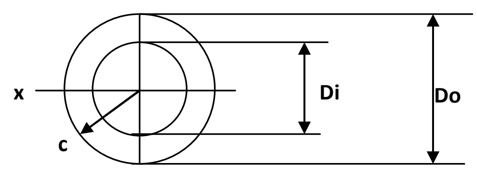


Figure 6: Dimensions of Circular Shaft

Where: J relationship for circular cross sectional areas = $(D_o^4\text{-}D_i^4)/32$

D_o and Di are the outer and inner diameters of the hollow shaft.

iv. Torsional Shear Stresses

Torsional shear stress: $S_S = Tc/J$ (37)

Where J is Polar moment of inertia = $\pi d^4/32$, c is radius of the shaft, T is Torque, d is diameter of shaft.

v. Shear Stress in a shaft

Shear stress: $S_S = 16T/\pi D^3$ (38)

Where: T = torque, D = diameter of the shaft = $(16T/\pi S_S)^{1/3}$ (39)

E. Electric power driven motor calculations

The electric power consumption is calculated from the equation (40) to (45)

The electric power input is given by equation 40 [41,42]

$P_{in} = IV$ (40)

where P_{in} is power input (W), I is current (A) and V is applied voltage (V)

Considering the rotational speed of the electric motor for the mechanical power output

ω = rotational speed x $(2\pi/60)$ (41)

Where ω is angular speed, rpm is the rotational speed in revolutions per minute, π is the mathematical constant pi (3.142) and 60 is the number of seconds in a minute.

$P_{out} = \tau \times \omega$ (42)

Where P_{out} is the output power, τ is torque of the electric motor and ω is the angular speed.

$P_w = 0.746 \times P_{hp}$ (43)

Where P_w is the electric motor power in watts and P_{hp} is the power in horsepower.

Torque $(\tau) = \frac{P_w \ 9.549}{n}$ (44)

Where τ is the torque of the electric motor, P_w is the power in watts and ***n*** is the rotational speed in revolutions per minute.

Table 1: Specifications and Dimensions of Various Section and Components

S/N	Parts	Parameters	Values
1	Cylindrical part	Volume	598284904.00 mm^3
		Area	3930760.73 mm^2
2	Base of the converter	Volume	12315043.20 mm^3
		Area	299079.62 mm^2
3	Sprue	Volume	61072561.18 mm^3
		Area	1198508.56 mm^2
4	Conical part	Volume	84203060.70 mm^3
		Area	1198508.55 mm^2
5	Spherical segment	Volume	225775792 mm^3
		Area	1994283.16 mm^2
6	Electric motor	Torque (τ)	0.015 Nm
		Power in watts	2.28 kW
		Angular speed (ω)	148.18 rad/s
		Power output	2.28 kW
7	Gear	Gear ratio	3:2 or 1½:1
8	Total Height of the converter shell	h_t	2480 mm (or 2.48m)

F. Design drawings of the converter

The design drawings are as shown in Figures 7 to 11

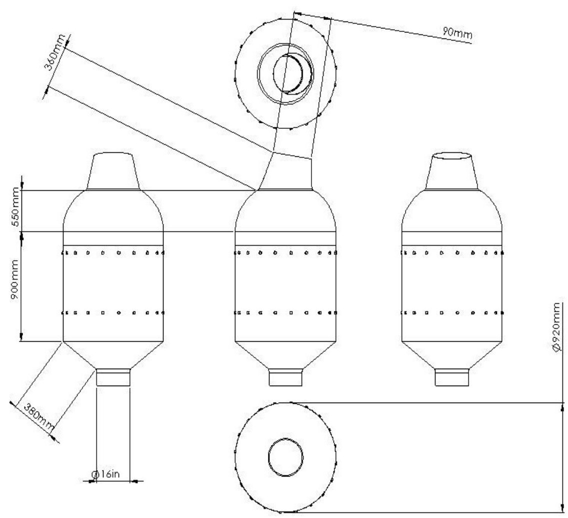
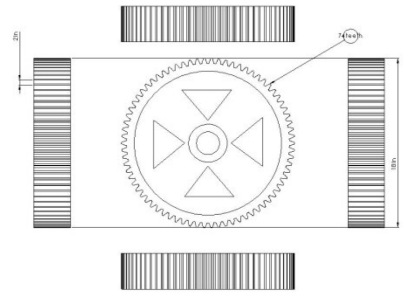
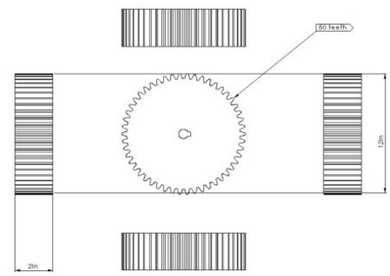


