# THE FUTURE OF SO2 /AIR CYANIDE DESTRUCTION PROCESS

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## ABSTRACT

The SO2/Air cyanide destruction process is the most common method used to destroy cyanide in the gold extraction sector globally. It was developed in an era when typical requirements were based on a relatively steady concentration of weak acid dissociable cyanide (WAD CN-) in the feed of 150 to 200 mg/L and a discharge limit of less than 50 mg/L. However, as the industry started to develop more metallurgically complex deposits, and environmental regulations became more stringent, the demands and performance expectations placed on cyanide destruction have changed. Feed to the SO2/Air often contains more than 650 mg/L of WAD CN- and is subject to large variations depending on the mill feed while the discharge limits well below 1 mg/L are not uncommon. Adding further complexity is that more often than ever, solutions contain elevated levels of thiosalts and/or thiocyanate (SCN-) which can interfere with cyanide destruction and yet other constituents can affect either the ability to recycle process water or the overall site environmental compliance. Finally, the industry began to embrace carbon footprint reduction and pursues increases in resiliency. This paper provides a holistic overview of the SO2/Air process, interconnections between metallurgical and environmental issues, and discusses changes in design and operations strategies needed to meet the requirements of modern gold extraction projects.

## KEYWORDS

Cyanide Detox, Inco Process, WAD CN-, Sulphur Burner, Oxygen Generator, Liquid SO2, Carbon Footprint, Operating Cost, Emission Factor

## INTRODUCTION

This paper provides a holistic overview of the Inco SO2/Air process, interconnection between metallurgical and the environmental issues, and discusses changes in design and operation strategies needed to meet the requirements of the modern gold extraction process.

With stricter limits globally being imposed on cyanide discharge levels in plant tailings, having a reliable and well-designed cyanide detoxification circuit is critical for any operation. The Inco SO2/Air method is most used process for cyanide detoxification worldwide. Sulphur dioxide and oxygen combine with copper to oxidize cyanide to the much less toxic cyanate. The goal is to produce a cyanide detox circuit in a way that reliably meets discharge target limits with the lowest operating cost and carbon emissions. It is time the industry pursues increases in resiliency and began to conduct cyanide detox operations in a way that leads to carbon footprint reduction.

## INNOVATION IN THE INCO PROCESS

Since the introduction of the Inco SO2 / Air process in the 1980s for cyanide destruction in mining wastewater, there have been a lot of changes experienced over the years in how the process is conducted with respect to the detox circuit and reagent system setup. This is due to increased CNwad levels expected in the wastewater because of the enhanced complexity of the metallurgical deposits being discharged, which requires a larger operation size and calls for more stringent environmental regulatory limits.

### Cyanide Destruction Process of Past

In the earlier years of the Inco SO2/Air process, air blowers were used to provide the oxygen required for the chemical reaction. The use of liquid SO2 was the selected reagent in North America due to cost and availability. The other regions of the world did not have much of a choice other than using sodium metabisulphite or peroxide. Back in the early 80' when the process was introduced to the industry, typical tonnage was in the range of 500 to 1000 mtpd. Cyanide levels as Weak Acid Dissociable (CNwad) ranged from 150 mg/L to 250 mg/L and the final discharge levels of CNwad ranged from 0.2 to 50 mg/L depending on what part of the world the operation was in. Metal targets were also part of the permitting in North America.

### Cyanide Destruction Process of Present

The operations of today are pushing tonnage in the excess of 10,000 to 100,000 mtpd and CNwad levels are reaching 600 to 700 mg/L due to gold/copper operations. Moreover, as the industry started to develop more metallurgically complex deposits, the environmental regulation became more stringent. The demand and performance expectations placed on cyanide destruction have changed. Adding further to the complexity more often than ever, solutions contain elevated levels of ammonia, thiosalts and or thiocyanate (SCN-) which interfere with cyanide destruction and their constitutes can affect the ability to recycle process water or the overall site environmental compliance. To deal with these new challenges and stringent limits, innovation in the SO2 and Air reagent system is required so that the industry can cope with the exceeding capital / operating costs and carbon footprint associated with the large operations of today.

## DESIGN CHANGES

The detailed design is at the center of what makes the cyanide destruction process operate safely and efficiently. This is where the flexibility in the design is built into the system to allow for a robust design that can handle the inevitable process upsets. Without the capacity to handle upsets, non-compliance and downtime threatens the overall operation. While many process failures are the result of fundamental mistakes such as aligning tanks in series rather than parallel, underestimating agitator power requirements or insufficient reagent supply for changing ore bodies, there are also some intricate design details that can affect the operability and reliability of a cyanide destruction circuit. The detailed design stage is also where decisions are made on the tradeoff of Capital vs. Operating costs and decisions on what "luxury items" such as Online Cyanide Analyzers should be included.

