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A Sustainable Approach to Steel Scrap Recycling and Management (Nigeria as Case Study)

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Abstract: This study has considered six steel scrap recycling plants, tagged A, B, C, D, E, F. The production process for each of the plants considered was separately observed and recorded. The investigation report revealed that none of the plant was following the due process involved in modern steel scrap recycling. Hence, a sustainable production flow system, deemed to be effective is proposed in this paper. The production data of each section was collected alongside the manpower and pollution control data. The data were analyzed mathematically using the models developed in this study. From the results obtained, pollution control was least in melting section with pollution control index of 33.8%, and highest in heat treatment with index of 51.9%. Comparatively, pollution control was least (37%) in plant A and highest (50.6%) in plant F. Also, manpower was least (32.4%) in plant A and highest (44.6%) in plant E. Mechanization was least (55.4%) in plant E and highest (73.2%) in plant B. Findings further indicated that melting section was running almost full capacity in Plant E (348 against 350 tons per day) and Heat treatment section was also running almost full capacity (342 against 350 tons per day in Plant C). The rest were running much below their design capacities.

Keywords: Heat Treatment, Plant, Pollution Control, Manpower, Mechanization, Steel Scrap Recycling.

1. Introduction

Every material or product has a life cycle. A life cycle is the journey a material or product goes through during its entire life. Every material starts in a raw or crude form, processed, and made into a finished product. After some period of time, the material or product reaches the end of its useful life. When the useful life of a product is exhausted, it is either discarded to return to earth or recycled into new product if possible. The most common disposal option used is to bury it in landfill sites, but this should only occur if the material is too toxic. Other disposal options include burning or put into permanent storage if it is too hazardous to the environment or humans (for example, radioactive materials like Uranium product [1].

The decrease in the rate of depletion of metal reserves by recycling of "metals-in-use" will contribute to the sustainable use of metals. It is obvious that recycling of metals results in appreciable savings of energy consumption (and hence reductions in greenhouse gas emissions associated) compared to primary metals production. The amount of energy consumed in recycling of metal depends largely on the metal in question, its application and the recycling process used, typical energy savings reported for metal recycling over primary metal production are aluminium 95%, nickel 90%, copper 84%, zinc 75%, lead 65% and steel 60% [2]. The electrical energy required for remelting of steel is 1.5GJ/t. It is also given as 1.7GJ/t or 2.2GJ/t [3-5].

The term recycling rate is often used in the literature but sometimes not with a clear meaning. It is also used

interchangeably with collection rate, recovery rate or return rate. Reuter et al suggest that the 'real' recycling rate of a metal should refer to the ratio of the production from secondary raw material (scrap) in the present year to the total production "n" years ago, where "n" is a weighted average lifetime of all products manufactured from this metal [6]. However, this is a purely theoretical figure as the number of goods and products and their respective lifetimes differs. However, practical recycling rates are based on current or present flows of materials. Various recycling metrics are adapted from [7]. Recycling rate is the amount of scrap that is remelted for product manufacture as a percentage of the total amount of available scrap. Recycled content (or return rate) is the amount of scrap remelted for product manufacture as a percentage of the total amount of material (primary plus scrap) used for manufacture of products [1].

The maximum amount of a material that can be recovered depends on the quantity put into service one average product lifetime earlier. Although it is a difficult task, the estimation typical lifespan of various metal products has been reported by [8-13]. According to, the useful life of steel in building and construction is 60 years, and for containers, the useful life is just 1 year. Steel used for vehicles have life span of 5 – 15years [14, 12].

Steel is one of the most valuable engineering materials. It is widely used for various purposes like sheet metal works, concrete reinforcement, railways, bridges, mechanical component, pipeline, etc. Due to its corrosive nature and other forms of failure such as crack, bending, wear, creep etc., steel has a limited service life. When the service life of steel member elapses there may be need for replacement. A whole assembly or a particular steel member may be replaced. The worn-out steel has little or no engineering value and referred to as scrap. Scrap is commonly found around us, sometime mixed up with non-ferrous materials and constitute waste around our vicinity.

However, due to its recyclability, the most economic way of managing steel scrap is recycling. This helps in reducing the level of scrap dump within our environment and it is also profit oriented. In Nigeria, many steel recycling plants produce reinforcement bars, angle bars, flat bars, sections, H-sections, seamless pipes, and others. Most recycling plants in Nigeria use induction furnaces of various capacities for steel scrap melting. The production processes adopted by most steel recycling plants are scrap collection, scrap sorting, scrap shredding, scrap melting, casting of billets or ingots, heat treatment of billets or ingots, rolling of billets or ingots into new products, and collection and transportation of finished product.

