Survey on Greenhouse Gas Emissions in the Steel Industry in Zimbabwe

L. K. Gudukeya, C. Mbohwa

Abstract **- Climate change is one of the greatest challenges worldwide. Its most severe impacts may still be avoided if efforts are made to transform current energy systems. The notion of climate change mitigation refers to the reduction of the rate of climate change via management of its causal factors such as the emission of greenhouse gases from fossil fuel combustion, agriculture, land use changes, cement and steel production etc. [4]. This paper gives results of a survey carried out on the steel industry in Zimbabwe. This gives a clearer indication on how much work is yet to be done in the mitigation of greenhouse gas emissions in this industry.**

Index Terms **– greenhouse gas, steel, steel industry, emissions.**

I. INTRODUCTION

Earth's climate is warming as a result of anthropogenic emissions of greenhouse gases, particularly carbon dioxide (CO_2). Anthropogenic emissions of non-CO_2 greenhouse gases, such as methane, nitrous oxide and ozone-depleting substances also contribute significantly to warming. Some non-CO_2 greenhouse gases have much shorter lifetimes than CO_2, so reducing CO_2 emissions offers a great opportunity to lessen future climate change. [6]. CO_2 is generally not a pollutant because it is a normal constituent of air. However, in its excess it becomes a contaminant because it leads to adverse effects on the climate. Temperature conditions and climate on Earth are controlled by the balance between absorbed solar radiation and outgoing terrestrial radiation. The greenhouse effect is when the radiatively active atmospheric constituents permit the short wavelength visible radiations to pass through but trap the infrared radiation, the longer wavelength (heat waves) reflected by the earth's surface.

This generally causes a warming of the planet's surface, compared to the case without atmosphere. Hence perturbing the radiation balance of the planet, e.g., by anthropogenic CO_2 emissions, induces climate change. [9]. The effects of environmental degradation due to climate change are already visible. Global surface temperature has increased by approximately 0.2°C per decade in the past 30 years, similar to the warming rate predicted in the 1980s in initial global climate model simulations with transient greenhouse gas changes. [2]. The climate will become gradually hot and likely effects are seen on sea levels and extermination of species. [5].

A number of countries in Africa are already faced with semi-arid conditions that make agriculture challenging, and climate change will be likely to reduce the length of growing season as well as force large regions of marginal agriculture out of production. [3]. From Cairo to the Cape, the impact of man-made climate change is already being felt. Farmers, people in cities, local scientists and governments all agree that there is evidence of more extreme and unseasonal weather taking place outside the natural variability and cycles of African climate, and that the poorest communities are the least able to adapt [10]. Climate change has taken its toll in Zimbabwe too. Rainfall exhibits considerable spatial and temporal variability characterised by shifts in the onset of rains, increases in the frequency and intensity of heavy rainfall events, increases in the proportion of low rainfall years, decreases in low intensity rainfall events, and increases in the frequency and intensity of mid-season dry-spells [11].

Extreme weather events, namely tropical cyclones and drought have also increased in frequency and intensity [7]. According to the Zimbabwe Meteorological Service, daily minimum temperatures have risen by approximately 2.6°C over the last century while daily maximum temperatures have risen by 2°C during the same period. Rainfall patterns and crop production progressively deteriorate from Region I to V, where Region 1 receives less that 1000mm rain annually and Region V receives less than 450mm. [1]. For example, Chinhoyi and Chibero and their surroundings have shifted from natural region II to natural region III while Kwekwe and its surroundings have shifted from natural region III to natural region IV. In addition, natural region I has reduced in size, natural region II has shifted further east and natural region III has shifted to the north. Overall, the climate in Zimbabwe is regionally differentiated, but is generally becoming warmer with more erratic rainfall patterns. [1]. This highlights the levels of climate change in Zimbabwe and the need for mitigation at every level.