To help evaluate different options when designing a cyanide destruction circuit, or any other process, carefully looking at Capital vs. Operating costs will help to determine the overall lowest life-of- mine cost. Will spending additional money now save more money down the road? A look into the equipment operation power requirements along with reagent and equipment transport can also provide a lot of insight on the carbon reduction potential and operating cost of the whole detox process. This is a critical part of the reagent and method selection for a cyanide destruction circuit. It means choosing the best method as well as the source of the reagent to destroy cyanide in the most economical and environmentally friendly way. The Inco SO2/O2 process has several different options for an SO2 source. The most common choices include Sodium Metabisulphite (SMBS), Liquid SO2, or SO2 gas from a Sulphur Burner.

**Sodium Metabisulfite (SMBS)**

SMBS requires only a simple reagent mixing and dosing system and has the lowest capital cost however, it can be an expensive reagent as it only produces approximately 67% SO2 by weight which means the reagent and transport cost is much higher to fulfill the same SO2 requirement. This can be further multiplied if working in a remote region. Moreover, the cost and hassle to deal with sodium sulfate remains an issue when using this reagent. For these reasons SMBS is typically not suitable for larger operations and not considered as a part of this study for simpler comparison due to having a different reagent chemistry altogether.

**Liquid SO2**

Liquid SO2 is common in Canada and Mexico where pure 100% liquid SO2 is produced by metal smelters and sold as a byproduct. Liquid SO2 comes with a higher capital cost than SMBS due to storage tanks and metering systems along with the safety risks associated with Liquid SO2 storage onsite. In addition, the reagent cost is very high, and it must be transported in a pressurized tanker truck in great amounts which significantly increases the transport costs, so the location of the mine site and reagent requirement dictates if this is an appropriate option.

**SO2 Gas from a Sulphur Burner System**

Sulphur Burners are becoming a more attractive source of SO2 to the higher tonnage operations. The cost of Sulphur is the lowest compared to the other reagents. The burners themselves are typically equal in capital cost to a liquid SO2 system or else pay-back in most cases is in less than two years. The feed stock is Sulphur which can be safely transported as a solid or molten to site. In addition, the combustion of Sulphur produces 2 grams of SO2 for every gram of Sulphur. This means that it has the lowest mass requirement for a reagent that must be transported so it is a preferred choice for remote locations and larger operations. Reagent availability and cost, as well as transportation costs need to be carefully examined when looking at the tradeoff between Capital and Operating Costs.

Another option in the detox circuit design that should be looked at when considering design changes, is the use of oxygen generators as opposed to air blowers to fulfill the oxygen requirement. The advantages of oxygen over air are better utilization as well as lower power requirements for both the oxygen generators and agitators. This helps reduce both the operating cost for the equipment and the overall process carbon footprint. In larger operations typically high-powered agitation is required so the likely hood of mechanical failure is reduced. Finally, oxygen provides an added safety factor to any chemistry changes in the mill or higher tonnage improvements without the need of any changes to agitator power in most cases.

## SCOPE OF STUDY

A study is conducted on the possible design changes and different ways of conducting the Inco SO2
/ Air Process to evaluate the capital and operating costs along with the associated carbon emissions with respect to the type of equipment and reagent used in the process. A set boundary is defined, and two different operating conditions are assessed depending on the cyanide load and size of the operations of the past and of the present. Possible cost and carbon footprint savings are analyzed and compared between the conventional process and the new innovations introduced in the detox circuit design.

### Study Boundary

A boundary is set for the purpose of this study to analyze the various costs, and carbon footprint, for all the methods of cyanide detox under study inside this defined boundary for simpler comparison. Figure 1 below clearly outlines this boundary for our cyanide detox operation. The appropriate Sulphur reagent and major equipment including oxygen generators, air blowers, Sulphur combustion system, SO2 handling, and agitators required for the Sulphur combustion process (where applicable) along with the cyanide detox and oxidation process are included in the boundary of the study. The costs and power requirements associated with the equipment and reagents for these different methods are analyzed to assess the carbon emissions and cost savings. Equipment and reagent transport is also included as part of the study. All miscellaneous equipment, catalyst requirements and side processes are not included in the study as they would approximately be the same for all the methods under study and do not form any basis of comparison between the analyzed cyanide detox methods.