The general objective of this paper is to present a sustainable approach to steel scrap recycling and management. Other specific objectives are: to have an overview on existing methods of steel scrap recycling in Nigeria in order to make positive changes, to develop an effective production flow system with minimal risk and maximized productivity, to generate a model for estimation of optimum furnace charge and the corresponding yield using Yield Test Results from various steel recycling plants, and to develop a model for pollution assessment in the steel recycling plants.

2. Overview of Steel Scrap Recycling

Nigeria has abundant steel scrap in almost all parts of the country. The large amount of steel scrap all over the nation indicates that steel scrap recycling in Nigeria is not fully employed and the few steel recycling plants in the country may not be running in full capacity. Other reasons may apply. Some steel recycling plants in Nigeria are show in Table 1.

Table 1. Some Steel Recycling Plant in Nigeria and Their Products [15]

Names of mills	Plant Location	Rolling capacity (tons per year)	Products
Integrated mills [2]	Ajaokuta Steel Co. Ltd. Ajaokuta	540,000	Bars, rods, light sections
	Delta Steel Co., Ovwian/Aladja	320,000	Bars, rods, sections
Rolling mills [13]	Alliance Steel Co., Ibadan	20,000	Bars
	Alliance Steel Co., Onitsha	20,000	Bars
	Asiastic Manarin Ind., Ikeja	60,000	Bars, sections
	Jos Steel Rolling Company, Jos	210,000	Bar, rods
	Kastina Steel Rolling Co., Kastina	210,000	Bar, rods
	Kwara Commercial, Metal and Chemical industries, Ilorin	40,000	Bars
	Mayor Eng. Co., Ikorodu	220,000	Bars, sections
	Metcombe Steel Co., Owerri	10,000	Bars, sections
	Oshogbo Steel Co., Oshogbo	210,000	Bar, rods
	Qua Steel Products, Eket	600,000	Bars, sections
	Selsametal, Otta	100,000	Bars
	Union Steel Co., Ilorin	20,000	Bars
	Baoyao futurelex, Abuja	20,000	Bars
Mini mills [7]	Federated Steel mill, Asaba	140,000	Bars, sections
	General Steel Industry, Otta	50,000	Bars
	Universal Steel Co., Ikeja	80,000	Bars, sections
	Nigeria Spanish Eng. Co., Kano	100,000	Bars
	Niger Steel Co., Enugu	40,000	Bars, sections

2.1 Stages in Steel Scrap Recycling

2.1.1 *Scrap Collection*

Scrap is collected from homes, schools, hospitals, industries, debris etc. as mix, which contains ferrous and non-ferrous materials. They are supplied to steel recycling plants by registered scrap marketers. In the recycling plants, the mix scrap is sorted and separated according to types and sizes. The heavy ferrous metals are cut into reasonable sizes for easy charging and melting in the furnace. Oxygen and acetylene are commonly used for the cutting [15].

2.1.2. Scrap Sorting

Steel scrap is classified in three main categories namely home scrap, new scrap, and old scrap. The category a steel scrap belongs depends on when the material becomes a scrap in its useful life.

- Home scrap: This is the scrap internally generated during the manufacturing of the new steel products in a steel plant. It is also called run around scrap. It is usually in the form of trimmings or rejects generated within a steel plant during production of iron and steel.
- New scrap: New scrap usually called prompt or industrial scrap is generated from manufacturing units involved in steel fabrication.
- Old scrap: scrap is also known as post-consumer scrap or obsolete scrap. It is steel discarded when it has served its useful life. Home scrap and new scrap usually have higher scrap value than old scrap looking at long term effect of corrosion. Scrap from the various sources are collected and transported to Scrap yard of the steel recycling plants for primary sorting before proceeding to shredder for secondary sorting and then to the melting furnace.

At the scrap yard, the materials are sorted and separated appropriately. Copper base metals,

aluminium base metals, ferrous metals and polymeric materials, etc. are duly separated. The ferrous materials are usually separated from the nonferrous by magnetic method. At this stage, all explosive materials (such as gas cylinders) are removed. This primary sorting may be done manually. Sorted scrap is conveyed to shredding plant where the material is being shredded and further sorted automatically. The shredder separates the mix scrap into copper base, ferrous, aluminium base, and polymeric materials. Scrap metal is sorted to ensure that the material charged into the melting furnace if mostly ferrous metals. Sometimes, the mix scrap is sorted to separate the high carbon steel scrap form those of low content. This is done based on industrial experience. Sorting will make the production quite easy as less slag will be produced and less alloying additives will be required to get the desired composition of the steel produced

2.1.3 Shredding

Shredding is done after primary sorting. The shredder is a unit in the recycling plant that cuts the large steel scrap into smaller and almost uniform sizes. Shredded scrap is sometimes compressed into scrap block for efficient charging melting in the furnace. As stated in subsection 2.1.1, further sorting is automatically done by the shredder, separating the ferrous scrap from the nonferrous, and this enhances productivity.