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II. BACKGROUND TO THE STEEL INDUSTRY

The global steel production has been growing for the last 50 years, from 200Mt in 1950s, exceeding 1000 million tonnes for the first time in 2004 and reaching 1 240Mt in 2006. The

main reason is that the steel production in China increased from 127 million tonnes to 421 million tonnes in 2006 (Remus R, et al, 2013). Iron and steel making industry is one of the most energy-intensive industries, with an annual energy consumption of about 24EJ ($24*10^{18}$ J), 5% of the world's total energy consumption. The steel industry accounts for 3%–4% of total world greenhouse gas emissions. [15]. Worldwide different methods of reducing greenhouse gas emission in the production of steel are being employed. These methods include recycling of granulated blast furnace slag and capturing CO_2 during the iron and steel manufacturing.

During the years 2004 and 2009 Zimbabwe faced its worst economic crisis and the steel industry was not spared. The largest steel making parastatal in Zimbabwe was the worst affected. However despite the slowing down of production at the parastatal, steel production was estimated to have increased in 2008 and 2009 owing to increased production from other private companies. [12]. An Asian company has invested US$ 750 million into the rehabilitation of the parastatal (The Sunday Mail, 2013) and the production of steel at full capacity is ready to resume [13]. With this development it is imperative to look at the current methods, if any, of mitigating emissions of greenhouse gases in the manufacturing of steel.

III. LITERATURE REVIEW

A. STEEL

Steel is a term given to alloys containing a high proportion of iron with some carbon. Other alloying elements are also present in varying proportions. These are: carbon, manganese, phosphorus, sulphur, silicon, and traces of oxygen, nitrogen and aluminium. Alloying elements intentionally added to modify the characteristics of steel include: manganese, nickel, chromium, molybdenum, boron, titanium, vanadium and niobium. [14]. The properties of steel are highly dependent on the proportions of alloying elements, so that their levels are closely controlled during its manufacture. The properties of steel also depend on the heat treatment of the metal. Steel has a global production of over 1 200 million tonnes. Its main advantages are high strength and low price. This makes its uses versatile ranging from structural steel in buildings to sheet steel used in motor vehicles and domestic appliances. The major disadvantage of steel is that it will oxidise under moist conditions to form rust. Typical steel has a density of about $7.7 g/cm^3$ and a melting point of about 1650^oC. [8].

B. PRODUCTION OF STEEL IN ZIMBABWE

There are two main ways in which steel is produced in Zimbabwe:

- from its elements at the parastatal
- from Scrap at other private companies

C. PRODUCTION OF STEEL FROM ITS ELEMENTS

The process starts at the coke ovens. Fig 1 shows the process that is followed in the coke ovens. During Coal Carbonisation waste gas that includes greenhouse gas emissions is produced during two procedures:

- combustion of coke oven gas or Blast Furnace produces - (carbon monoxide) CO, (carbon dioxide) CO_2, (sulphur oxides) SO_X, (nitrogen oxides) NO_X and trace elements and these are released directly into the atmosphere.

- conversion of coal to coke produces raw coke oven gas $C_{10}H_8$, C_6H_6, Tar, NH_3, HS_2, HCN and trace elements. The raw coke oven gas then goes through a cleaning process that recovers Ammonia, Crude Benzol and Naphthalene out of it.

The Blast furnace has a gas cleaning process that is shown in Fig 2.Coke that is less than 20mm in size produced at the Coke Plant is sent to the Sinter plant. The sintering process is a pre-treatment step in the production of iron, where fine particles of iron ores and in some plants, also secondary iron oxide wastes (collected dusts, mill scale), are agglomerated by combustion. Accumulation of the fines is necessary to enable the passage of hot gases during the subsequent blast furnace operation. Sintering involves the heating of fine iron ore with flux and coke fines or coal to produce a semi-molten mass that solidifies into porous pieces of sinter with the size and strength characteristics necessary for feeding into the blast furnace. The solidified sinter is then broken into pieces in a crusher and is air-cooled. Product outside the required size range is screened out, oversize material is re-crushed, and undersize material is recycled back to the process.

