

THE UNIVERSITY OF ZAMBIA

SCHOOL OF MINES

DEPARTMENT OF METALLURGY AND MINERAL PROCESSING

FINAL YEAR PROJECT REPORT

***DEPARTMENT OF BISMUTH, NICKEL, LEAD, COBALT,
GOLD AND SILVER***

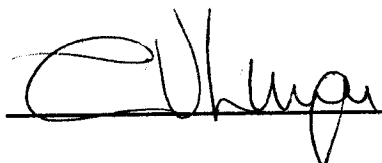
BY

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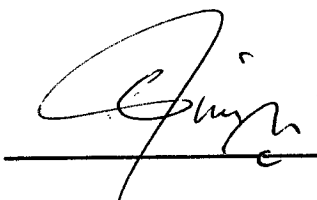
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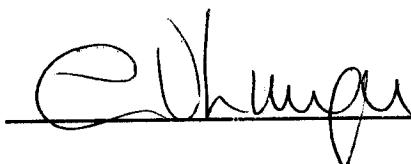
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DEDICATION

I gladly dedicate this report to **Auntie and Uncle, Mrs. and Dr. Malyangu and Brothers** for their love as well as encouragement during my studies.

ABSTRACT

The project was carried out to assess the distribution of impurities during the converting stage. The assays of these impurities are summarized into a mass/material balance to account for all elements of interest. These metals are bismuth, silver, gold, nickel, lead and cobalt and the balance were carried out over the converter.

Samples were collected from various strategic points of streams such as at the matte settling furnace tap, converter mouth and under a ventilation discharge pipe. These were then taken to the laboratory for analysis.

The results obtained showed that these metals occur in very small quantities although they might have some negative effect on the production of copper. These results were given in percentages.

From the conclusion, it will be seen that the metals of interest are a very small fraction of the whole mass of materials in and out of the converter. Among the elements of interest it can be observed that cobalt occurs in larger amounts than others. Otherwise various amounts depend on the type of blend carried out on a particular blow. In particular, flue dust particles contain bismuth.

Recommendation will be made that the next time the project is proposed it should be extended from the concentrate shed where blending occurs to the smelter section. Perhaps it can further be extended to the refinery section where effects are felt. The best way to control high levels of these impurities is to apply evaporative precipitation.

ACKNOWLEDGEMENTS

My hearty thanks go to **management of Mopani Copper Mines Plc**, Mufulira site for giving me an opportunity to work on my final year project with the company. They supported me in different ways.

I wish to thank my **project supervisor Mr. C. V. Lungu**(Lecturer and Head of Metallurgy department, School of Mines, University of Zambia) for positive criticism, fruitful suggestions, corrections and directives. I further wish to thank **Mr. Richard Phiri**(Plant metallurgist south) for his wonderful supervision as well as constructive criticisms during my project. I am also indebted to the entire Smelter Staff, especially Metallurgists for their encouragement, helpful suggestions and support. My final appreciation goes to **Mr. J. Kapaya** for the assistance rendered during my stay.

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1.0 INTRODUCTION

Mopani Copper Mines PLC is Zambia's second largest registered mining company owned by Carlisa Investments Corporation. Carlisa Investments is a joint venture company made up of Glencore International AG and First Quantum minerals Ltd. ZCCM-IH is also a shareholder in this venture company. The assets of the Zambia consolidated Copper Mine Limited (ZCCM) were bought by Mopani on April 1, 2000. These assets comprising the Underground Mine, Concentrator, Smelter and Refinery at Mufulira site while the assets at Nkana included the Underground Mines, Concentrator and Cobalt plant. They were purchased from the Government of the Republic of Zambia (GRZ) following the privatization program by the State.

Mopani produces blister copper of approximately 99.5% purity with a target of producing 270,000 tonnes of copper cathodes per annum. The company is located on the Copperbelt with its head office established in Kitwe. The Nkana and Mufulira site has been in operation since 1931 and 1933, respectively. Mufulira site lies 50 kilometers north of Kitwe.

In producing copper and cobalt, the Nkana Mine operates from four sources namely North Shaft, Mindolo sub vertical, central shaft and South ore body (SOB), were as the mining operation at Mufulira is done at Mufulira west and the recently commissioned insutu leach Mufulira project.

1.1 Brief description of Mufulira smelter

1.1.1 Process Description

The process of copper smelting begins with the feed preparation which includes mixing, blending, conditioning and fluxing of feed material. Copper smelting is the term given to a series of processes designed to extract the metal copper from the raw feed materials. The raw feed materials, technically called "concentrates" are mixtures of copper bearing minerals and waste minerals. These copper bearing minerals fed to smelters include sulphur as one of its main components. It is for this reason that they are sometimes called sulphide concentrates. Iron, silicon and other metals in trace amounts makes up the total composition.

1.1. 2 Feed preparation

Apart from the concentrate receiving area as well as the reverts storage area, feed preparation comprise a bin-loading system, 4 concentrate bins, 2 flux bins, recycled dust bin, coal bin and revert bin. For emergency reduction charge to the ISASMELT, kibbles are used. Hence a feed system mechanism is specially designed for that purpose. Before blending is undertaken, the concentrates are weighed at the weighbridge following the delivery either by truck or by train. Fluxes and coal are delivered to the concentrate shed in designated stockpile areas for storage and awaiting processing. Reverts to be charged, are further processed to ensure they are of correct size and that foreign elements are eliminated. Two dust cleaning facilities namely the waste heater boiler and the electrostatic precipitator dust whose streams are recycled from the ISASMELT to the feed preparation area may be conveyed separately by pneumatic conveying systems to a single dust bin. They are then discharged from the bin in required proportions as mixed dust. The concentrates are transferred to the screening loading hopper by front- end loaders from the shed. In the screening loading hopper, rocks, large lumps and foreign materials from the concentrates are classified and thereafter concentrates are transported to the ISASMELT feed bins via the conveyor system. Using a similar method, fluxes and coal are charged to the silica bin, limestone bin or the coal bin.

Having been delivered to the bins, the concentrates, fluxes, coal and reverts are then ready to be discharged for smelting in the ISASMELT furnace. These materials are transported using conveyor belts which are designed in such a way that they may run simultaneously serving their respective bins. At the same time conveyor belts may run in any combination depending on the type of blending to be carried out as well as the operating requirements. The feed material is dragged out of the bin by a flat feeder conveyor beneath the bin which is equipped with conveyor belt weighers responsible for measuring and controlling the rate of discharge from the bins.

The paddle mixer feeder conveyor, which is a common collector conveyor, receives materials from all ISASMELT bins. The water addition to ISASMELT feed is done here if required. The discharge from paddle mixer is transported onto one transfer conveyor to another conveyor which empties its contents to the ISASMELT plant where the mixed ISASMELT feed is finally delivered to the final feed conveyor. This whole flexible feed system is under close control of feed composition to the ISASMELT plant. Since there is no storage bins in the immediate

positions between the ISASMELT feed bins and the furnace, there are no important time delays between a change in the bin discharge rates and a change in composition of the feed to the ISASMELT furnace. It should be noted that the final feed conveyor can act as a reversible conveyor whereby when running in the reverse direction feed materials are delivered to the bypass chute that dumps the feed materials to the ground thereby eliminating off-specification feed from the ISASMELT feed bins and belts. It can also be used to run conveyor tests and to run "live-load" tests to calibrate the various conveyor belt weighers. At the same time when this belt is running in the forward direction, feed materials are delivered to the ISASMELT furnace feed chute for smelting.

In the feed preparation system, one of the most important tasks carried out is the collection of regular, representative sample of the feed materials with the aim of determining the composition of different feed material streams. These procedures are conducted by hand or via automated sampling machines.

Since the company buys concentrates from different mining companies which do not have the capacity to smelt their own concentrates, it is in the company's best interest to make sure that the purchased concentrates meet their stated specification. For the company to know if they reach this requirement, process of sampling and assaying is done in concentrate storage areas.

Blending is one of the most important aspects in copper smelting which employs sampling and assaying in the concentrate storage shed so that a plan can be made on how to mix these materials in proper proportions.

To facilitate total control of the ISASMELT process, flux streams as well as coal must be sampled and assayed. For example when switching from one type of silica flux to another type, any differences in composition must be known before the switch occurs. The control of ISASMELT process might be disrupted if the composition changes are not detected ahead of time. This may require several hours to regain control.