2.1.4 Scrap Melting

The shredded steel scrap and sometimes the non-shredded are transported to the melting furnace where the metals are melted into liquid steel with over laying slag in the crucible. Some steel recycling plants in Nigeria such as those in Odogunyan Ikorodu Lagos State and in Ogijo Ogun State use open induction furnaces of various capacities.

Due to the nature of the furnaces and lack of efficient pollution control systems, these plants generate a lot of pollution into the air which imposes health hazards to people within the location of the plant.

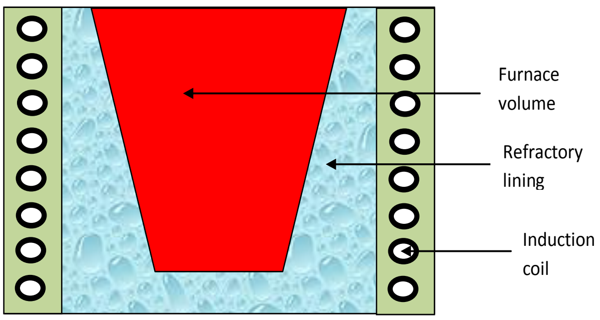

Figure 1. Longitudinal Section of induction furnace

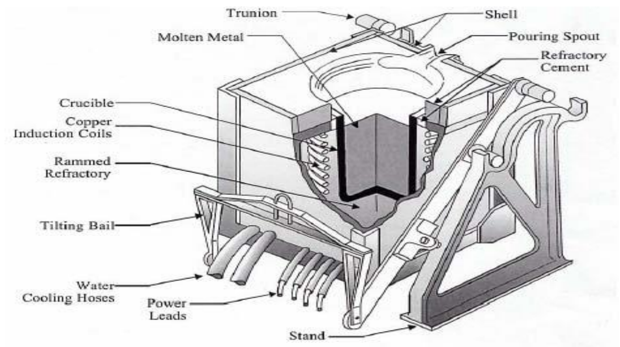

Figure 2. Schematic diagram of induction furnace [16]

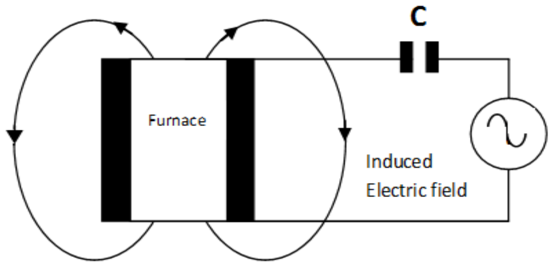

Figure 3. Schematic of the working principle of induction furnace

The operation of induction furnace is based on the principle of electromagnetic induction that was first established by Michael Friday. The induction furnace capacities range from less than one kilogrammes to one hundred of tones. It is used to melt iron and steel, copper, aluminium, and precious metals. Longitudinal sectional of an induction furnace is given as Figure 1 while and its basic components are shown as Figure 2.

There are two basic types of induction furnaces: the core type or channel furnace and the coreless. The core type induction furnace is useful for small foundries with particular requirements for large castings, especially if off-shift melt is practiced. It is usually applied for in duplexing operations and installations in which production requirements demand a safe mitigation approach for readily available molten metal. For the coreless type, it is used when a fast melt of an alloy is desired, or it is required to alter alloys regularly.

Heat production in induction furnace is without combustion or simply clean. The working is such that a high frequency source of alternating current supplies power to the induction coil and high magnitude electric field is developed around the coil as shown in Figure. 3. The wave generated by the electric field produces fire and heat within the volume of the furnace and at due temperature, the heat melts the metal in the furnace.