Emissions from the sintering process arise primarily from materials-handling operations, which result in airborne dust, and from the combustion reaction on the strand. Combustion gases from the latter source contain dust entrained directly from the strand along with products of combustion such as CO, CO_2, SO_x, NO_x, and particulate matter. The concentrations of these substances vary with the quality of the fuel and raw materials used and combustion conditions.

Atmospheric emissions also include volatile organic compounds formed from volatile material in the coke breeze, formed from organic material under certain operating conditions. Metals are volatilized from the raw materials used, and acid vapours are formed from the halides present in the raw materials. Combustion gases are most often cleaned in electrostatic precipitators (ESPs), which significantly reduce dust emissions but have minimal effect on the gaseous emissions. This cleaning process is in Fig 3.

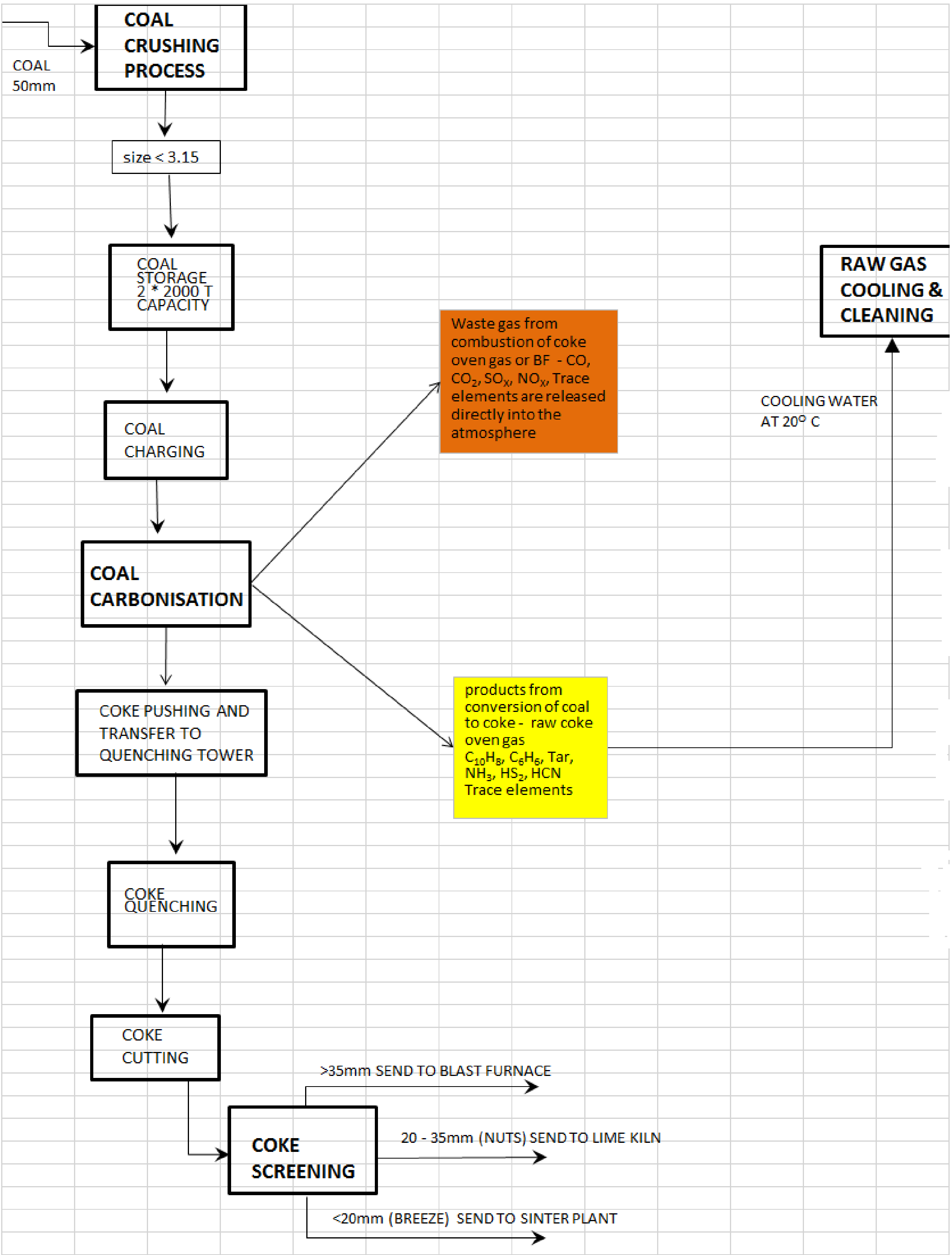

Fig 1: the process that is followed in the coke ovens

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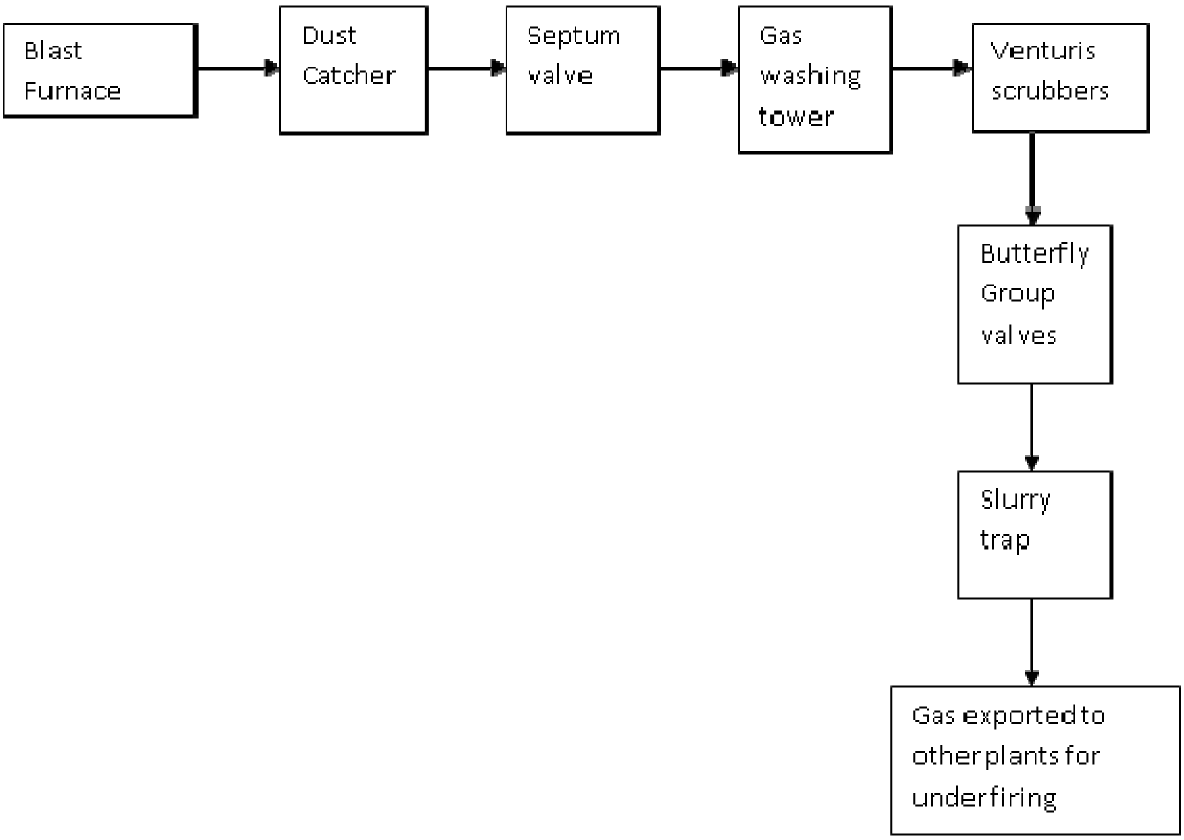