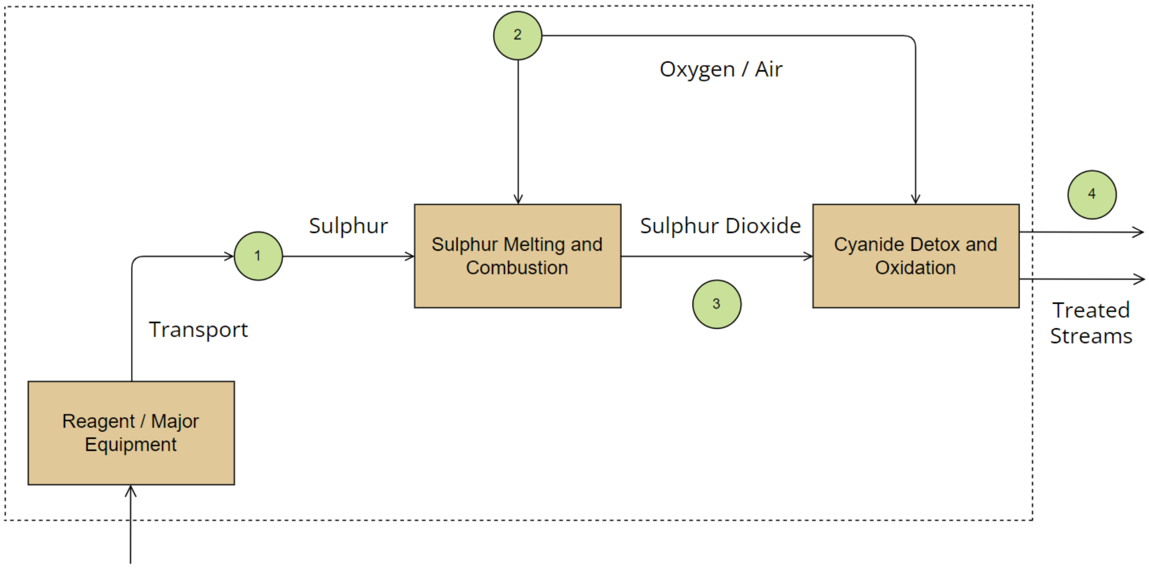


**Figure 1 – Defined set boundary for the Cyanide detox study**

### Operating Conditions and Specs

As discussed previously, there has been a lot of change observed between the cyanide detox operations of the past and of today. In the past few decades, the metallurgical deposits have become more complex, and the operation requirements and limits have become stricter. This study analyzes the operations of the past and present under a defined set of operating conditions for each type of operation.

### Lower-end Operating Conditions

The operating size and overall feed requirements for the older operations were on the lower end due to lesser CNwad levels in the wastewater and gentler discharge limits. Hence, the operations of the past are defined under the lower end operating conditions. Table 1 below displays the operating conditions for older cyanide detox operations.

### Upper-end Operating Conditions

The operating size and overall feed requirements for the newer operations have significantly increased due to more complex metallurgical deposits that raise CNwad levels in the wastewater and introduced more stringent environmental discharge limits. The reagent dosage per gram of CNWAD also needs to be increased to cope up with more complex deposits. Hence, the operations of the present are defined under the upper end operating conditions. Table 1 below displays the operating conditions for recent cyanide detox operations.

**Table 1 – Defined operating conditions for Cyanide detox operations of the past and present**

| Type of Operation | $SO_2$ Requirement (tonnes/day) | Detox Feed Rate (tonnes/day) | Cyanide Load (kg/hr.) | CNwad Concentration (mg/L) | Discharge Limit (mg/L) | Reagent Dosage Ratio (g $SO_2$/g CNWAD) | Number of Detox Tanks Required |
|---|---|---|---|---|---|---|---|
| Lower end | 8 | 10000 | 83 | 150 | 50 | 4 | 2 |
| Upper end | 50 | 10000 | 360 | 650 | 1 | 6 | 4 |

## Ways of Conducting the Inco SO2 / Air Process

The conventional way of conducting the Inco process is to buy liquid SO2 as reagent and use an air blower to meet the oxidation requirement in the detox circuit. This has been the most common Inco process method that has been employed by the industry for cyanide detox operations for many decades now. In recent times, new innovations have been introduced in the Inco process to treat cyanide, to deal with the ever- growing size of the operations and maximize utilization of air while keeping reagent costs, operating costs, and carbon emissions at a minimum. Recently, the breakthrough innovation has been the installation of Sulphur burners to produce SO2 gas onsite rather than purchasing Liquid SO2 to cope with the rising reagent costs. Another change that has been observed is the usage of oxygen generators to fulfill the oxygen requirement instead of air blowers as they result in maximum utilization of oxygen reducing the agitation requirement and require lesser power itself to run which in turn leads to reduction in operating costs and the carbon footprint of the overall process.

Four different ways are selected for conducting the Inco SO2 / Air process to treat cyanide for both the operating conditions under study. Each unique way explores a unique parameter change in terms of the reagent and oxidation system used in the Cyanide detox operation. Each selected way of conducting the Inco process has its own flow specifications and detox tank agitation requirements depending on the type of reagent and oxidant used.

## Liquid SO2 / Air

This conventional method requires Liquid SO2 to be bought directly from a vendor to be used as the Sulphur reagent in the cyanide detox process. Common industrial Air blowers are used to fulfill the oxidation the requirement. This method has a higher agitation requirement than the others as it utilizes an air blower for oxidation that has approximately only 20 % to 30 % oxygen utilization thus requiring more mixing for proper treatment of cyanide. The air flow and reagent amounts required are also significantly higher which increase the overall power requirement and reagent costs respectively. Table 2 below lays down the flow specs and agitation requirements for this method of conducting the Inco process for both operating conditions under study.