This process is required in all the feed streams to the ISASMELT furnace to measure the moisture content of each stream so that efficient operation of the ISASMELT process-all ISASMELT feed streams are controlled on a dry basis, to make sure the water content of all streams is under control and is accurately known. Wrong moisture values will affect apparent

efficiency of the ISASMELT furnace although it may not visibly affect ISASMELT operation. This means that if the moisture content is incorrect, the actual feed rate of the ISASMELT furnace will not be in agreement with the indicated feed rate on the PWCS. This may exaggerate the efficiencies of the ISASMELT furnace. Assays and feed rates are needed for all feed streams in calculation of "metal balances". This simply refers to a method of accounting for masses and movements of copper within smelter section. Therefore, the efficiency of all plant processing can be measured. When the preparations are done and the feed material is delivered to the ISASMELT furnace, the smelting of copper will now commence. The following section looks at the operations of the ISASMELT furnace in detail.

1.1.3 Isasmelt furnace

It is a high-intensity primary smelting unit consisting of a tall, vertical, cylindrical furnace with a single smelting lance. It's supported on a concrete base and it's basically a steel shell which is approximately 5.5 metres internal diameter. This furnace, whose height is 16 metres, is lined with 450 millimetres chrome-magnesite brick alongside a backing lining to give an approximate internal diameter 4.4 metres with a height of 13.6 metres. The lance which moves up and down facilitates the charging of materials consisting of a mixture of concentrates, reverts and fluxes along with coal that forms part of the fuel. Injected into the molten bath through this device is air enriched with industrial oxygen to conduct smelting reactions. With a new feed rate of 850,000 tonnes per annum, the ISASMELT lance is lowered until it's tip is submerged into the molten bath so that it's responsibilities are carried out smoothly. There are three reasons why the air is oxygen enriched

It reduces the capacity of off gas stream from the furnace which means less load on the WHB and Sulphuric Acid plant (SAP)

Increases the concentration of SO_2 in the off gas stream (improves SAP)

Temperature control in the ISASMELT furnace improves process control, reduces the amount of additional fuels required, and increases furnace refractory life due to operating temperatures.

A wide range of feed materials can be accepted by the ISASMELT furnace following good preparations. Copper matte, molten iron-silicate and high tenor off gas are produced in the ISASMELT furnace.

Fuels are supplied to the ISASMELT furnace either via the feed system or via the lance (e.g fuel oil injected by the lance). The energy required for smelting reactions depend on the type of concentrate and the amount of industrial oxygen available. In fact, the furnace may require no additional fuel at all. In such a case, melting and smelting processes will proceed in the forward directions. Most ISASMELT furnaces have the ability to blend feed streams so that a small amount of extra fuel is needed for melting and smelting the feed for reasons of process control. To control the temperature in the furnace, the fuel rate is varied. The following section looks at the detail description of how the lance air reacts with solid feed fuels.

In as much as a range of solid fuels can be admitted to the ISASMELT furnace it is possible to inject fine particles of solid fuels via the lance. However, it is more common to simply add solid fuels to the feed stream. Some examples of fuels used by the furnace are coal, coke, and coke dust and petroleum coke.

Fuel coal injected into the furnace via the lance does not burn directly with the air; instead oxygen responsible for combustion is supplied by the magnetite (Fe_3O_4) in the molten slag phase. Coal is mostly composed of carbon (c) which burns as well as ash, which does not. Carbon dioxide is formed from the reaction of carbon and magnetite. For every two oxygen atoms, two magnetite molecules are consumed in turn for every atom of carbon burned. Carbon cannot burn without coal. The following section looks at how matte and slag are separated in the ISASMELT furnace.

The ISASMELT furnace is run as a continuous, intensive smelting operation where both the matte and slag is made to flow out of tap hole together and then tapped in batches. The mixture is tapped from a holding furnace. The aim of holding furnace is to separate the matte and slag. It is the aim of the operator to produce a slag with a low concentration of copper so that it becomes economical to discard the slag and there after transport the matte to the copper converting operations required.

ISASMELT matte and slag are different physical phases with various physical and chemical properties such as immiscibility and density. This means that if a mixture of matte and slag is allowed to settle in a non-agitated molten bath, where conditions such as those of the bath inside a holding furnace will exist. The matte will then sink to the bottom and the slag will float on top.

In quiescent conditions where the bath is not disturbed, some droplets of matte will be suspended in slag phase especially when the slag phase is very viscous. To arrest this condition, the furnace is kept hot to prevent the slag from freezing in an effort to make the matte settle out of the slag phase and move into its own phase. This principle is called "slag settling". Low-copper slag will be produced from ISASMELT operations in this way. Since the two phases have different densities, the phases are easily separated from each other. The slag is simply skimmed off from the top of the matte which is then removed later.

If the bath is not given chance to attain quiescent conditions in the holding furnace, that is if it is constantly being disturbed by either agitation, loss of temperature or possibly ingress of fresh material, then the copper content of the skimmed slag will increase. Following the operations of the ISASMELT furnace are the operations of the converter. The following section demonstrates how the matte fed to the converter from the ISASMELT furnace is treated.

1.1.4 Copper converting

The converter section of the smelter department is responsible for the changing of copper matte from the ISASMELT furnace to white metal (Cu_2S) and eventually to blister copper. This section is made up of five converters which measures 2.74m by 2.44m at the mouth opening to facilitate converter charging, skimming and escape of gases and blister copper transfer to the anode furnaces. In fact converting is batch operations where a Pierce-Smith converter is employed to carry out converting tasks. The Pierce-Smith converter is a horizontal, cylindrical, rotary furnace. Matte is fed to the furnace through a hole in the roof of the vessel called the "mouth". Silica and reverts (recycled materials) are charged to the bath. There are holes along the side of the converter called "tuyeres". These holes which are 30-60 in number must be regularly cleaned with metal bars in an operation called "tuyere-punching". The blast air is slightly oxygen enriched. Converters operate with a violently-agitated bath and so splashes are mostly encountered in the furnace.

1.1.5 Anode furnace

The purpose of taking the blister copper from the converter to anode furnace is to produce high-purity anodes. In here the blister copper is upgraded to approximately 99.50% copper by removal of impurities by airing and polling processes. The metal is cast into anodes from the anode furnaces and consequently railed to refinery Tank house for further re-work.

Fire-refining employs furnaces that appear very similar to the Pierce-Smith converters, except that they have limited number of tuyere (typically two, but sometimes three or four). Just as converting is carried out in two steps, fire-refining is also conducted in two stages. There are 22 moulds on each of two Walker casting wheels. In each mould anode copper is cast in open cast master moulds and weighs approximately three tonnes.

1.1.6 Copper refinery

In this section the main operations are called electro-refining. This is done mostly by dissolving the copper anodes in a sulphuric acid solution, and causing the copper to reform as a new, more pure copper plate (a cathode). This task is conducted by submerging the anodes and cathode “starter plates” in the acid solution, then passing electric current through the plates. The cathode copper must be pure enough to provide as little resistance to the electric current as possible. Scrap cathode and off-specification cathode are normally recycled to the converter especially if the smelter department and the refinery are close to each other. On the other had if these two departments are far each from each other, the refinery may choose to treat scrap and off-specification cathode on site using small smelting furnaces.

2.0 OBJECTIVE

The main objectives of this investigation were to study

- The distribution of impurities in the different streams leading to and out of the converter.
- The negative impacts of these impurities in the production of copper especially during the converting stage.
- Ways of reducing their contents in the streams.

3.0 PROJECT BACKGROUND

This research carried out at Mopani Copper Mine is entitled “the study of deportment of bismuth, nickel, lead and cobalt, silver and gold during converting”. Therefore, the next section looks at the sources of these impurities. There are mainly two sources of these metals.

The first one is the ore body from which the ore is extracted. The chemical composition of the ore body differs from each other depending on where the mining is taking place. Hence the amounts of these metals (bismuth, nickel, lead, cobalt, silver and gold) changes from time to time. The amount of these metals also depends on the type of processing employed.

The second one is the blend to be fed to the process. The blend is a mixture of concentrates from different mining companies which take their respective concentrates to Mopani Copper Mines for treatment at the smelter. Thus, each concentrate will possess a certain composition of impurities. When these concentrates are mixed together in a specific blend a suitable stock feed is produced with a new chemical composition.

It was realized that due to the build up of impurities during the converting stage, copper produced by Mopani Copper Mines plc of late, has been of low quality as opposed to the contractual specifications:

Basically these impurities can be classified into three groups according to their behaviour during the refinery process. In fact, they have had a negative impact on the cathode produced as they are the main carriers of these impurities are the anodes which are produced during secondary smelting (converting stage).