Fig 2: The gas cleaning process in the Blast Furnace

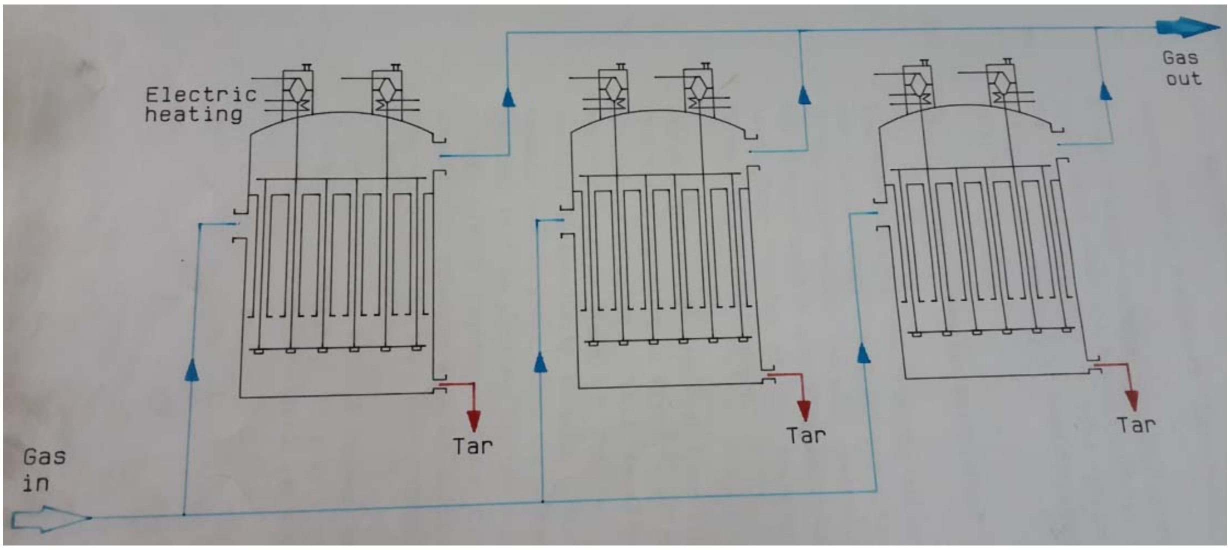

Fig 3: the cleaning of combustion gases in electrostatic precipitators

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From the Sinter plant the next stage is the Iron plant. The summarised process is in Fig 4. At this stage the hot metal slag is moved to the Steel making plant. Steel making process involves the conversion of pig iron into steel. This is done by reducing the quantities of carbon, silicon, manganese, sulphur and phosphorus. This reduction is done using the oxidation process. Generally the reduction levels are as shown in Table 1:

Table 1: Reduction levels of different elements

ELEMENT	FROM (%):	TO (%):
Carbon	4.25	0.07
Sulphur	0.05	Nearly zero
Phosphorus	0.12	Nearly zero
Manganese	0.80	0.20
Silicon	0.05 – 0.09	Nearly zero

Hot molten pig iron arrives at the steel making plant at 1250^{o}C having been tapped from the blast furnace at temperatures above 1450^{o}C. When hot metal arrives at the plant it is stored in three stationary hot metal mixers. Two of the mixers have a capacity of 800 tonnes each and the third has a capacity of 500 tonnes. The hot metal mixer temperature is maintained at 1250^{o}C using coke oven gas. In addition to maintaining the hot metal temperature the mixers also homogenise chemical variations of hot metal batches. Hot metal is transferred from the mixers to the basic oxygen furnace (BOF) using 60 tonne capacity ladles. There are two BOFs each with a capacity of 60 tonnes each. If sulphurs are high the hot metal is first sent to the desulphurisation plant where the sulphur levels are reduced to 0.05% or less before being charged into the BOF.