**Table 2 – Flow and agitation specs for Liquid SO2 / Air cyanide detox system**

| Type of Operation | Sulphur Mass Flowrate (kg/hr.) | Air Flowrate ($Nm^3$/hr.) | SO2 Mass Flowrate (kg/hr.) | Total Agitation Requirement (hp) |
|---|---|---|---|---|
| Lower end | - | 4,000 | 332 | 250 |
| Upper end | - | 26,900 | 2,100 | 1,200 |

## SO2 Gas from Sulphur Burner System / Air

This method differs from the first one as it employs the use of a Sulphur burner system on site to produce SO2 gas for cyanide treatment. This reduces the reagent requirement and cost by a great amount as Sulphur is much cheaper to buy than Liquid SO2 and the reagent amount required reduces by half as 1 g of Sulphur combusts to produce 2 g of SO2 gas. At the same time, air flow required is slightly higher than the Liquid SO2 / Air method as extra air is needed in the combustion system to burn Sulphur and produce SO2. This slightly increases the power requirement of the air blower. The agitation requirement in the detox tank remains the same since both methods rely on air blowers for oxidation. Table 3 below outlines the flow and agitation specs for this method of conducting the Inco process for both operating conditions under study.

**Table 3 – Flow and agitation specs for Sulphur burner / Air cyanide detox system**

| Type of Operation | Sulphur Mass Flowrate (kg/hr.) | Air Flowrate ($Nm^3$/hr.) | SO2 Mass Flowrate (kg/hr.) | Total Agitation Requirement (hp) |
|---|---|---|---|---|
| Lower end | 166 | 4,400 | 332 | 250 |
| Upper end | 1,050 | 29,300 | 2,100 | 1,200 |

## Liquid SO2 / Oxygen

This method uses the conventional Liquid SO2 as the Sulphur reagent however, air requirement for oxidation is fulfilled by pure oxygen instead of air. Oxygen generators are used for this purpose which produce approximately 90-93 % oxygen by weight as opposed to just the 21 % by air blowers. Since the concentration of oxygen per unit volume increases, the required flowrate decreases drastically compared to the methods that use air blowers for oxidation. Moreover, oxygen generators generally have a much lower power requirement than its predecessor and reduce the agitation requirement in the detox tank due to easier mixing and oxidation. The costs associated with the reagent purchase and transport are still the highest however, a switch to oxygen generators helps reduce the overall power requirement and hence, reduce equipment operating costs and the carbon footprint of the system. Table 4 below outlines the flow and agitation specs for this method of conducting the Inco process for both operating conditions under study.

**Table 4 – Flow and agitation specs for liquid $SO_2$ / Oxygen cyanide detox system**

| Type of Operation | Sulphur Mass Flowrate (kg/hr.) | Air Flowrate ($Nm^3$/hr.) | $SO_2$ Mass Flowrate (kg/hr.) | Total Agitation Requirement (hp) |
|---|---|---|---|---|
| Lower end | - | 200 | 332 | 200 |
| Upper end | - | 1,200 | 2,100 | 1,000 |

## SO2 Gas from Sulphur Burner System / Oxygen

This method incorporates both the suggested innovations in the cyanide detox process: The Sulphur burner system and the oxygen generators. This results in maximum utilization of the oxidant, and low power and reagent requirements. The usage of the cheapest reagent along with the high concentration oxygen generator leads to the lowest operating cost and carbon footprint of the system. Moreover, incorporating both the new changes in the detox system leads to the highest amount of savings in costs and carbon emissions, in the long run, compared to the other methods under study. Table 5 below outlines the flow and agitation specs for this method of conducting the Inco process for both operating conditions under study.

**Table 5 – Flow and agitation specs for Sulphur burner / Oxygen cyanide detox system**

| Type of Operation | Sulphur Mass Flowrate (kg/hr.) | Air Flowrate ($Nm^3$/hr.) | $SO_2$ Mass Flowrate (kg/hr.) | Total Agitation Requirement (hp) |
|---|---|---|---|---|
| Lower end | 166 | 300 | 332 | 200 |
| Upper end | 1,050 | 1,700 | 2,100 | 1,000 |

## ECONOMIC ANALYSIS

To understand the tradeoff between operating and capital costs as well as the total cost savings in the long run between the Inco process methods under study, certain fixed costs along with the yearly recurring costs are analyzed and compared. Fixed costs such as the cost of the major equipment involved, and their transport give insight on the capital cost of the cyanide detox plant. Yearly recurring costs such as the major equipment operating costs, and reagent purchase and transport costs, provide an understanding of the majority cost of operating the detox plant every year. Assessing the tradeoff between these costs lays down the cost savings expected when the discussed innovations (Sulphur burners and oxygen generators) are applied to the conventional Inco SO2 / Air process.

**Fixed Costs**

Setting up a cyanide detox circuit, requires a set of major equipment that form the main part of the process and are necessary components for the Inco process to function. The appropriate selection of these equipment according to their respective process methods, depict the power requirements of the detox process. The set of major equipment included in the analysis are **agitators, oxygen generators, air blowers, detox tanks, Sulphur combustion system and SO2 handling and storage system**, depending on the type of detox method under study and defined operating conditions of the plant.