The first group of impurities is that of metals composing silver and gold. These have not been a big challenge because they simply settle to the base of the cells as slimes. They are insoluble and are not electro positive with respect to cathode. Hence, they are mechanically removed.

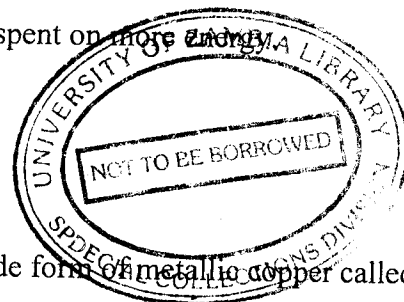
The second group of impurities dissolves in the electrolytes but do not deposit on the cathode. The control mechanism employed is to remove some electrolyte out of the cell so that some concentration is reduced in an effort to reduce the build up. Such metals are nickel, lead and cobalt

The final groups of foreign material are those that portray the same behaviour as copper. Such an impurity of such nature is bismuth. They tend to co-deposit on the cathode. So they tend to contaminate the copper product. To control high levels of bismuth in the electro-refinery, the electrolyte with high concentration of bismuth is directed to the liberator cells where the value of flow rate is manipulated. By changing the flow rate of the electrolyte, high levels of bismuth can be eliminated to prevent it from depositing itself on the copper cathode.

These impurities in general adversely affect the cathode by rendering them inert, by chemically passivating them. This means more energy is to be expended than it is supposed to be under normal conditions. This actually calls for more money to be spent on more energy.

4.0 LITERATURE REVIEW

4.1 Converting in General



Converting is a process that turns the copper matte into a crude form of metallic copper called “blister copper” (99 wt% cu) and also makes a slag to eliminate impurities. Converting slag contain a large amount of copper which must be retreated (as defined in the furnace training manual). From the smelting point of view converting is considered as the secondary smelting were as primary smelting is that done in the ISASMELT furnace. The following section will discuss the aim of converting process.

It aims at removing the impurities that are present in the matte, mainly iron, sulphur, bismuth, nickel, lead, cobalt, gold and silver. The iron exists primarily as iron sulphide (FeS) with smaller amount of magnetite (Fe_3O_4). On the other hand sulphur exists both as iron sulphide and copper sulphide (according to the Converter Operator-Training Manual).

In order to get rid of these impurities, oxygen must be blown in the converters via the tuyeres. The oxygen then reacts with iron sulphide to form slag and sulphur dioxide. In addition to removing the iron some of the impurity metal within the matte will also react with oxygen and become part of the slag. These include bismuth and nickel. Other impurity metal such as lead is removed with the offgas as vapour. The copper sulphide will form copper upon reacting with oxygen. Copper is made after the production of slag, because the oxidation of the elements is done in selective order, first iron, second sulphur and third copper. The chemical reaction

between the iron, sulphur and oxygen provide heat to the converter, and keep the process going by increasing the converter temperature (according to H. Loyola).

The molten matte has to be hot because its temperature helps to heat up the converter fast. The matte grade is the percentage of copper in the matte, and is associated with iron. Normally high matte grade means it contains low iron. The following section highlights some properties of elements of interest.

Bismuth is a block p, group 15, period 6 element. It has a low thermal conductivity than any metal except for mercury but has a high electrical resistance. It also has a highest Hall Effect of any metal (i.e. greatest increase in electrical resistance when placed in magnetic field). Bismuth expands on solidification, a property that makes its alloys particularly suited to the making of sharp castings of objects subject to damage by high temperatures. It forms low-melting alloys which are extensively used for safety devices in extinguishing systems and fire detection. It can further be used as a catalyst for making acrylic fibers and in producing malleable irons.

Silver is a block D, group 11, period 5 element. On the periodic table, it is in the same group as gold. This means they have the same chemical properties. Silver has a brilliant white metallic luster. It's a little harder than gold. It's very ductile and malleable exceeded only by gold and palladium. Pure silver has the highest thermal and electrical conductivity of all metals, and posses the lowest contact resistance. It's stable in pure air and water but tarnishes when exposed to the ozone, hydrogen sulphide, or air containing sulphur. Silver chloride is an important compound, due to its malleability and its ductility. On the other hand, silver nitrate has wide application in painting, xerography, chemical electroplating, in components of electric batteries and in medicine as a catalyst.

Lead is a block P, group 14, period 6 element. Lead is a bluish-white metal of bright luster, naturally occurring as a mixture of four stable isotopes: ^{204}Pb (1.48%), ^{206}Pb (23.6%), ^{207}Pb (22.6%) and ^{208}Pb (52.3%). It is highly resistant to corrosion and can be used to contain corrosive liquids such as sulphuric acid. Great quantities of lead both as dioxide and the metal are used in batteries, cable covering, plumbing, and ammunition. Alloys include solder, type metal and various ant-friction metal compounds. It is extremely effective at absorbing sound and vibration. It is also used as radiation shielding for X-ray equipment and nuclear reactors. Oxides

of lead are used in producing fine “crystal glass” and “flint glass” of a high index of refraction for achromatic lenses. The following section will look at the source of these impurities

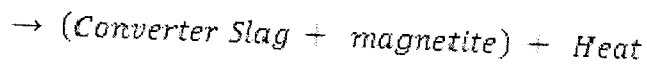
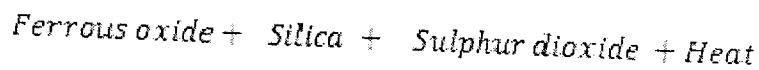
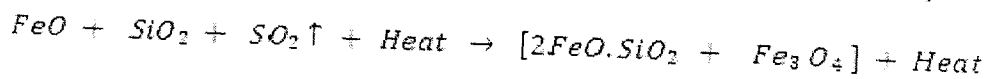
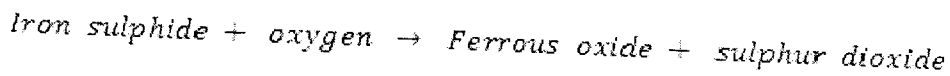
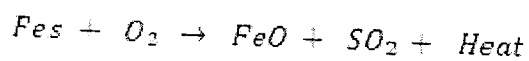
The first one is the ore body from which copper is mined from. The type and nature of the ore body in terms of chemical composition is very important. The chemical composition varies from place to place depending on where the mining is taking place. Different types of minerals in various proportions will be found in an ore. These will be carried alongside a desired mineral during beneficiation and mineral process.

The second one is the blended material to be processed. The materials used in this mixing is accessed from different companies such as Kansanshi Mine, Dikulushi Mine and others which send their concentrates to Mopani Copper Mine for treatment. Various concentrates in different proportion from different mining companies are blended to produce the desired stock feed. So these metals from different areas come together in the process.

4.1.1 Slag Blow (FeS)

Consequently, with little iron it's difficult to form a good slag and heat converter (according to H. Loyola).

The conversion process is carried out into two stages namely: slag blow and copper blow. In the first part of the blow oxygen coming in the blast iron is blown to ferrous oxide (FeO), according to the following chemical reaction.



The aim of the slag forming stage is to eliminate almost all iron sulphide by way of oxidizing it to iron oxide and sulphur dioxide. When silica flux (SiO_2) is charged to the converter it will react with the iron oxide to form fayalite ($2\text{FeO} \cdot \text{SiO}_2$). This is the main component of the slag — a separate phase that forms in the converter (according to the Converter Operator-Training Manual)

In the converter, the slag will be on top of the metal since the slag is lighter than the white metal. It is on this basis that the separation of the slag and white metal is made possibly by simply skimming the slag off the top just like the mixture of oil and water is carried out.

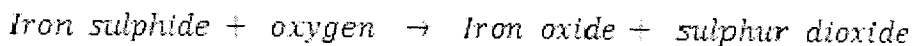
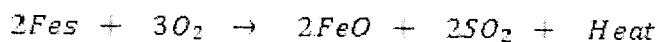
This procedure of charging the matte, adding air and feeding silica to form slag to the converter is repeated several times.

The amount of copper (as white metal) in the converter gradually increases until there is sufficient for a final copper making “bow”. At this point, the Iron Sulphate in the matte is blown down to about 1%, then the final slag is removed from the resulting “white metal”. At the end of the slag forming the stage the converter contains:

Molten Slag: fayalite ($2\text{FeO} \cdot \text{SiO}_2$), containing 15-30% solid magnetite (Fe_3O_4) and up to 15% entrained Copper.