Limestone ($CaCO_3$) is mined and crushed to 80mm size before being transferred to the lime processing plant by conveyor belts. The limestone is processed in shaft furnaces called lime kilns. The process involves calcination of limestone using coke. Limestone and coke are charged at the top of the kiln and air is blown from the bottom. The heat supplied by burning coke drives out the carbon dioxide in the limestone to form lime according to the following reaction

$$CaCO_3 + \text{Heat} \quad = \quad CaO + CO_2$$

The lime reaches the bottom of the kiln at about 40^{o}C. It is then crushed to 30-50mm size before being transferred to the BOF where it is used in the steel making process. Hot metal and scrap are charged into the BOF and oxygen is blown into the charge. Lime is also added into the BOF about a third way (i.e. 6 minutes) into the blowing process. The charge weight is 58 – 65 tonnes and scrap is ranges from 15 to 25% of the total charge depending on hot metal chemical analysis. The oxygen blowing process reduces the carbon content in the hot metal to levels required in steel through the following exothermic reaction:

$$2C + O_2 \quad = \quad 2CO$$

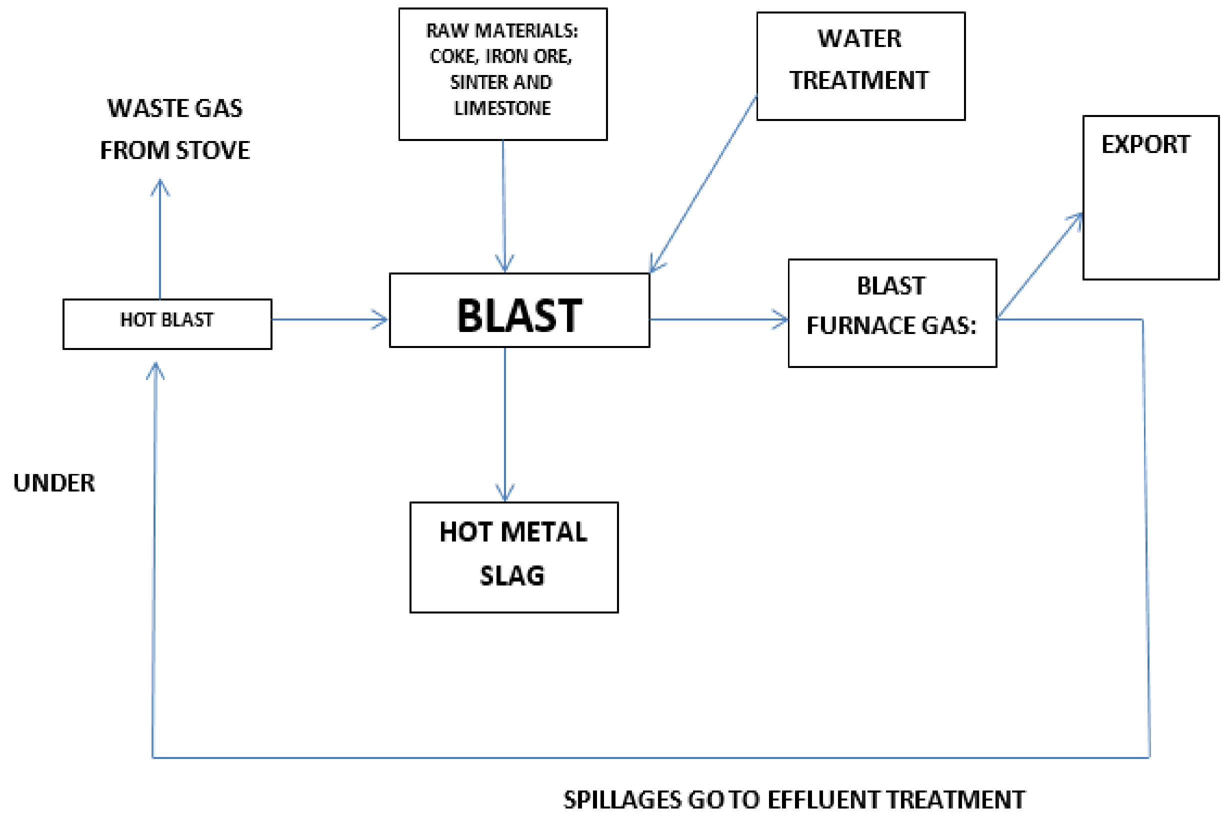

Fig 4: Summarised process of the Iron Plant

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Lime is a carrier of oxides formed during the process of steel making. All oxides combined are called slag. Silicon is the main component in the slag. It is acidic and will therefore react with lime which is basic. The lime is added in enough quantities to make the slag basic and capable of removing unwanted elements during the steel making