Transport of these equipment is also required to site depending on the location of the site and distance. For this study, a constant distance of 2000 km from the vendor to site, is considered. A **transport cost factor of $ 0.41 per tonne-km** (Barton, 2006) is selected which corresponds to a class 8 heavy vehicle truck or trailer under congested conditions.

Table 6 below outlines these fixed costs for each type of Inco process method and operating condition under study. All costs including the transport cost factor are in US dollars (investing.com, n.d.) and account for inflation (US Bureau of Labor Statistics, n.d.). It can be observed that methods involving a Sulphur burner have significantly higher equipment costs when compared to the conventional liquid SO2 system especially for larger operations. This is due to the installation of the Sulphur burner system which contains all the components ranging from basic structure, melting system and cooling towers up till pumps, compressors, and piping instrumentation. This system costs more in comparison to the conventional liquid SO2 system and the cost difference increases drastically with capacity as a conventional system requires a simple handling and storage system which is much less costly. Moreover, the switch from air blowers to oxygen generators also increases the equipment cost as oxygen generators cost more and have a smaller capacity per unit. For these reasons, the oxygen fired Sulphur burner detox systems are the most expensive capitally and the conventional liquid SO2 / air blower systems are the least, as can be seen in table 6. Fixed equipment transport costs are very similar for each Inco process method regardless of Sulphur burning systems and oxygen generator units weighing slightly more and pushing the cost up. Furthermore, these costs are very low and do not make a significant difference in the comparison in the big picture.

**Table 6 – Fixed costs associated with the major equipment and their transport**

| Type of Inco process method | Lower-End Operating Condition | | | Upper-End Operating Condition | | |
|---|---|---|---|---|---|---|
| | Equipment Cost (USD) | Transport Cost (USD) | **Total Fixed Cost (USD)** | Equipment Cost (USD) | Transport Cost (USD) | **Total Fixed Cost (USD)** |
| Liquid $SO_2$ / Air Blower | $ 2,534,000 | $ 126,000 | **$ 2,660,000** | $ 5,304,000 | $ 216,000 | **$ 5,520,000** |
| Air Fired Sulphur Burner System | $ 3,558,000 | $ 139,000 | **$ 3,697,000** | $ 14,834,000 | $ 255,000 | **$ 15,089,000** |
| Liquid $SO_2$ / Oxygen Generator | $ 3,192,000 | $ 137,000 | **$ 3,329,000** | $ 8,038,000 | $ 289,000 | **$ 8,327,000** |
| Oxygen Fired Sulphur Burner System | $ 3,678,000 | $ 151,000 | **$ 3,829,000** | $ 18,890,000 | $ 353,000 | **$ 19,243,000** |

**Yearly Recurring Costs**

Running the Inco process effectively at a cyanide detox plant comes with a set of yearly costs that are associated with major equipment operations, and reagent requirement and transport. These costs recur every year throughout the life of the mine and depend immensely on the type of reagent system used.

There are two types of reagents considered in this study: Liquid SO2 or SO2 gas produced from a Sulphur burner installed on site. The first one is the conventional reagent that requires direct Liquid SO2 purchase from the vendor whereas, the latter requires the purchase of Sulphur as a secondary reagent from the vendor which is then utilized on site to produce SO2 gas. The Sulphur burner systems add significantly to the fixed cost of equipment depending on the type on Inco process method under study however, Sulphur costs $350 per tonne (Sulfur price in Canada, 2022) which is a very cheap reagent compared to its conventional competitor that has a high cost price of $1200 per tonne. This high vendor price of Liquid SO2 is associated with the cost of producing the reagent using the appropriate raw materials along with the complications of pressurization and liquefication. On the other hand, Sulphur is a byproduct of the largely popular oil and gas industry in Canada and is available in abundance thus lowering its cost price in comparison. Moreover, the reagent requirement for Sulphur is half of that of liquid SO2 which in turn reduces the overall yearly reagent cost even further and means that the transport costs are also halved. Additionally, Liquid SO2 is transported in pressurized tankers as liquid phase which poses an added safety risk and requires an easily accessible site location whereas, Sulphur can easily be delivered to site in crates as solid powder.

Table 7 below displays the yearly reagent purchase and transport costs associated with the two selected reagents for both the operating conditions under study. Transport cost factor and conditions selected are same as for fixed transport cost calculations. It can be observed that the difference in the total cost is huge when you switch from the conventional liquid SO2 to Sulphur, and the total cost savings increase approximately from $ 4M to $ 26M as the capacity and operation size of the plant increases. Furthermore, the added cost of the Sulphur burner system to the total fixed costs, as observed previously in table 6, due to the change of reagent system is recovered in a year or less depending on the capacity of the detox plant plus additional savings are also expected.