White Metal: principally copper sulphide (Cu_2S) is with less than 1% Iron sulphide (FeS). These two phases are immiscible and the slag is easily separated from the white metal by carefully tilting the converter (Accord to the Converter operator-Training Manual).

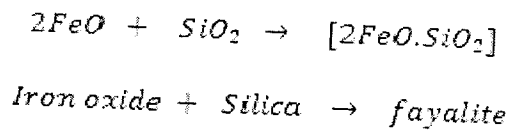
Chemical Reactions: During the slag blow, the first reaction taking place is iron sulphide (FeS) reacting with oxygen (O_2) to form iron oxide (FeO), and sulphur dioxide (SO_2) in the molten bath. This can be summarized as



When the air enters the converter through the tuyeres the iron sulphide (FeS) in the bath comes into contact with the oxygen (O₂) at the surfaces to react with it. This is an exothermic reaction in which heat is produced. Therefore, this energy can be used to sustain the converter material in their molten state throughout the process. This reaction also produces sulphur dioxide (SO₂), which is captured at an acid plant to manufacture sulphuric acid with an aim of reducing the amount of flue gas in the atmosphere, thereby reducing levels of poisonous gas below the permissible limit.

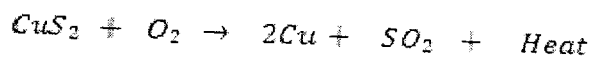
The iron oxide (FeO) produced in the above reactions can be made to react further under different conditions therefore the following section looks at the reaction of iron oxide in the presence of silica.

Silica is often charged to the converter in an effort to make fayalite slag (2FeO.SiO₂); chemically this can be represented as



4.1.2 Copper Blow (Cu₂S)

In this stage air is blasted into the converter via the tuyeres at a certain air flow rate. In the bath a reaction of oxygen in the air and white metal produces sulphur dioxide alongside blister copper which is left in the converter to be transported to the anode furnaces.



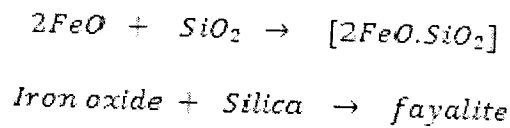
Copper blow follows the immediate completion of slag blow with almost all of the iron sulphide (FeS) being oxidized and eventually eliminating the iron oxide from the converter as slag.

In as much as, silica should be added at the right time, the right amount of silica should be taken into consideration to avoid leaving the silica on the bath which is consequently contributes to the foaming of converter .

When the air enters the converter through the tuyeres the iron sulphide (FeS) in the bath comes into contact with the oxygen (O₂) at the surfaces to react with it. This is an exothermic reaction in which heat is produced. Therefore, this energy can be used to sustain the converter material in their molten state throughout the process. This reaction also produces sulphur dioxide (SO₂), which is captured at an acid plant to manufacture sulphuric acid with an aim of reducing the amount of flue gas in the atmosphere, thereby reducing levels of poisonous gas below the permissible limit.

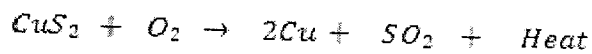
The iron oxide (FeO) produced in the above reactions can be made to react further under different conditions therefore the following section looks at the reaction of iron oxide in the presence of silica.

Silica is often charged to the converter in an effort to make fayalite slag (2FeO.SiO₂); chemically this can be represented as



4.1.2 Copper Blow (Cu₂S)

In this stage air is blasted into the converter via the tuyeres at a certain air flow rate. In the bath a reaction of oxygen in the air and white metal produces sulphur dioxide alongside blister copper which is left in the converter to be transported to the anode furnaces.

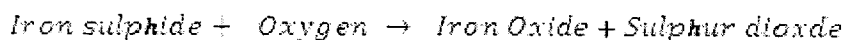
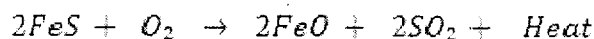


Copper blow follows the immediate completion of slag blow with almost all of the iron sulphide (FeS) being oxidized and eventually eliminating the iron oxide from the converter as slag.

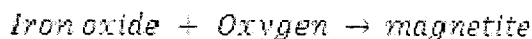
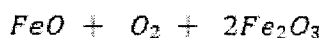
In as much as, silica should be added at the right time, the right amount of silica should be taken into consideration to avoid leaving the silica on the bath which is consequently contributes to the foaming of converter .

With experience, the indication of iron sulphide being completely oxidized is when the flame turns completely green. Then all iron has been oxidized and a fluid slag is produced in readiness for effective and efficient skimming.

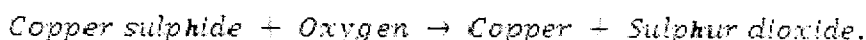
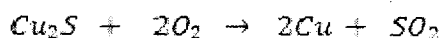
At the end of slag blow, a small amount of iron left in the converter reacts with oxygen to form iron oxide according to



The Iron oxide formed is further oxidized to produce magnetite since in this stage silica is not fed to the converter.



The following chemical activities take place in the copper blow state



In this second stage oxygen in the blast air oxidizes the sulphur left in the white metal (Cu_2S) producing sulphur dioxide gas and at the end of blister copper plus heat.

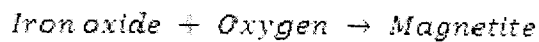
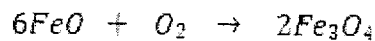
Slag is a mixture of iron silicate that results from oxidation of the iron sulphide (FeS) in matte and the reaction of iron oxide (FeO) with silica (SiO_2). The slag is lighter than matte, so it forms a layer on top of the molten bath (according to Converter Operator Training Manual).

The iron sulphide and copper sulphide making up the composition of the matte settles at the bottom of the converter while the iron silicate floats on top since the matte is heavier than the slag. Hence, slag can be skimmed off, thereby removing iron from matte. But this slag can only be produced by feeding silica to the converter during operations of the slag blow. During this process some impurities such as bismuth, nickel, cobalt, lead, silver and gold will be present in the matte, scrap metal, flux, fine dust particles, blister copper and converter slag. The next

section highlights some general properties of these impurities which can have major negative impacts even though they exist in small amounts.

Slag is taken back to the matte settling furnace for more retreatment through the return slag launder abbreviated as (RSL) because the slag still contains some copper content ranging from 6 to 8%. It is clear from the above discussion that without fluxing the converter with silica we cannot form slag and eventually no iron is eliminated from the converter. The next section demonstrates what happens to the iron oxide in the event that there is not enough silica.

If there is not enough flux the iron sulphide (FeS) that turns into iron oxide (FeO), will further oxidize to magnetite (Fe₃O₄) (According to converter operator-training manual) .

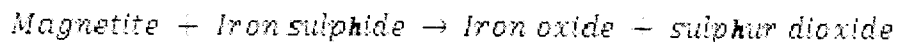
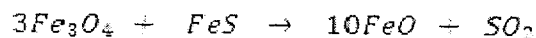


When under control magnetite is beneficial as it puts a lining on the bricks and thus protects the refractory of the converter from a high intensity heat. When it's out of control it leads to a viscous slag and entrains large quantities of matte. This will further lead to copper losses. This problem can be particularly observed towards the end of the slag blow.

To arrest the above problems of magnetite build up, a high temperature is administered to the converter processes because

- It promotes the minimization of magnetite (Fe₃O₄) by iron sulphide (FeS)
- The combination of iron oxide (FeO) and silica (SiO₂) to form slag is enhanced.
- The solubility of magnetite (Fe₃O₄) in slag is increased.

The reaction below demonstrates how the magnetite reverts back to iron oxide upon reacting with iron sulphide in the matte.



Finally in the case where there is air starvation into the matte, the oxidation of iron is cut off. This means that even if the flux is charged to the converter, slag will not be formed. This air is blown at specific flow rate to imply that maintenance of flow rate is one of the most important operating parameter in a converter.

The slag blow starts with charging of matte in the converter, after which flux is added during the process. At the same time, air is blasted into the converter to finally make the slag. The review of this literature cannot be complete without discussing the slag chemistry.

The problem mentioned above of magnetite build up can also be minimized by controlling the slag composition and can reduce copper losses. Therefore, the study of converter slag chemistry is of prime importance in optimum converter operation. On average the slag is composed of 12-18% magnetite Fe_3O_4 and 26.28% Silica (SiO_2). A good slag contains about 50% iron oxide (FeO) and 27% silica (SiO_2). These exist together as fayalite ($2\text{FeO}.\text{SiO}_2$). It also contains about 15% magnetite (Fe_3O_4), 6% copper (Cu) and 1% other impurities (according to Converter Operator-Training Manual)..