There are three stages in melting of steel scrap in induction furnace and are:

- First stage: At this stage, melting is done up to 50%of the furnace capacity by mass and the molten steel is deslagged the first time. A sample of the molten steel is taken, quenched and analyzed in the laboratory to check the carbon composition and the compositions of other alloying elements. The result of the analysis is a guide on the selection of the type of scrap needed for further charging of the furnace and the alloying additives required to achieve the desired compositions of the final product.
- Second stage: This is the stage at which the furnace is run up to 75% of its capacity by mass, and at this stage, the molten steel is deslagged the second time and a sample of the molten steel is taken, quenched and analyzed the second time to verify the chemical compositions of the steel in order to know the next suitable treatment needed to achieve the desirable compositions of the final product.
- Third stage: It is the final melting stage at which the furnace is run to about the furnace full capacity by mass. At this stage, the molten steel is treated by addition of deficient alloying elements. This is achieved by addition of some materials like: Ferro-silicon, Ferro-manganes, Silicon-manganes, Aluminium notch, and so on. After addition of the alloying elements, a sample of the steel is analyzed for chemical composition. Finally, when the desired composition is met, the molten steel is tapped into a ladle and surface of the molten steel is shielded using a mixture of metal oxides in powdery form, called radex powder. This powder shields the surface of molten steel against heat loss and penetration of atmospheric element like nitrogen, hydrogen carbon (iv) oxide etc. which possibly form hard phases and mar the quality of the steel. Addition of radex powder helps in maintaining of the

liquid state of the metal until the casting commences.

2.1.5 Billets/Ingot Casting

At the end of stage three, the molten steel is transported to the casting machine, usually a Continuous Casting Machine (CCM) via overhead crane. The tundish is properly positioned underneath the ladle and bottom nozzle of the ladle is opened using oxygen lancing. The molten steel in the ladle then runs into the turndish and from turndish to the mould hence from the mould a solid metal (billet) is formed. Sometimes, ingots are rather produced. The hot billets are quenched by high pressure water splash running over the surface of the hot billet at speed of about 220litres per minute. The billets are cut into appropriate lengths, and transported to the billet yard where they are stacked and allowed to cool naturally to ambient temperature.

2.1.6 Heat Treatment

Billets or ingots are taken from billet yard and properly aligned in the heat treatment furnace. The heat treatment furnace runs at constant temperature of about 1200ºC and the billets are allowed for a soaking time of about 48hours before ejecting them into the rolling mill where they are rolled out in different sizes and shapes. Billets are heat treated to minimize flaws in the final product such as voids, segregations, inclusions, dislocation, cracks, pin-holes and so on.

1.2.7 Rolling

Heat treated billets are ejected at regular time intervals from the heat treatment furnace into a system of rolls along which the hot billets are reduced into appropriate cross-section and shapes as reinforcement bars, angle bars, seamless pipes etc., depending on the shape of the exit die.

1.2.8 Furnace Lining

Generally, there are various forms of furnace maintenance. However, one of the most regular maintenance of metallurgical interest is furnace relining. Furnace relining is the replacement of the worn-out refractory linings of a furnace for more efficient and safe use. Furnace production is run in batches. One heat of 25 tons takes about 2 hours for completion. After running a maximum of 16heats, the furnace is relined to prevent the penetration of molten steel towards the induction coil and bridging of the circuit. Relining is also done to maintain the furnace capacity for each heat production.

In furnace relining, a mild steel sheet is used to fabricate a former whose volume is the estimated capacity of the furnace. For 25tons furnace the volume of the former is about 3.5cubic meters. The former, usually a frustum shape is inserted into the induction coil with a gap of about six inches from the coil. The lining material (called ramming mass) is poured into the gap between the coil and the former and properly compacted. Ramming mass is a mixture of metallic oxides aluminium, silicon, magnesium etc., mixed with sodium silicate and boric acid. Boric acid is usually 1.4% by mass. After relining the furnace, a sintering heat is run to strengthen the furnace lining before subsequent heats.

1.2.9 Man Power

Man power is the strength or effort of human being put to work. The Application of artificial intelligent (AI), big data and digitalization is seen to be driving the industry forward, allowing for more efficient, cost-effective, and safe operations. As this technology gives advantages, the human role of any activity, particularly crane operations will always be vital. Undoubtedly, the world is moved by global advancement in technology across all aspect of human endeavor. However, the effort of man still remains very vital in providing the coordination and management of industrial activities including machine operations.

3. Materials and Methods

Many researchers have presented different flowcharts representation of steel/iron scrap recycling processes. For instance, in a flowchart of steel scrap recycling process ended in iron rods as the last product of the process [15]. In the same chart, the melting and heat treatment furnaces were not specified for clarity and the slag collection is not at one point. Also, in, another interesting recycling chart was presented. The chart showed the general principles of metal recycling without detail description of steel scrap recycling [1]. However, in this paper, six steel recycling plants tagged A, B, C, D, E, and F and their various recycling processes are shown in Table 2.