**Table 7 – Yearly costs associated with reagent purchase and transport for both operating conditions**

| Type of Reagent | Lower-End Operating Condition | | | | Upper-End Operating Condition | | | |
|---|---|---|---|---|---|---|---|---|
| | Reagent Requirement (tonnes/day) | Reagent Cost (USD/year) | Reagent Transport Cost (USD/year) | **Total Reagent Cost (USD/year)** | Reagent Requirement (tonnes/year) | Reagent Cost (USD/year) | Reagent Transport Cost (USD/year) | **Total Reagent Cost (USD/year)** |
| Liquid $SO_2$ | 8 | $ 3,490,000 | $ 2,385,000 | **$ 5,875,000** | 50 | $ 22,075,000 | $ 15,085,000 | **$ 37,160,000** |
| Sulphur | 4 | $ 509,000 | $ 1,192,000 | **$ 1,701,000** | 25 | $ 3,219,000 | $ 7,542,000 | **$ 10,761,000** |

The correct choice of equipment for any process reveals the approximate power requirement which in turn determines the carbon footprint and operating costs associated with that process equipment. Each Inco process method under study has its own unique set of equipment depending on the reagent and oxidant used. The power requirement of these major set of equipment is used to determine the costs associated with operating them. Figures 2 and 3 below display the major equipment operating costs associated with each type of Inco process method under study for lower-end and upper-end operating conditions respectively. The energy requirement per year for each type of equipment, inside the scope of the study, is calculated. The plant is assumed to be operating 24/7, 365 days a year and the electricity cost per kilowatt-hour is $ 0.08 (Hydro-Quebec, 2022) which is calculated as a national average of all the major heavy duty industrial cities. It can be observed from the figures that the Oxygen generators / Air blowers and Agitators depict majority of the equipment operating costs whereas, the Sulphur combustion or Liquid SO2 handling systems contribute the least. The process methods that include Sulphur combustion have a slightly higher air flow requirement so the contribution of oxygen generators / Air blowers towards the costs is also greater compared to the liquid SO2 systems which raises the overall equipment operating costs. The switch from Air blowers to Oxygen generators lowers the agitation and flow requirement which in turn lowers the contribution of generators towards the overall costs. The Liquid SO2 systems that use oxygen generators for oxidation have the lowest overall equipment operating costs.

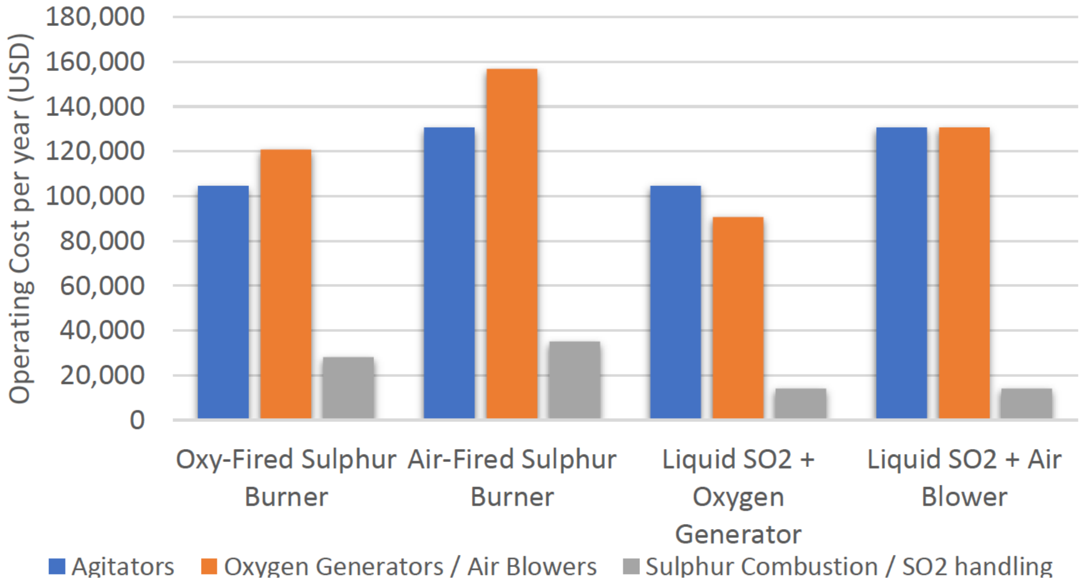


**Figure 2 – Major equipment operating costs associated with each type of Inco process method under study for lower-end operating condition**