Figure 7: Orthographic Projection Showing Top View, Side Views and Bottom View of Converter

Figure 8: 3D View of the Converter Shell



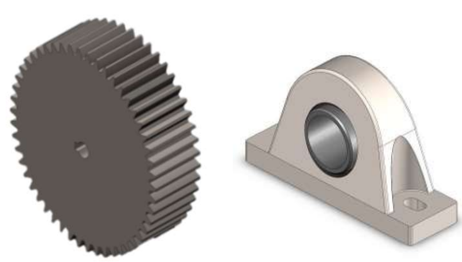
(a)



(b)

Figure 9: 2D view of (a) Driven Gear (b) Driver Gear

(a) (b)



(c) (d)

Figure 10: A 3D view of (a) Electric Motor (b) Driven Gear (c) Driver Gear (d) Pillow Bearing

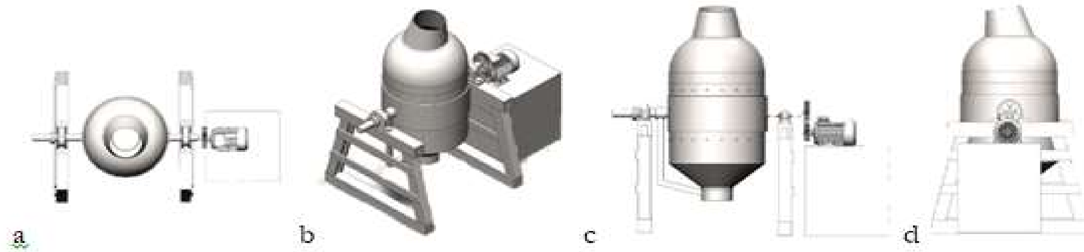


Figure 11: 3D Views of Assembly Drawings (a-d) of the Converter

Table 2: Part List of Converter

S/N	Parts	Specifications	Functions and Properties	Nos
1	Electric motor	1440 rpm, 3 hp	This is the AC electric motor that the shaft is linked with which convert its electrical energy to mechanical energy.	1
2	Driven gear	External Diameter of gear = 457.2 mm Internal Diameter of gear = 60 mm Teeth thickness = 50.8 mm No of teeth = 75	It transmits rotary motion, as well as power from pinion to the converter shell via the shaft.	1
	Driver gear (pinion)	External Diameter of gear = 304.8 mm Internal Diameter of gear = 60 mm Teeth thickness = 50.8 mm No of teeth = 50	They transmit rotary motion, as well as power from electric motor via the one shaft to another gear via belt.	1
3	Pillow bearing	Internal Diameter = 60 mm	It gives support a shaft that rotates	2
4	Shaft	Shaft diameter = 60 mm Shaft length = 38.1 mm Shaft thickness = 10 mm	Is a rotating machine element usually circular in cross section, which is used to transmit power from one part to another	2
6	75mm Angle steel bar and 100 mm U channel stand	Special alloy steel	Used as frame for stand, to make the converter stand firm.	2
7	Converter Shell	Mild steel sheet	It is made from 2 mm mild steel plate and it serves as housing for the refractory and molten pig iron needed for the conversion to steel	3
8	Bolt and nut	Size = 17 mm	Fasteners used to hold different sections of the Bessemer Converter	60
9	Hollow Shafts		It connects the converter shell to the gear, to aid the ease of tilting the vessel	2
10	Refractory bricks	150mm x75mm x50mm	Lining materials	240
11	Refractory cement		Fixing the bricks	
12	Vertical Flap bars	50 mm x 5mm thick flat bar	Fasten the shell	3
13	Horizontal	50 mm x 5mm thick flat bar	Fasten the shell	40

G. Materials Selection

The materials (Table 3) used during the design and fabrication of the work were selected based on some important engineering properties such as wear resistance, material durability, material density and the purchasing cost [43].