Looking at Table 2, it can be seen that none of the plants is following the complete processes involved in modern steel recycling hence a complete chart is proposed as shown in Figure. 4.

Expressing other parameters in terms of total yield, Y except total furnace capacity, C, gives:

$$SC = 1.1829Y; A = 0.0001748Y; SL = 0.1545Y$$

Solving for L in (1) in terms of Y gives: $L = 0.0286\,Y$

From the above model, it could be concluded that for every one ton of steel produced, 1.1829tons of scrap is Key: 1 - Steel scrap from various sources, 2-magnetic separation, 3- Nonferrous metals, 4-Sorted steel scrap, 5-Scrap shredding, 6- Nonferrous metals, 7-shredded scrap, 8-Scrap melting , 9-Slag,10-

Alloying,11-Billets or ingots,12-Casting of billets and ingots, 13-Home scrap and Mill scale return, 14- Heat treatment of billets or ingots, 15-Rolling of billets or ingots into finished products, 16-Rolling mill product(bars, sections, pipes and others).

3.1 Proposed Furnace Yield Model

One of the objectives of this work is to determine the furnace yield of the recycling and their productivities via the yield test results. In this work, it is also an objective to use the yield test result to develop a general model for estimating the furnace charge required to run a furnace to full capacity or less with factor of safety. In order to achieve this, yield test was conducted on different furnaces used by the recycling plants visited and the results obtained were presented in Table 3.

The results were further analyzed and used to develop a model for calculating the quantity of material required for a less or full-scale production of any of the furnaces without endangering the life of the furnace.

Key: Total furnace capacity, *C* =130 tons, total scrap used, *SC* = 145.5 tons, total alloying added, *A* = 0.0215 tons, total yield, *Y* = 123 tons, total slag tapped, *SL* = 19 tons.

Table 2. Steel Scrap Recycling Processes in Various Plants

Plant	Recycling process
A	ST $\rightarrow$ SH $\rightarrow$ CP $\rightarrow$ ML $\rightarrow$ CS $\rightarrow$ HT $\rightarrow$ RL
B	ST $\rightarrow$ ML $\rightarrow$ CS $\rightarrow$ HT $\rightarrow$ RL
C	ST $\rightarrow$ ML $\rightarrow$ HT $\rightarrow$ CS $\rightarrow$ HT $\rightarrow$ RL
D	ST $\rightarrow$ SH $\rightarrow$ ML $\rightarrow$ CS $\rightarrow$ HT $\rightarrow$ RL
E	ST $\rightarrow$ ML $\rightarrow$ CS $\rightarrow$ HT $\rightarrow$ RL
F	ST $\rightarrow$ SH $\rightarrow$ CP $\rightarrow$ ML $\rightarrow$ HT $\rightarrow$ CS $\rightarrow$ RL $\rightarrow$ HT

Key: ST= Scrap sorting, SH=Scrap shredding, CP = Compression of scrap into metal blocks, ML = Melting, CS = Casting of molten steel into billets or ingots, HT = Heat Treatment, RL = Rolling of billets or ingots into final product.

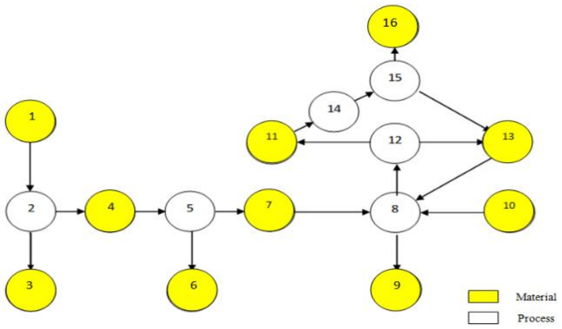

Figure 4. Schematic diagram of steel scrap recycling process

Table 3. Yield Test Results from Various Furnaces

Plant	Location	Furnace Capacity(tons)	Scrap Used(tons)	Alloying Added(tons)	Furnace Yield (tons)	Slag(tons)
A	Ogun state	30	34	0.006	28	3.6
B	Lagos State	25	27	0.004	25	1.9
C	Delta State	15	16	0.002	13.5	2.3
D	Ogun state	25	28	0.003	24	3.7
E	Lagos State	10	11.5	0.0015	9	2.2
F	Ogun state	25	29	0.005	23.5	5.3

A general rule for calculating furnace yield is developed as follows:

$$\frac{C}{SC} = \frac{130}{145.5} = 0.8935\,;\ \frac{Y}{SC} = \frac{123}{145.5} = 0.8454\,;$$
$$\frac{A}{Y} = \frac{0.0215}{123} = 0.0001748\ ;\ \frac{SL}{Y} = \frac{19}{123} = 0.1545$$

Let the quantity of metal loss be, *L*:

$$SC + A = Y + SL + L \quad (1)$$

used, 0.1748kg of alloy is added, 0.1545tons of slag is generated, and 28.6kg of steel is lost. This model could be generally used to estimate the maximum furnace charge and avoid over charging which may cause explosion of the furnace.