$$2Mn + O_2 = 2MnO$$

These oxides are retained in the slag formed by the lime added. Some sulphur is removed as sulphur dioxide in the following reaction:

$$S + O_2 = SO_2$$

Some reacts with manganese and enters the slag as sulphides of manganese according to the following reactions:

$$MnO + FeS = MnS + FeO$$

$$FeS + Mn = MnS + Fe$$

Phosphorous goes into the slag as a compound of the oxide and lime and the reactions which take place in slag containing iron oxides can be represented as follows:

$$4P + 5O_2 + 8CaO = 2(CaO)_4.(P_2O_5)$$

$$4P + 5O_2 + 6CaO = 2(CaO)_3.(P_2O_5)$$

The reactions of silicon and manganese with oxygen are highly exothermic and the heat generated raises the temperature to steel making temperatures of 1600^{o}C. So much heat is generated that it is necessary to add the scrap as a coolant to control the temperatures. The process of oxygen blowing takes about 20 minutes and by this time the aim temperature of 1650^{o}C should have been achieved. If the temperature is below 1650^{o}C oxygen may be re-blown to raise it to the target final temperature.

When oxygen blowing is completed the temperature is measured and samples are taken for chemical analysis as follows:

1. Bath analysis: Steel sample for analysis of the steel

2. Slag analysis: Slag sample for analysis of slag

After passing the tests the steel is tapped into a ladle. During Tapping de-oxidants are added to the ladle to remove dissolved oxygen. Elements that are required to meet steel specification are also added. Coke is added to

process. The ratio of CaO to SiO_2 is called basicity and a value of 3.0 is the standard slag basicity used. Some of the iron is also oxidised and finds its way into the slag. During the oxygen blowing process silicon and manganese are also oxidised according to the following reactions:

$$Si + O_2 = SiO_2$$

meet the carbon specification and ferrosilicon and ferromanganese are added to meet silicon and manganese specifications respectively. The steel yield from the BOF is 91.2% of the original charge. The steel is then ready for casting but most qualities require that it goes through the ladle furnace first. At the ladle furnace the temperature is raised to the required casting temperature and homogenised. Fine tuning of elements is also carried out to meet the required chemical specification of the steel.

Carbon dioxide generated during blowing is released as gaseous carbon monoxide or carbon dioxide.

D. PRODUCTION OF STEEL FROM SCRAP

This process is well illustrated in Fig 5.

IV. RESULTS AND RECOMMENDATIONS

The processes carried out when manufacturing steel from its elements show some measures put in place to clean the gases before releasing them into the air. In some cases, however, greenhouse gases are just released into the atmosphere. The processes used to manufacture steel from scrap do not have measures put in place to mitigate the release of greenhouse gases into the atmosphere. In both cases newer methods of mitigating gas emissions are needed. In order to come up with a solution to these problems the following questions need to be answered:

a) What raw materials and processes can be used in the Zimbabwean steel industry in order to minimise environmental impacts in the production of steel?
b) How can Carbon and other greenhouse gas emissions be reduced in the Zimbabwean steel industry?
c) What are the potential cleaner production options that can be implemented in the Zimbabwean steel industry with a view to reducing waste, improving resource efficiency and implementing green manufacturing?
d) How can energy and water efficiency be maximised in the Zimbabwean steel industry?
e) What are the opportunities for the: reduction, recycle, and reuse strategies in the Zimbabwean steel industry?