A good slag should look like

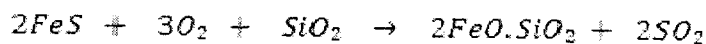
51% iron (Fe)

26% silica (SiO_2)

6% copper (Cu)

15% magnetite

The converter must always be supplied with enough silica for high matte grade. The following reaction takes place.



Therefore, the following section will look at the source of bismuth, nickel, lead, cobalt, gold and silver. These metals can be traced mainly from two sources

5.0 METHODOLOGY

5.1 Sample collection and preparation

Sampling was done on the streams entering and leaving the converter. At the end of the day, we want to establish if the amount of impurities entering the converter is equal to that leaving. Sampling was done on the matte leaving the matte settling furnace which was fed to the converter. It was also carried out on the flux, reverts and chunks charged to the converter. On the other hand, the samples were collected from the streams leaving the converter while the converter slags were skimmed off during the slag blow stage.

Collection of these samples commenced at the exit of matte settling furnace as this matte obtained here is fed to the converter. Before the flux, chunks charged in the matte in the converter, sampling were carried out right there in the boat containing flux, chunks or reverts.

In this investigation sampling of flue dust particles were carried out during the slag blow and copper blow. The plastic bag was set under the pipe capturing the flue dust particles. Using a metal spoon, the slag samples were collected when the converter were tilted to skim off the slag. By the way, the matte samples were also collected in their molten state and left to solidify. They were also collected with the help of metal spoon.

Samling was done on each converter, afterwhich a set of samples were taken for analysis at the laboratory.

5.2 Test work outline

The established standard analytical laboratory test flow sheet and test conditions were followed for each sample specimen. The following procedure is the best operating practice that describes the method for the determination of bismuth, cobalt, nickel and lead. The sample is decomposed with a mixture of hydrofluoric, nitric and perchloric acids. The residue obtained is dissolved in nitric acid and finally aspirated on an Atomic Absorption Spectrophotometer.

The main objectives of these tests are to determine the level of constituents (metals) in the concentrates for purposes of metal balancing in the converters. That is to say that the amount of metals charged to the converters must be equal to that being discharged.

5.3 Apparatus

The laboratory experiments were conducted by using the following apparatus/ equipments:-

Beakers

Volumetric flasks, 100 ml grade "A" or calibrated "B".

Atomic Absorption Spectrometer.

Analytical balance, with 0.1000 mg accuracy.

5.4 Reagents

The following chemicals were used during laboratory experiments:-

Nitric, Cp

Perchloric acid, AR

Ceasium chloride, 16%

Stock solution

The following is the activity undertaken during the tests: - initially, the samples of Bi, Ni, Co and Pb must weigh 1 g (catch weight) of the samples into PTFE beakers. Then sample decomposition is achieved as follows:-

Add 10 ml of nitric acid, 5 ml of hydrochloric acid and a few drops of perchloric acid.

Fume to dryness on an asbestos covered hot plate.

Cool and add 10 ml of nitric acid and 10 ml of distilled water.

Warm to dissolve the salt.

Cool and transfer into 100 ml volumetric flasks for the elemental samples.

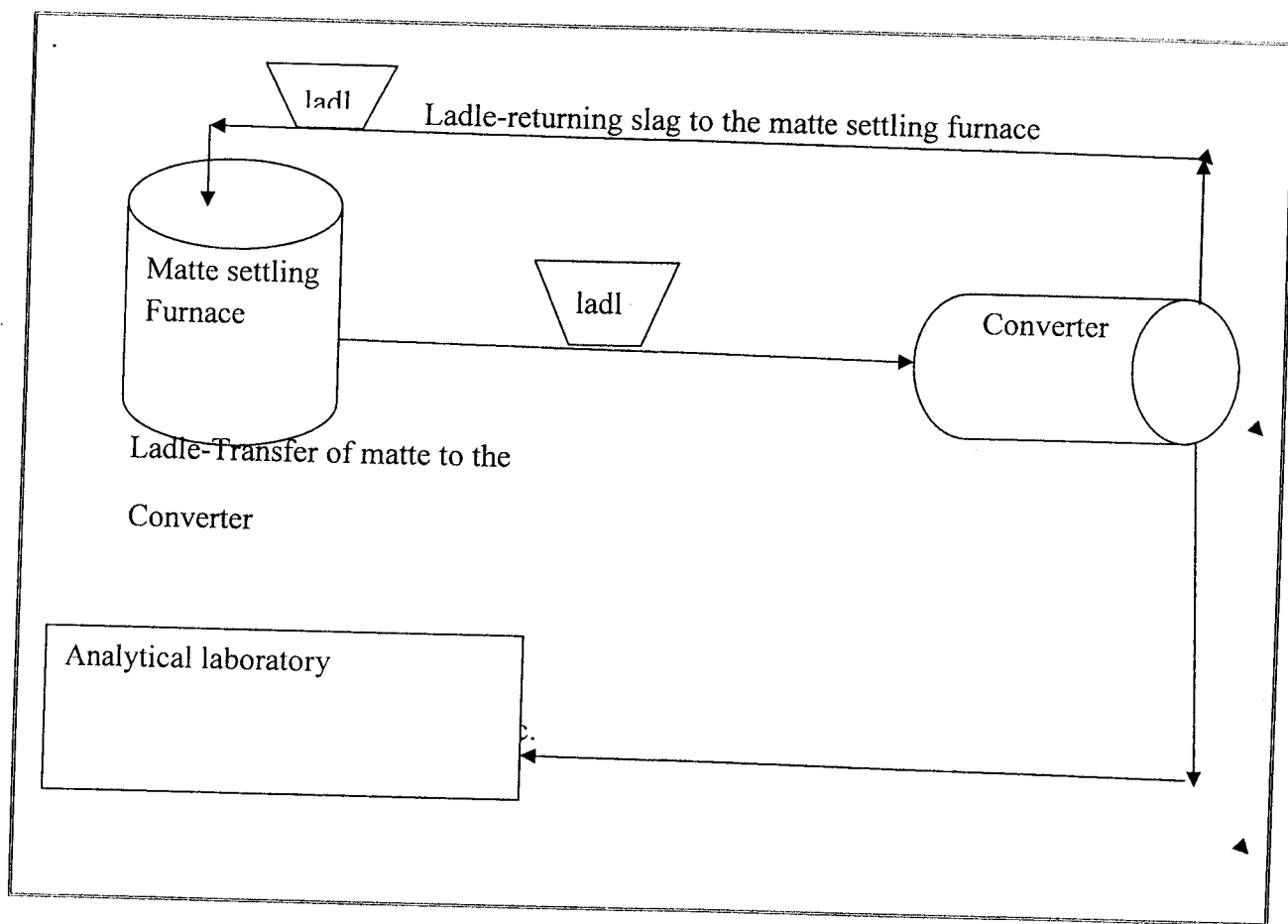
Then add 4 ml of ceasium chloride to both sets of samples and make up to the volume with distilled water. Mix well.

Filter a portion through a whatman No. 540 filter paper or equivalent.

Then a reagent blank is run through all stages of analysis. Potassium chloride or lanthanum chloride of equivalent concentration can also be used, except potassium chloride can only be employed if there is no potassium determination required.

The reagent blank is aspirated; standards and samples solutions into the flame of an Atomic Absorption Spectrometer and absorbance recorded.