Table 3: Cost of component and consumables

SN	Materials	Quantity	Rate (₦)	Cost (₦)
1.	45 mm x 45 mm x 3 mm (thick) angle bar	4	4500	18,000
2.	2 mm thick mild steel plate	3 sheets	20,000	60,000
3.	2.28 W electric motor	1	36000	36,000
4.	Gear (406.4 and 304.8 Dia by 50.8 thickness)	2	14000	28,000
5.	Pillow bearing	2	5000	10,000
6.	5 mm thick Circular plate	4	2000	4,000
7.	60 mm Dia Hollow shaft	1	9000	9,000
8.	25.4 mm x 25.4 mm x 5 mm (thick) angle bar	1	2500	2,500
9.	Bolts and nuts	5 dozen	600	3,000
10.	G.12 Oerlikon® SMAW electrode	1 packet	5500	5,500
11.	Cutting disc (2 mm thick)	7	1200	8,400
12.	Grinding stone (5 mm thick)	2	1500	3,000
13.	100 mm x 50 mm x 6 mm (thick) U-channel bar	1	27800	27,800
14.	80 mm x 50mm x 3 mm (thick) U-channel bar	1	17500	17,500
15.	Vertical Flap bars	3	4500	13,500
16.	Horizontal fastening plate	40	250	10,0000
17.	Welding Accessories			150000
18.	Logistics			20,000
19.	Consultations			25,000
20.	Drawing and drafting			7,500
21.	Literature sources			195,000
22.	Data and Internet solving			15,500
23.		**Total**		**₦759,200**

H. Fabrication and assembling of converter.

The stand was fabricated from 100 mm x 50 mm x 6 mm U-channel steel bar, cut to specified sizes and joined together as support to the weight of the shell, gears, shafts, and the electric motor. A 2 mm thick mild steel sheet was cut and rolled to 900 mm x 900 mm cylinder. The shell was joined by welding formed from cylindrical, conical and hemispherical shape components and the sprue. The base of the converter was made to form a closed ends cylinder which serves as the air box with a diameter 280 mm. The weight of the converter shell was suspended on both sides via the two hollow shafts using pillow block bearings mounted on the upper surfaces of the stands. The shafts were to be connected by welding onto the body of the shell at opposite sides. The gears and electric motor were connected to one of the shaft end to rotate the suspended shell and allow for ease of pouring. The converter shell is divided into three major parts fastened together by three (3) vertical fastening flat steel bars/flaps and two sets of twenty (20) horizontal short fastening flat steel bars/flap (in two rows) around the upper and lower ends of the cylindrical component of the shell (Figure 12). The whole assembling was mounted on the concrete floor through the stands.