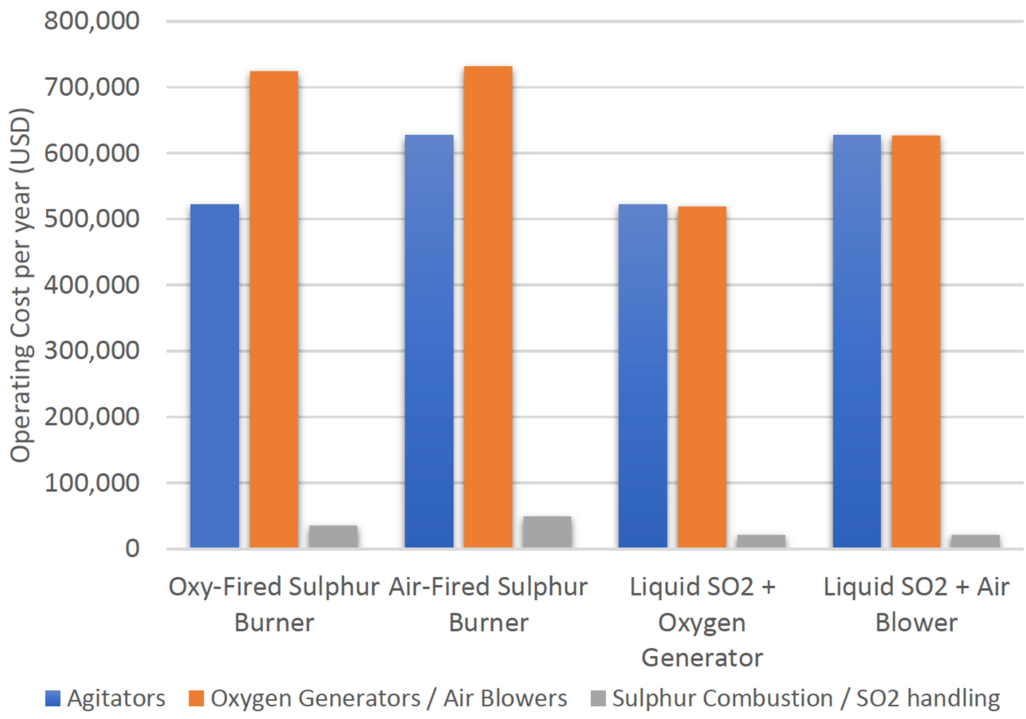


**Figure 3 – Major equipment operating costs associated with each type of Inco process method under study for upper-end operating condition**

**CARBON FOOTPRINT ANALYSIS**

Operating the Inco process at a cyanide detox plant requires a certain amount of power and electricity that is associated with all the major equipment utilized at the plant to conduct the Inco cyanide detox process. Moreover, transporting this equipment and the reagent from vendor location to site requires a heavy class 8 trailer or tanker truck that runs on an accessible type of fuel such as diesel. The fuel utilized for transport, or the power extracted from the electricity grid are both associated with carbon emissions that are calculated in $CO_2$ eq terms using certain emission factors defined by the US EPA. These set of emissions related to the Inco process equipment operations and transport are included in the study and combine to form the Carbon Footprint of each detox system under study. **The selected process emission factor is 0.433 kg $CO_2$ eq per kWh (**EPA, 2021) and the **transport emission factor is 0.20 kg $CO_2$ eq per tonne-km** (Sims, 2014). A constant distance of 2000 km from vendor to site is considered for transport emission calculations and the plant is assumed to be operating 24/7, 365 days a year.

The carbon emissions released by equipment operations depend on the choice of reagent and oxidant system. The correct choice of reagent also depicts the severity of emissions related to transport as reagent transport emissions make up approximately 90 % of the total transport emissions. The fixed emissions related to equipment transport are similar for each process method under study and does not have any significant effect on the comparison. On average the fixed emissions for equipment transport are 60 tonnes $CO_2$ eq and 130 tonnes $CO_2$ eq for the lower-end and upper-end operating condition respectively. Table 8 below outlines the emissions related to major equipment operations and reagent transport along with the overall combined yearly carbon footprint of each type of Inco process method under study, for both the defined operating conditions. The Oxygen fired Sulphur burning system has the lowest overall carbon footprint per year which makes it the most environmentally friendly Inco process method to run for Cyanide detox whereas, the Liquid $SO_2$ / Air blower system is the most carbon intensive method contributing the most towards the greenhouse effect.

**Table 8 – Yearly carbon footprint of each Inco process method under study for both operating conditions**

| Type of Inco process method | Lower-End Operating Condition: Process Footprint (tonne $CO_2$ eq/year) | Lower-End Operating Condition: Reagent Transport Footprint (tonne $CO_2$ eq/year) | Lower-End Operating Condition: **Total Carbon Footprint (tonne $CO_2$ eq/year)** | Upper-End Operating Condition: Process Footprint (tonne $CO_2$ eq/year) | Upper-End Operating Condition: Reagent Transport Footprint (tonne $CO_2$ eq/year) | Upper-End Operating Condition: **Total Carbon Footprint (tonne $CO_2$ eq/year)** |
|---|---|---|---|---|---|---|
| Liquid $SO_2$ / Air Blower | 1490 | 1160 | **2650** | 6900 | 7360 | **14,260** |
| Air Fired Sulphur Burner System | 1750 | 580 | **2330** | 7620 | 3680 | **11,300** |
| Liquid $SO_2$ / Oxygen Generator | 1020 | 1160 | **2180** | 5530 | 7360 | **12,890** |
| Oxygen Fired Sulphur Burner System | 1330 | 580 | **1910** | 6660 | 3680 | **10,340** |

The choice of selecting Sulphur as the reagent, halves the reagent mass requirement for treatment compared to Liquid SO2 which in turn, halve the entire emissions related to reagent transport. However, that choice means installing a Sulphur combustion system on site that requires extra power and fuel to run, compared to the Liquid SO2 system, that adds up slightly to the overall carbon emissions related to process operations. The right choice of oxidant is also very important as it depicts the overall flow and agitation requirement and hence, the power requirement of the system. In comparison to Air blowers, Oxygen generators release a greater concentration of oxygen by volume and thus have a lower flow and overall power requirement. Furthermore, Oxygen generators also reduce the total agitation power requirement of the system as the abundance of oxygen particles lead to easier mixing. These two reasons combined make the switch from air blowers to oxygen generators environmentally favorable and reduce the overall carbon footprint of the system.