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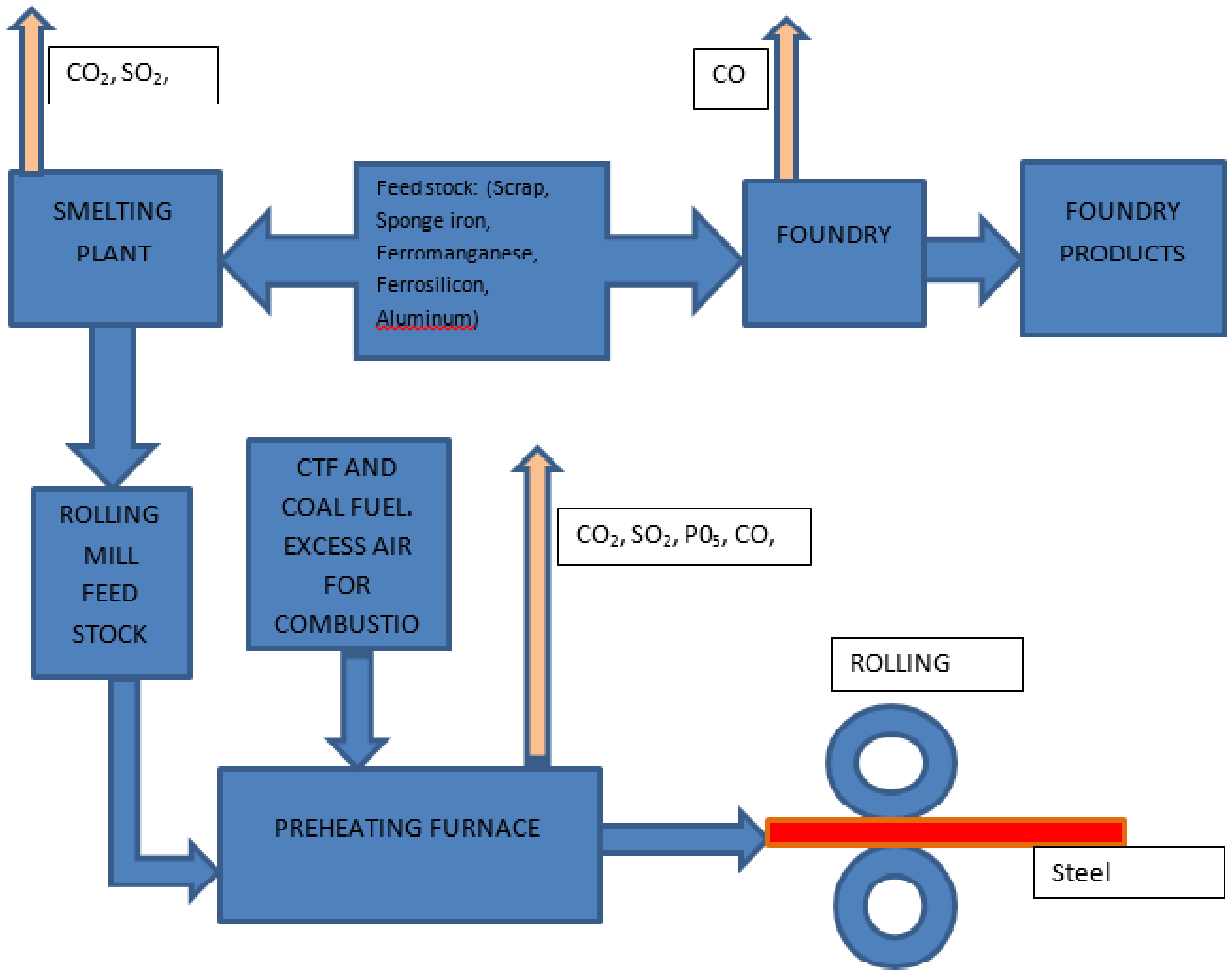

Fig 5: Production of Steel from scrap

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