3.2 Proposed Equations

In this study, the basic production data were obtained from the Quality Control Departments (QC) of each of the visited plants and the data were properly analyzed. The design capacity, actual production per day, time input, number of activities in a production process, the number of activities carried out by manpower and the number of activities carried out by machines were obtained from the QC departments of each of the plants. In addition, the amount of toxic wastes generated by each section, and the amount of the wastes totally detoxified before discharge were also obtained from the Health and Safety Department of each plant. A model is proposed in this article for estimating the percentage manpower and percentage mechanical power used by each section. A model was also proposed for estimating the percentage pollution control in each section of the plants.

3.2.1 Proposed Model for percentage Manpower and Percentage Mechanical Power

Suppose a section of a plant carries out 6 activities, say A_1, A_2, A_3, A_4, A_5, and A_6. In this paper, each activity is allotted a dimensionless weight of unity.

$$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 = 6 \quad (2)$$

If 2 activities are carried out by manpower while the rest 4 are carried out by machines, the proposed model for percentage manpower and machine power of the section stated as:

$$\%Manpower = \frac{A_{man}}{A} \times 100 = 33.33\%$$
$$\%Mech..power = \frac{A_{mech}}{A} \times 100 = 66.6\%$$

where A_{man} is the sum of the weights of all the activities done by manpower in a process and A_{mech} is the sum of the weights of all the activities done by machine in the same process. For instance, in a typical Scrap melting Section (SMS) of any steel recycling plant, the following activities are common: Charging (done manually or by machine), Furnace power regulation (manual), Stirring of the molten steel (Barrel men or machine power), Temperature check (Barrel men or automatic display), Tapping of slag and molten steel (crane) and, Transportation of the molten steel SMS to CCM (crane).

The way these activities are done vary from plant to plant based on the equipment available in the plant. The Man Power and Mechanical Power Models in this study were developed to provide information about the Level of mechanization in each of the plants.

3.2.2 Pollution Assessment Model

A model for pollution assessment is proposed for estimating the percentage of a pollution control of a steel recycling plant. The model is given by

$$PCI = \frac{1}{n}\sum_{i=1}^{i-n} \frac{P_i A_i}{AT_i} \quad (3)$$

where *PCI* = pollution control index, $\%Detox._i$ = percentage detoxification of pollutant *i* per day (or pollution control index of pollutant i, termed Pi), A_i = mass or volume of pollutant *i* treated in the section per day, AT_i = Total amount of pollutant *i* generating per day for a section, $i = 1,2,3,\cdots n$ = number of pollutants generated by a section per day. It should always be noted that %Detox.i and Pi have the same meaning as given in equation 3.

$$\%Detox._i = \frac{C_{oi} - C_{di}}{C_{oi}} \times 100 \quad (4)$$

where C_{oi} = initial concentration of pollutant *i*, C_{di} = discard concentration of pollutant *i*.

For a pollutant having initial concentration of 40g/l and discard concentration of 15g/l, the pollution control index $P_i = 62.5\%.$ In the case where concentration ratio C_R is given, Eq. (4) can be expressed as:

$$\%Detox._i = 100\left(1 - C_R\right), \quad C_R = C_{di}/C_{oi} \quad (5)$$

3.2.3 Pollution Control Index Calculation

Suppose the melting section of a plant generates 12000 litres of a toxic liquid per day and 20000cm3toxic fumes per day. If 5000litres of the liquid is 50% treated per day before disposal and 7000 cm3 of the toxic fume is 40% treated per day before flaring it into the air, then the Pollution Control Index of the melting section per day is given as:

$$PCI = \frac{1}{2}\left\{\frac{50 \times 5000}{12000} + \frac{40 \times 7000}{20000}\right\} = 17.42\%$$

On the other hand, suppose all the 12000litres of the toxic liquid is 100% detoxified and all the 20000cm^3 of the toxic fume is 100% treated before flaring, then

$$PCI = \frac{1}{2}\left\{\frac{100 \times 12000}{12000} + \frac{100 \times 20000}{20000}\right\} = 100\%$$

However, it should be noted that 100% pollution control may not be feasible in scrap melting section of a steel recycling plant.