SUMMARY OF METHODOLOGY



6.0 RESULTS AND DATA ANALYSIS

Table 6.1.0

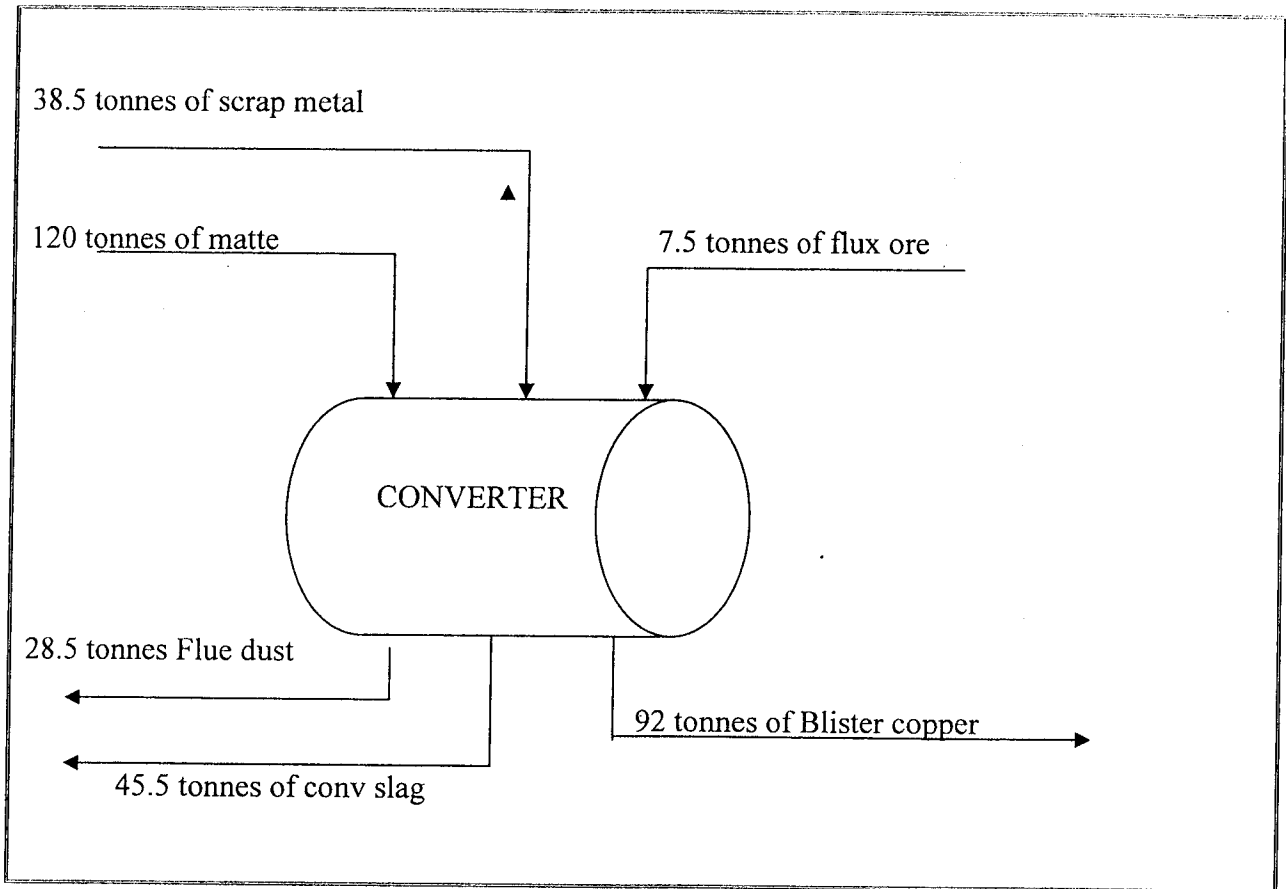
Weight of a full ladle of matte	15 tonnes
Weight of matte button sample	200 grams
Weight of a full matte in a converter	120 tonnes (8 ladles)
Weight of both flue dust particles for both slag and copper blow.	400 grams
Weight of full ladle of blister copper	23 tonnes
Capacity of an empty ladle	6 cubic meters
Weight of a full boat of flux	6 tonnes
Weight of a full boat of scrap metal	3 tonnes
Amount of blister copper ladles produced	3 ladles (69 tonnes)

Table 6.1.1, amount and weight of samples obtained.

Weight of matte samples obtained	1600 grams (8 buttons)
Weight of blister copper samples obtained	1600 grams
Weight of scrap metal samples obtained	800 grams
Weight of flux samples obtained	800 grams
Weight of flue dust particles samples obtained for slag blow	400 grams
Weight of flue dust particles samples obtained for copper blow	400 grams
Weight of converter slag samples obtained	1600 grams

The following section shows material balance over the converter.

CONVERTER BALANCE



There are six impurities in each of the above streams of the converter namely: bismuth, nickel, lead, cobalt, silver and gold. A material balance will be established over each impurity.

MATERIAL IN = MATERIAL OUT

First we consider cobalt in the matte.

$$(0.03/100) * 120 = 0.036$$

The following table shows the amount of cobalt, nickel and in all the streams of the converter.

6.0 RESULTS AND DISCUSSION

Laboratory test were conducted on the following samples; blister copper, converter slag, flue dust particles, scrap metal and flux. There were analysed for bismuth, cobalt, nickel and lead. It was unfortunate that analytical laboratory was not capable of testing for silver and gold as these test procedures and reagents were too expensive and time consuming. Furthermore, the laboratory is understaffed.

The assays of bismuth, cobalt, nickel and lead were obtained. These were used to obtain a mass balance across a converter so that we can analyse how these metals are distributed in different streams. In general these metals occur in very small amounts although they effects can be detrimental to the production of copper.

In striking a balance between the streams to be charged in and those to be discharged, the amount of each metal is determined in each stream (matte, scrap metal, flux, converter slag, and blister copper and flue dust particles). As seen from the above calculations it can be seen that they are some discrepancies between the amounts of metals charged and those discharged from the converter. This means the difference between the amounts of the streams going in and those going out were not equal to zero but rather equal to some value. This is due to some factors which will be highlighted in the next section.

The first factor which causes material imbalance over the converter is the fact that some converters are over loaded with matte at the beginning of slag blow. This practice causes the converter to splash badly, spitting out silica, together with the first magnate formed, and producing a big-build around the converter mouth. This means that, in the calculations the total amount of flux charged in the converter is underestimated as opposed to the standard amount.

A phenomenon called cold blanket also contributes to the material imbalance. This is basically the material left from the previous charge which is slag overblown during the whole copper blow. It is formed by the slag not removed from the slag blow, and by poor quality cold dope charged. Blanket is very high in magnetite and requires a lot of heat to be smelted, reduced and dissolved in a hot slag. This material retains some amount of metals being considered and are not accounted for in the calculations above.

Magnetite formation due to low temperatures and under fluxing of the converter may contribute to the failure of material balances. When under control magnetite is beneficial as it covers the walls of the converter with a thin layer thereby protecting the bricks, reducing refractory wear. Magnetite reduces the capacity of the converter thereby reducing the volume of all the material charged in the converters. This means the total amount of the converter is less than the standard amount therefore affecting the mass balance across the converter.

7.0 CONCLUSION

Generally, it can be seen from the results above that the metals occur in very small amounts relative to the whole mass of materials fed and those discharged out of the converter. The distributions of these metals are highlighted in the following section.

Cobalt is generally occurring in larger amounts than other metals which were being considered. Nickel, bismuth and lead occur in various amounts depending on the type of blending carried out on a particular blow. In particular, flue dust particles contain bismuth which is a volatile metal.

8.0 RECOMMENDATION

In this project, the following recommendation will be made if the intended task is to be achieved successfully. The next time such a project is formulated it should be extended from the converters to the concentrate shed where the blending is carried out as this is the source of metals that were being considered. Perhaps it can further be extended to the tank houses where the effects of these metals are felt.

The best way to control the high levels of these metals in the systems is to apply evaporative precipitation.

9.0 REFERENCES

1. Wills, B.A., 'Mineral Processing Technology', Pergamon Press, 3rd Edition (1955).
2. Leja, J., 'Surface Chemistry of Flootation', Plenum Press, New York (1982)

10.0 APPENDICES

Appendix 1

Table 6.1.2 a

Amount of bismuth in streams

Stream	Amount (tonnes)
Matte	0.036
Scrap metal	0.00385
Flux	0.0015
Converter slag	0.0091
Blister copper	0.0092
Flue dust particles	0.00855

Amount in = 0.04135 tonnes

Amount out = 0.02685 tonnes.

(Amount in – Amount out) = 0.0145 tonnes

Table 6.1.2 b

Amount of lead in streams

Stream	Amount (tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.01365
Blister copper	0.0092
Flue dust particles	0.00855

Amount in = 0.02860 ton

Amount out = 0.0314 ton

(Amount in – Amount out) = 0.0028 ton

Table 6.1.2c

Amount of cobalt in streams

Stream	Amount (tonnes)
Matte	0.396
Scrap metal	0.00385
Flux	0.003
Converter slag	0.30485
Blister copper	0.0092
Flue dust particles	0.0228

Amount in = 0.40285 tonnes

Amount out = 0.33685 tonnes

(Amount in – Amount out) = 0.066 tonnes

Table 6.1.2 d

Amount of nickel in streams

Stream	Amount(tonnes)
Matte	0.264
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0728
Blister copper	0.0828
Flue dust particles	0.0912

Amount in = 0.40285 tonnes

Amount out = 0.33685 tonnes

(Amount in – Amount out) = 0.066 tonnes

Table 6.1.3 a

Amount of nickel in streams

Stream	Amount(tonnes)
Matte	0.264
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0728
Blister copper	0.0828
Flue dust particles	0.0912

Amount in = 0.26860 ton

Amount out = 0.2468 ton

(Amount in – Amount out) = 0.0218 ton.