III. Results and Discussion

A. Fabrication of components

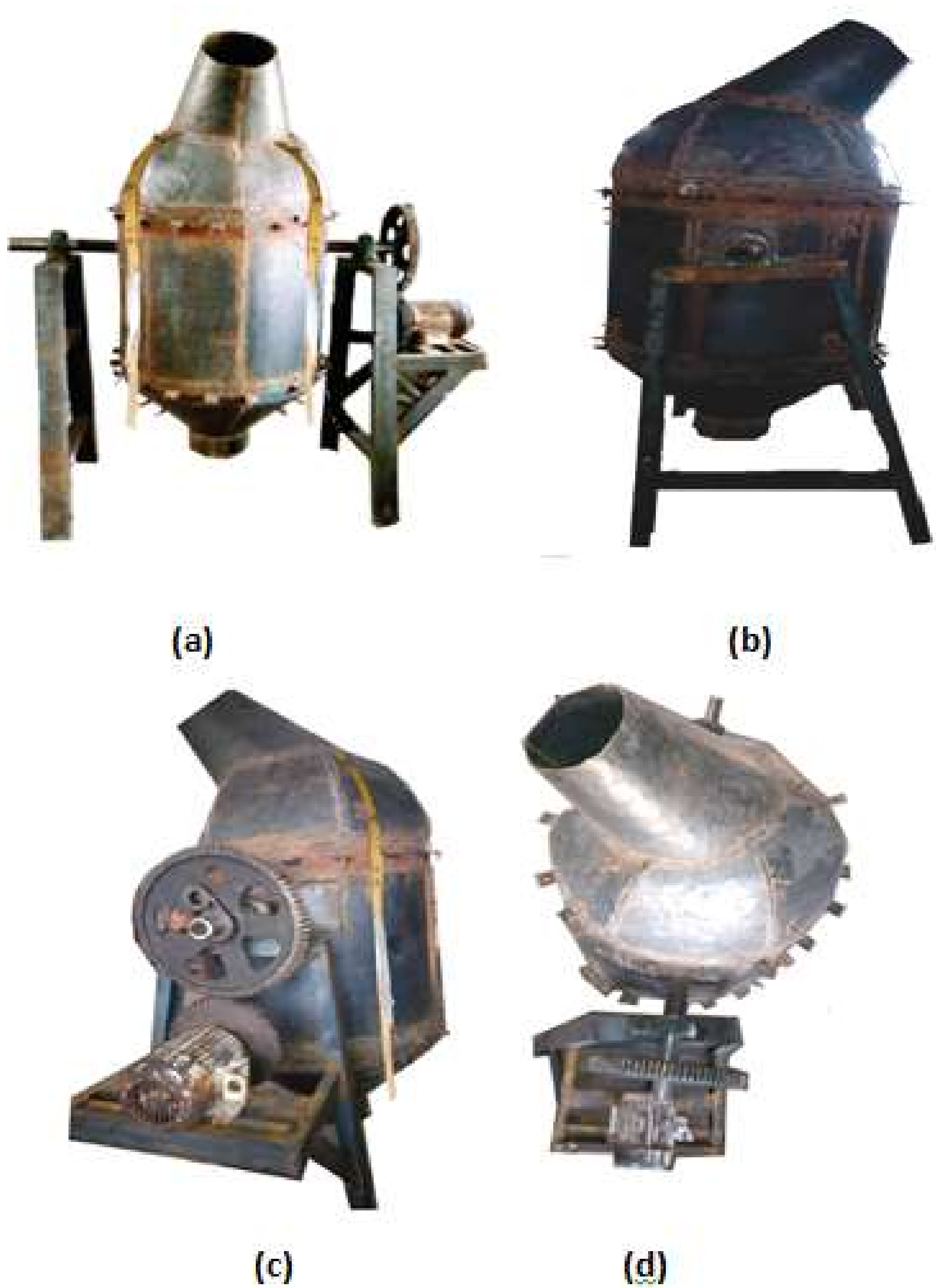
The design calculations and materials in Tables 1 and 2 were used in the fabrication of components as shown in Figures 12 to 13. The fabrication process includes measurement of component dimension, cutting and joining.

(a) (b)

Figure 12: Parts of the Converter Shell (a) before and (b) after Welding, and Fastened Hinge with Bolts and Nuts.

B. Assembling of parts

Different parts were joined by welding and bolt and nuts as shown in Figures 13 (a-d)



(a) (b) (c) (d)

Figure 13: Photographs Showing (a) Front Side (b) Right Side, (c) Left Side and (d) Top Side Views of the Converter

C. Testing, operation and safety instructions

The parts and components attached to the converter were thoroughly examined and found to be in accordance with the design specifications. However, the conversion processes could not be carried out because the work is at present limited to the fabrication of the Bessemer converter shell and the tilting mechanism, without the refractory linings.

i. The converter shell should be horizontally balanced before conversion process takes place.
   Proper inspection of the converter should be done before, during and after using the converter for the conversion process.
ii. All necessary personal protective wares should be used by the operator from fire and hazardous gases.
iii. The operators must be distanced away from the converter during the conversion process, to avoid splashing of the molten metal.
iv. Chimney should be connected above the sprue, to carry exhaust and hazardous gases during the conversion process.

The principle adopted in the designing and fabricating of the Bessemer converter was derived from existing Bessemer converter. However, this design is unique due to flexibility in its fabrication such that the joining method of the converter was modified into a more easily assemble, affordable and accessible.

IV. Conclusions

The materials and process involved in the design and fabrication of the Bessemer converter were based on acceptable international standards. The tilting mechanism works appropriately as designed. The fabrication was made from locally available materials at affordable cost. Further research is recommended on the refractory lining of the converter. The lining should be experimented and developed from locally available refractory materials.

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