4. Results and Discussion

The pollutants generated by all the sections of the recycling plants used for this survey were properly identified. The total amount of each pollutant generated, the amount treated and the percentage detoxification after treatment were collected from the Health and Safety departments of the plants as raw data. The raw data collected is presented in Table 3 and (3) was used to calculate the percentage pollution control of each section of the plant and hence the overall percentage pollution control of each plant. The results obtained were tabulated as shown in tables 4 to 8.

Table 4. Pollution Assessment Data of Plant A

	Plant A								
Sections	**Toxic Solid waste**			**Toxic fume**			**Toxic Sewage**		
	Amount (tons) generated per day	**Amount (tons) Treated per day**	**%Detox. per day**	**Amount (cum) generated per day**	**Amount (cum) Treated per day**	**%Detox. per day**	**Amount (litres) generated per day**	**Amount (litres) Treated per day**	**%Detox. per day**
Rolling Mill	Nil	Nil	Nil	250	180	67	2500	1500	75
Shredding	50	30	45	300	200	40	Nil	Nil	Nil
Casting	Nil	Nil	Nil	150	110	75	6500	5000	45
Heat Treat.	Nil	Nil	Nil	150	80	62	Nil	Nil	Nil
Melting	15	0	0	450	350	60	3000	2500	65

Rolling Mill Section Pollution Control Index,

$$PCI = \frac{1}{2}\left\{\frac{180X67}{250} + \frac{1500X75}{2500}\right\} = 46.6\%$$

Shredding Section Pollution Control Index,

$$PCI = \frac{1}{2}\left\{\frac{30X45}{50} + \frac{200X40}{300}\right\} = 26.8\%$$

Casting Section Pollution Control Index,

$$PCI = \frac{1}{2}\left\{\frac{110X75}{150} + \frac{5000X45}{6500}\right\} = 44.8\%$$

Heat Treatment Pollution Control Index,

$$PCI = \left\{\frac{80X62}{150}\right\} = 33.1\%$$

Melting Section Pollution Control,

$$PCI = \frac{1}{3}\left\{\frac{0}{15} + \frac{350X60}{450} + \frac{2500X65}{3000}\right\} = 33.6\%$$

Table 5. Production Data of Plant A

Plant A						
Sections	**Daily production time (hr)**	**Production**		**Power**		**PCI**
		Design Capacity (tons)	**Actual Prod. (tons)**	**%Man power**	**%Mach.power**	
Rolling	6	350	300	35	65	46.6
Shredding	8	350	280	45	55	26.8
Casting	8	400	300	32	68	44.8
Heat Treat.	24	400	320	30	70	33.1
Melting	7	300	230	20	80	33.6

Average percentage manpower,

$$\%A_{manpower} = 1/5(35 + 45 + 32 + 30 + 20) = 32.4\%$$

Average percentage machine power,

$$\%A_{manpower} = 1/5(65 + 55 + 68 + 70 + 80) = 67.6\%$$

Average Pollution Control Index,

$$A_{PCI} = 1/5(46.6 + 26.8 + 44.8 + 33.1 + 33.6) = 37\%$$

Table 6. Summarized Production data of the various Plants

Plant	**Rolling**		**Shredder**		**Casting**		**Heat treatment**		**Melting**	
	Full cap.	**Actual prod.**	**Full cap.**	**Actual prod.**	**Full cap.**	**Actual prod.**	**Full cap.**	**Actual prod.**	**Full cap.**	**Actual prod.**
A	350	300	350	280	400	300	400	320	300	230
B	250	200	300	250	350	300	380	340	300	200
C	300	280	330	300	350	330	350	342	300	275
D	350	320	400	300	450	320	480	380	350	248
E	400	350	450	420	470	450	380	350	350	348
F	450	430	400	350	380	340	420	390	380	340

Key: Full cap. – full capacity; Actual prod – actual production

Table 7. Summarized pollution control data and mechanization of the various plants

Plant	**% Aman power**	**% Amach. power**	**A_{PCI}**
A	32.4	67.6	37.0
B	26.8	73.2	44.7
C	37.2	62.8	40.2
D	38.6	61.4	49.8
E	44.6	55.4	43.1
F	43.2	56.8	50.6

Table 8. Summarized pollution control data of the various plant sections

Plant	Rolling mill section (%)	Shredder section (%)	Casting section (%)	Heat treatment section (%)	Melting section (%)
A	46.6	26.6	44.8	33.1	33.6
B	51.9	48.2	43.3	54.0	26.0
C	29.7	36.0	48.0	46.7	40.6
D	42.3	44.0	55.6	70.8	36.2
E	42.3	50.4	58.1	37.2	27.8
F	55.6	30.8	58.2	69.7	38.6
Avg	**44.8**	**39.3**	**51.3**	**51.9**	**33.8**