Table 6.1.3 b

Amount of bismuth in streams

Stream	Amount(tonnes)
Matte	0.048
Scrap metal	0.00385
Flux	0.0091
Converter slag	0.0182
Blister copper	0.0092
Flue dust particles	0.00855

Amount in = 0.06095 tonnes.

Amount out = 0.03595 tonnes.

(Amount in – Amount out) = 0.025 tonnes

Table 6.1.3 c

Amount of cobalt in streams

Stream	Amount (tonnes)
Matte	0.168
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0728
Blister copper	0.0092
Flue dust particles	0.07695

Amount in = 0.1726 tonnes

Amount out = 0.15895 tonnes

(Amount in – Amount out) = 0.01365 ton

.Table 6.1.3 d

Amount of lead in streams

Streams	Amount (tonnes)
Matte	1.392
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.37
Blister copper	0.0184
Flue dust particles	0.00285

Amount in = 1.3966 tonnes

Amount out = 0.39125 tonnes

(Amount in – Amount out) = 1.00535 tonnes

Table 6.1.4 a

Amount of lead in streams

Streams	Amount (tonnes)
Matte	0.096
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.019717
Blister copper	0.0092
Flue dust particles	0.03135

Amount in = 0.1006 ton

Amount out = 0.060267 ton

(Amount in – Amount out) = 0.04033 ton.

Table 6.1.4 b

Amount of bismuth in streams

Streams	Amount (tonnes)
Matte	0.33
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0546
Blister copper	0.0092
Flue dust particles	0.057

Amount in = 0.3346 ton

Amount out = 0.1208 ton

(Amount in – Amount out)= 0.2138 ton

Table 6.1.4 c

Amount of cobalt in streams

Streams	Amount (tonnes)
Matte	0.252
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.182
Blister copper	0.0092
Flue dust particles	0.0399

Amount in = 0.2566 ton

Amount out = 0.2311 ton

(Amount in – Amount out) = 0.0255 ton

Table 6.1.4 d

Amount of nickel in streams

Streams	Amount (tonnes)
Matte	0.156
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0455
Blister copper	0.0092
Flue dust particles	0.0513

Amount in = 0.1606 ton

Amount out =0.106 ton

(Amount in – Amount out)= 0.0546 ton

Table 6.1.5 a

Amount of lead in streams

Streams	Amount (tonnes)
Matte	0.036
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.020475
Blister copper	0.0092
Flue dust particles	0.00855

Amount in = 0.1606 ton

Amount out = 0.106 ton

(Amount in – Amount out) = 0.0546 ton

Table 6.1.6 a

Amount of bismuth in streams

Streams	Amount (tonnes)
Matte	0.384
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.006825
Blister copper	0.0092
Flue dust particles	0.01425

Amount in = 0.3886 ton

Amount out = 0.030275 ton

(Amount in – Amount out) = 0.358325 ton

Table 6.1.6 b

Amount of cobalt in streams

Streams	Amount (tonnes)
Matte	0.39
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0182
Blister copper	0.0092
Flue dust particles	0.1197

Amount in = 0.3946 ton

Amount out = 0.1471 ton

(Amount in – Amount out) = 0.2475 ton

Table 6.1.6 c

Amount of nickel in streams

Streams	Amount (tonnes)
Matte	0.156
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0273
Blister copper	0.0092
Flue dust particles	0.0513

Amount in = 0.1606 ton

Amount out = 0.0878 ton

(Amount in- Amount out)= 0.0728 ton

Table 6.1.6 d

Amount of lead in streams

Streams	Amount (tonnes)
Matte	0.036
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.015925
Blister copper	0.0092
Flue dust particles	0.0114

Amount in = 0.0406 ton

Amount out = 0.036525 ton

(Amount in – Amount out) = 0.004075 ton

Table 6.1.7 a

Amount of bismuth in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.00455
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.2446 ton

Amount out = 0.0166 ton

(Amount in – Amount out) = 0.228 ton

Table 6.1.7 b

Amount of cobalt in streams

Streams	Amount(tonnes)
Matte	0.372
Scrap metal	0.00385
Flux	0.00225
Converter slag	0.3822
Blister copper	0.0092
Flue dust particles	0.0171

Amount in = 0.4 ton

Amount out = 0.4 ton

(Amount in – Amount out) = 0.0 ton

Table 6.1.7 c

Amount of nickel in streams

Streams	Amount (tonnes)
Matte	0.18
Scrap metal	0.00385
Flux	0.001125
Converter slag	0.05915
Blister copper	0.0092
Flue dust particles	0.05415

Amount in = 0.184975 ton

Amount out = 0.1225 ton

(Amount in – Amount out) = 0.062475 ton

Table 6.1.7 d

Amount of lead in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0091
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.0286 ton

Amount out = 0.02115 ton

(Amount in – Amount out) = 0.00745 ton.

Table 6.1.8 a

Amount of bismuth in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.00455
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.0286 ton

Amount out = 0.0166 ton

(Amount in – Amount out) = 0.012 ton

Table 6.1.8 b

Amount of cobalt in streams

Streams	Amount (tonnes)
Matte	0.624
Scrap metal	0.00385
Flux	0.002625
Converter slag	0.39585
Blister copper	0.0092
Flue dust particles	0.0114

Amount in = 0.630475 ton

Amount out = 0.41645 ton

(Amount in – Amount out) = 0.214025 ton.

Table 6.1.8 c

Amount of nickel in streams

Streams	Amount (tonnes)
Matte	0.18
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.04095
Blister copper	0.0092
Flue dust particles	0.0513

Amount in = 0.1846 ton

Amount out = 0.10145 ton

(Amount in – Amount out) = 0.08315 ton

Table 6.1.8 d

Amount of lead in streams

Streams	Amount (tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0182
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.03 ton

Amount out = 0.03 ton

(Amount in – Amount out) = 0.00 ton

Table 6.1.9 a

Amount of bismuth in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.00455
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.0286 ton

Amount out = 0.0166 ton

(Amount in – Amount out) = 0.012 ton

Table 6.1.9 b

Amount of cobalt in streams

Streams	Amount (tonnes)
Matte	0.588
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.5096
Blister copper	0.0092
Flue dust particles	0.00855

Amount in = 0.5926 ton

Amount out = 0.52735 ton

(Amount in – Amount out)= 0.06525 ton

Table 6.1.9 c

Amount of nickel in streams

Streams	Amount (tonnes)
Matte	0.156
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.05005
Blister copper	0.0092
Flue dust particles	0.0399

Amount in = 0.1606 ton

Amount out = 0.09915 ton

(Amount in – Amount out) = 0.06145 ton

Table 6.1.9 d

Amount of lead in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.015925
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.0286 ton

Amount out = 0.027975 ton

(Amount in – Amount out) = 0.000625 ton

Table 6.2.0 a

Amount of bismuth in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.00455
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.0286 ton

Amount out = 0.0166 ton

(Amount in – Amount out) = 0.012 ton

Table 6.2.0 b

Amount of cobalt in streams

Streams	Amount (tonnes)
Matte	0.828
Scrap metal	0.00385
Flux	0.002625
Converter slag	0.6734
Blister copper	0.0092
Flue dust particles	0.02565

Amount in = 0.834475 ton

Amount out = 0.70825 ton

(Amount in – Amount out) = 0.126225 ton.