All the major equipment part of the Inco process and involved in this study, including agitators, oxygen generators, air blowers, Sulphur combustion system and SO2 handling system, contribute to the overall process carbon footprint according to their own power requirement. These contributions are synchronous with the equipment operating costs since both these parameters depend on the power and energy requirement of the equipment for each process method. Agitators and oxygen/air generators are the highest contributors towards carbon emissions released from Inco process operations. Figures 4 and 5 below display the individual contributions of each piece of major equipment towards the overall process carbon footprint for lower-end and upper-end operating conditions respectively.

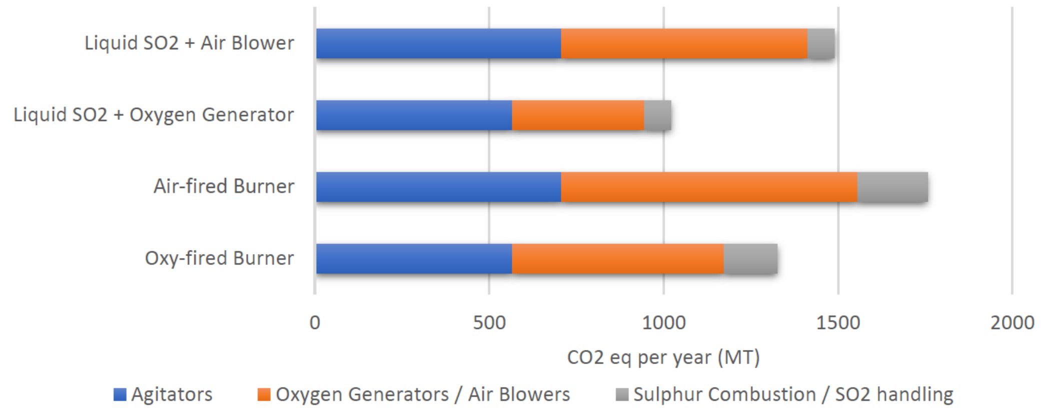


**Figure 4 – Contribution of each piece of major equipment towards the overall process carbon footprint for lower-end operating conditions.**

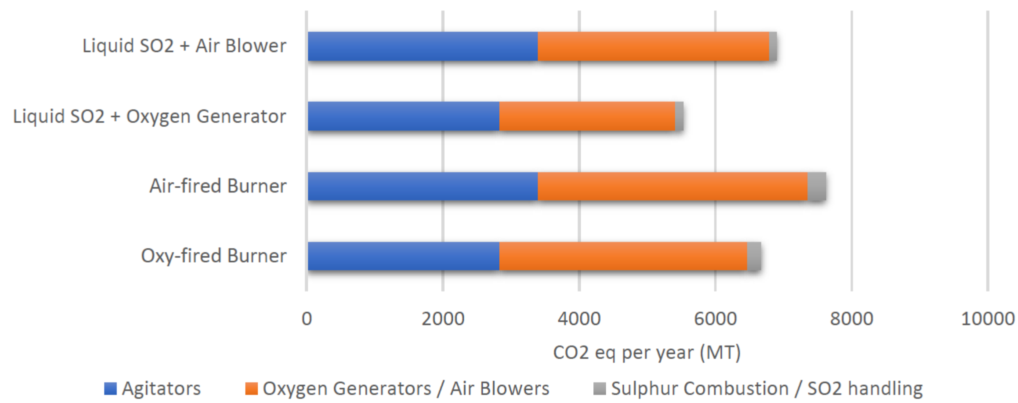


**Figure 5 - Contribution of each piece of major equipment towards the overall process carbon footprint for upper-end operating conditions.**

## CONCLUSION

Cyanide destruction is an additional cost to mine sites that does not yield any additional income. The goal is to reduce this cost and carbon footprint as much as possible while maintaining adequate quality effluent to ensure environmental protection and continuation of the social license to operate. By spending additional money upfront for test work to understand the cyanide destruction requirements of the ore body as it changes and selecting proper design for the Inco process, work together to reduce operating costs and allow the circuit to operate reliably in a more carbon friendly manner. Moreover, additional money inputted on the capital side to introduce Sulphur burner systems and oxygen generators into the design is recovered in a year and results in significant savings in costs and carbon emissions in the long run.

Based on the findings of the carbon footprint study and economic analysis conducted on the new design changes to the Inco process, the installation of Oxygen fired Sulphur burners to produce SO2 gas on site is the most cost effective and environmentally friendly way of conducting the Inco process for cyanide detox resulting in optimal yearly savings in costs and carbon emissions throughout the life of the mine.

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