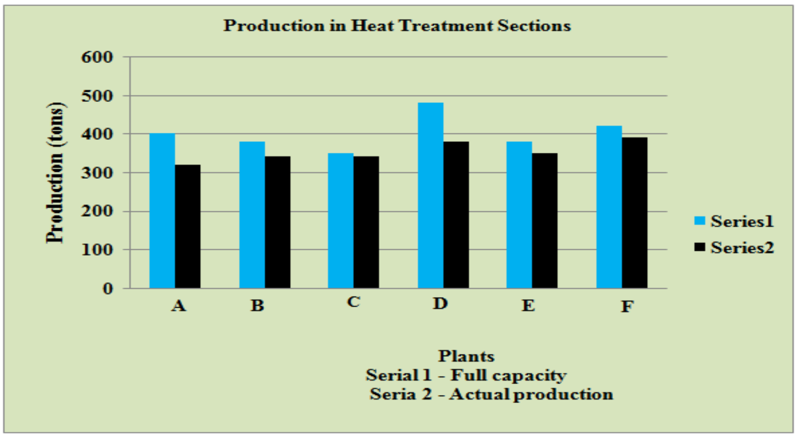

Figure 5. Production in Heat treatment Sections of the various

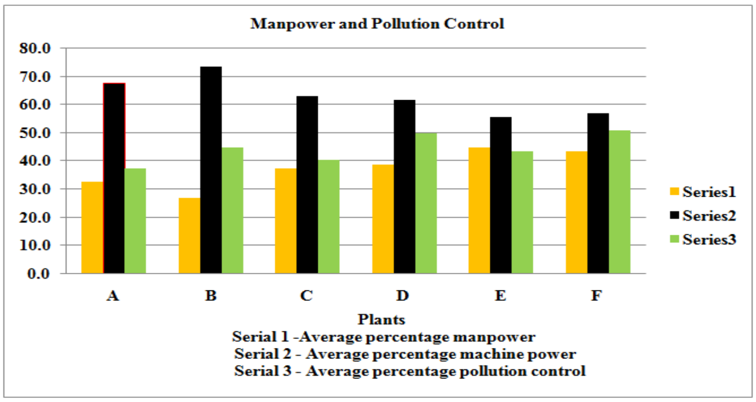

Figure 6. Man power and pollution control result of the various plants

From Table 5, it is seen that for plant A, the rolling mill section rank highest in pollution control (46.6%) followed by casting section (44.8%), while the rest of the sections rank less than 35%. The shredding plant is the least (26.8%). This indicates that the shredding section of plant A is not much committed to pollution control. From Table 8, it is shown that for plant B, the heat treatment section ranks highest in pollution control (54%) while melting section ranks least (26%). Generally, on average pollution control, Table 8 shows that heat treatment section of the plants ranks highest in pollution control (51.9%) followed by casting section (51.3%) while shredding section and melting section rank least with 39.3% and 33.8% pollution control respectively. Table 6 shows that only melting section of plant E runs almost full-scale production, that is 348 tons per day against 350 tons (this has been shown further in Fig. 5) The rest of the melting sections run below the plant capacity. It also shows that none of the shredding sections of all the plants run full scale production. Regarding the rolling mills of the plants as in Table 6, all the plants run below the full capacity. A similar case is seen in casting section. Furthermore, Table 6 shows that heat treatment sections of plants C and E run almost full-scale production. The manpower and pollution control of the plants were compared as in Table 7 and Fig. 6. It can be seen that plant E has highest manpower (44.6%) followed by plant F (43.2%). This signifies that plant E and F have less mechanized production process. It is also seen that plants D and F have high pollution control indices (above 50%), although their level of mechanization is low compared to plants A and B.

5. Conclusion and Recommendation

In this study, emphasis was on the assessment of level of mechanization, pollution control and productivity of some steel recycling plants in Nigeria. From the results obtained, it may be said that pollution from steel recycling plants is generated from melting and shredding sections. On the other hand, less pollution was generated from heat treatment and rolling mill sections. Looking at the all the sections of the plants, none of the plants was running full scale production. The level of mechanization of the production process is low. From low mechanization observed in the various sections of the plants, the manpower usage is high. Thus, modern technologies are required to reduce the level of manpower.

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Conflict of interest

The Authors have no conflicts of interest to declare that they are relevant to the content of this article.

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