Table 6.2.0 c

Amount of nickel in streams

Streams	Amount(tonnes)
Matte	0.12
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0364
Blister copper	0.0092
Flue dust particles	0.0741

Amount in = 0.1246 ton

Amount out = 0.1197 ton

(Amount in – Amount out) =0.0049 ton

Table 6.2.0 d

Amount of lead in streams

Streams	Amount (tonnes)
Matte	0.036
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0182
Blister copper	0.0092
Flue dust particles	0.00855

Amount in = 0.0406 ton

Amount out = 0.03595 ton

(Amount in – Amount out) = 0.00465 ton

Table 6.2.1 a

Amount of bismuth in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.00455
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.0286 ton

Amount out = 0.0166 ton

(Amount in – Amount out) = 0.012 ton

Table 6.2.1 b

Amount of cobalt in streams

Streams	Amount(tonnes)
Matte	0.504
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.364
Blister copper	0.0092
Flue dust particles	0.0285

Amount in = 0.5086 ton

Amount out = 0.4017 ton

(Amount in – Amount out) = 0.1069 ton

Table 6.2.1 c

Amount of nickel in streams

Streams	Amount(tonnes)
Matte	0.132
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.04095
Blister copper	0.0092
Flue dust particles	0.03705

Amount in = 0.1366 ton

Amount out = 0.0872 ton

(Amount in – Amount out) = 0.0494 ton

Table 6.2.1 d

Amount of lead in streams

Streams	Amount(tonnes)
Matte	0.036
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.02275
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.0406 ton

Amount out = 0.0348 ton

(Amount in – Amount out) = 0.0058 ton.

Table 6.2.2 a

Amount of bismuth in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.00455
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.0286 ton

Amount out = 0.0166 ton

(Amount in – Amount out) = 0.012 ton

Table 6.2.2 b

Amount of cobalt in streams

Streams	Amount(tonnes)
Matte	0.036
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.2184
Blister copper	0.0092
Flue dust particles	0.00855

Amount in = 0.0406 ton

Amount out = 0.03817 ton

(Amount in – Amount out) = 0.00243 ton.

Table 6.2.2 c

Amount of nickel in streams

Streams	Amount(tonnes)
Matte	0.252
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.07735
Blister copper	0.0092
Flue dust particles	0.03705

Amount in = 0.2566 ton

Amount out = 0.1236 ton

(Amount in – Amount out) = 0.133 ton

Table 6.2.2 d

Amount of lead in streams

Streams	Amount(tonnes)
Matte	0.036
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0182
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.2566 ton

Amount out = 0.03025 ton

(Amount in – Amount out) = 0.01035 ton

.Table 6.2.3 a

Amount of bismuth in streams

Streams	Amount(tonnes)
Matte	0.12
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.00455
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.1246 ton

Amount out = 0.0166 ton

(Amount in – Amount out) = 0.108 ton

Table 6.2.3 b

Amount of cobalt in streams

Streams	Amount(tonnes)
Matte	0.432
Scrap metal	0.00385
Flux	0.0015
Converter slag	0.24115
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.4366 ton

Amount out = 0.2532 ton

(Amount in – Amount out) = 0.1834 ton

Table 6.2.3 c

Amount of nickel in streams

Streams	Amount(tonnes)
Matte	0.12
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0455
Blister copper	0.0092
Flue dust particles	0.0684

Amount in = 0.1246 ton

Amount out = 0.1231 ton

(Amount in – Amount out) = 0.0015 ton

Table 6.2.3 d

Amount of lead in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0182
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.03 ton

Amount out = 0.03 ton

(Amount in – Amount out) = 0.00 ton.

Table 6.2.4 a

Amount of bismuth in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.00455
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.0286 ton

Amount out = 0.0166 ton

(Amount in – Amount out) = 0.012 ton

Table 6.2.4 b

Amount of cobalt in streams

Streams	Amount(tonnes)
Matte	0.66
Scrap metal	0.00385
Flux	0.00225
Converter slag	0.5187
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.6661 ton

Amount out = 0.53075 ton

(Amount in – Amount out) = 0.13535 ton

Table 6.2.4 c

Amount of nickel in streams

Streams	Amount(tonnes)
Matte	0.108
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.03185
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.1126 ton

Amount out = 0.0439 ton

(Amount in – Amount out) = 0.0687 ton

Table 6.2.4 d

Amount of lead in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0182
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.03 ton

Amount out = 0.03 ton

(Amount in – Amount out) = 0.00 ton

Table 6.2.5 a

Amount of bismuth in streams

Streams	Amount(tonnes)
Matte	0.024
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.00455
Blister copper	0.0092
Flue dust particles	0.00285

Amount in = 0.0286 ton

Amount out = 0.0166 ton

(Amount in – Amount out) = 0.012 ton

Table 6.2.5 b

Amount of cobalt in streams

Streams	Amount(tonnes)
Matte	0.732
Scrap metal	0.00385
Flux	0.0015
Converter slag	0.6188
Blister copper	0.0092
Flue dust particles	0.0057

Amount in = 0.73735 ton

Amount out = 0.6337 ton

(Amount in -- Amount out) = 0.10365 ton

Table 6.2.5 c

Amount of nickel in streams

Streams	Amount(tonnes)
Matte	0.108
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.0364
Blister copper	0.0092
Flue dust particles	0.0228

Amount in = 0.1126 ton

Amount out = 0.0684 ton

(Amount in -- Amount out) = 0.0442 ton

Table 6.2.5 d

Amount of lead in streams

Streams	Amount(tonnes)
Matte	0.036
Scrap metal	0.00385
Flux	0.00075
Converter slag	0.02275
Blister copper	0.0092
Flue dust particles	0.00285

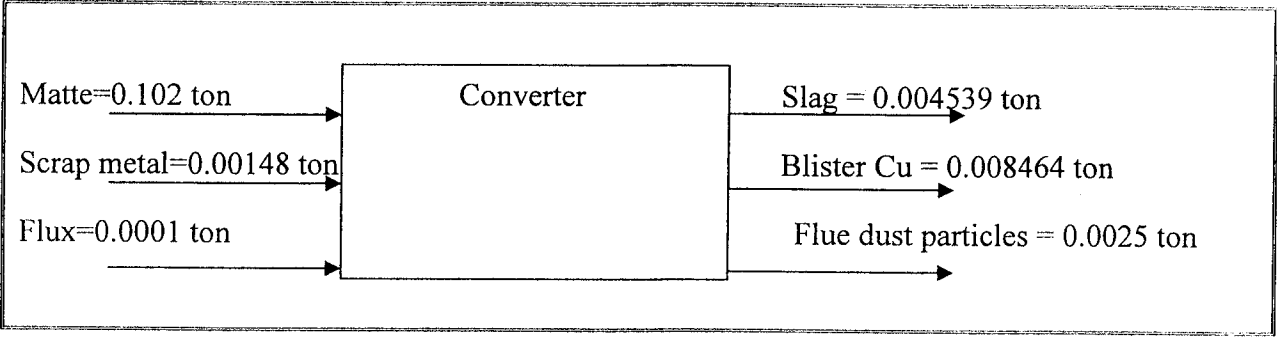
Amount in = 0.0406 ton

Amount out = 0.0348 ton

(Amount in – Amount out) = 0.0058 ton

Appendix 2

BISMUTH BALANCE



Ave % Bi in matte

$$(0.036+0.048+0.33+0.384+0.024+0.024+0.024+0.024+0.024+0.024+0.12+0.024+0.024)/13=$$

0.085%.

Bi in matte

$$(0.085/100)*120= 0.102 \text{ ton}$$

Ave % Bi in Scrap metal

$$0.00385\%$$

Bi in Scrap metal

$$(0.00385/100)*38.5= 0.001482 \text{ ton}$$

Ave % Bi in Flux

$$(0.0015+0.0091+0.00075+0.00075+0.00075+0.00075+0.00075+0.00075+0.00075+0.00075+0.00075+0.00075+0.00075)/13=0.001335\%$$

Bi in Flux

$$(0.001335/100)*7.5=0.0001 \text{ ton}$$

Ave % Bi in Slag

$$(0.0091+0.0182+0.0546+0.006825+0.00455+0.00455+0.00455+0.00455+0.00455+0.00455+0.00455+0.00455+0.00455)/13= 0.009975\%$$

Bi in Slag

$$(0.009975/100)*45.5=0.004539 \text{ ton}$$

Ave % Bi in Cu

$$0.0092\%$$

Bi in Cu

$$(0.0092/100)* 92= 0.008464 \text{ ton}$$

Ave % Bi in Flue dust particles

$$(0.00855+0.00855+0.057+0.01425+0.00285+0.00285+0.00285+0.00285+0.00285+0.00285+0.00285+0.00285+0.00285)/13=0.00877$$

$$(0.00877/100)*28.5= 0.0025$$

Amount of Bi lost = Amount of Bi in – Amount of Bismuth out.

$$(0.102+0.001482+0.0001) + (0.004539+0.008464+ 0.0025) =0.0880 \text{ ton}$$

