Universitat Jaume I

Escola Superior de Tecnologia i Ciències Experimentals

Grau en Enginyeria Química

Integration of the solar thermal energy for the blast preheating in the copper smelting process

Trabajo Fin de Grado

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Extract from the “O Alquimista”, Paulo Coelho:

“Certo mercador enviou seu filho para aprender o Segredo da Felicidade com o mais sábio de todos os homens. O rapaz andou durante quarenta dias pelo deserto, até chegar a um belo castelo, no alto de uma montanha. Lá vivia o Sábio que o rapaz buscava.

“Ao invés de encontrar um homem santo, porém, o nosso herói entrou numa sala e viu uma atividade imensa; mercadores entravam e saíam, pessoas conversavam pelos cantos, uma pequena orquestra tocava melodias suaves, e havia uma farta mesa com os mais deliciosos pratos daquela região do mundo. O Sábio conversava com todos, e o rapaz teve que esperar duas horas até chegar sua vez de ser atendido.

“O Sábio ouviu atentamente o motivo da visita do rapaz, mas disse-lhe que naquele momento não tinha tempo de explicar-lhe o Segredo da Felicidade. Sugeriu que o rapaz desse um passeio por seu palácio, e voltasse daqui a duas horas.

“– Entretanto, quero lhe pedir um favor – completou o Sábio, entregando ao rapaz uma colher de chá, onde pingou duas gotas de óleo. – Enquanto você estiver caminhando, carregue esta colher sem deixar que o óleo seja derramado.

“O rapaz começou a subir e descer as escadarias do palácio, mantendo sempre os olhos fixos na colher. Ao final de duas horas, retornou à presença do Sábio.

"– Então – perguntou o Sábio – você viu as tapeçarias da Pérsia que estão na minha sala de jantar? Viu o jardim que o Mestre dos Jardineiros demorou dez anos para criar? Reparou nos belos pergaminhos de minha biblioteca?

"O rapaz, envergonhado, confessou que não havia visto nada. Sua única preocupação era não derramar as gotas de óleo que o Sábio lhe havia confiado.

"– Pois então volte e conheça as maravilhas do meu mundo – disse o Sábio.

– Você não pode confiar num homem se não conhece sua casa.

"Já mais tranquilo, o rapaz pegou a colher e voltou a passear pelo palácio, desta vez reparando em todas as obras de arte que pendiam do teto e das paredes. Viu os jardins, as montanhas ao redor, a delicadeza das flores, o requinte com que cada obra de arte estava colocada em seu lugar. De volta à presença do Sábio, relatou pormenorizadamente tudo que havia visto.

"– Mas onde estão as duas gotas de óleo que lhe confiei? – perguntou o Sábio.

"Olhando para a colher, o rapaz percebeu que as havia derramado.

"– Pois este é o único conselho que eu tenho para lhe dar – disse o mais Sábio dos Sábios. – O segredo da felicidade está em olhar todas as maravilhas do mundo, e nunca se esquecer das duas gotas de óleo na colher".

Abstract

Abstract

This work treats the subject of integrating a Central Tower System (SCT) as a source of thermal energy in the preheating of the blast of an Outokumpu Flash Furnace. The economic profitability of the process, as well as the environmental impact, are evaluated in addition to the analysis of the smelting process and the consequences of preheating the blast using solar thermal energy.

The simulations developed in this work show clearly how removing the oil as an input of the process greatly reduce the volume of gases inside de furnace, allowing a higher feed rate and hence increasing the production and the profitability. As a contra, the removal of the fossil fuel implicates further enriching the blast in oxygen and/or preheating the blast.

As the industrial oxygen is a source of economic losses for the process, and regarding the environmental impact of producing industrial oxygen, the preheating of the blast up to 600 K allows a reduction of the 17.43 mass-% of industrial oxygen. This would mean saving up to $2,443,878 per year in oil and industrial oxygen if we suppose that the copper production is kept constant at 75 ton per hour independently of the temperature of the preheating.

On the other side, it has been noticed that preheating the blast expands greatly the volume of the gases inside the furnace, consequently reducing the production of copper and sulfuric acid, the two sources of economic incomes. If the down in the production is considered in the economic analysis, the results show that the inversion in a SCT system wouldn't be economically profitable.

Regarding the performance of the SCT system, it's perfectly suitable for the preheating of the blast up to 1200 K. Without storage system, it would be possible to reach the energetic needs for the preheating 7 hours per day in average, providing around 4 MW in the case of preheating up to 600 K.

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Acknowledgments

Acknowledgments

This work is the product of four years of higher education, and so I keep in mind a long list of names which should be mentioned in these few lines of acknowledgments. Nevertheless, there are always some special people who play a key role in your life. Some of them can be the help you desperately needed to enlighten a tricky problem in your work, some others are the sweet "bad influence" that brings you to stop overworking yourself, and start enjoying the rest of the day, laughing and sharing your thoughts and hopes. Some of them just are the reason you wake up every morning.

First of all, I must thank María del Carmen Ramos and Eduardo Parra, mama y papa, the two people who have been and continue being the greatest influence in my life. Without their support I would be a person completely different, their understanding and kindness are the only reason I've been able to keep accomplishing my dreams. If someone needs proof of how good they are as parents and educators just meet my beautiful sister, María. I love you beba, you're my constant and unconditional support, and the only thing I can reproach her is keeping all the good genetics for herself.

Right after my family it comes all the educators and professionals that have helped me with the elaboration of this project, or said in other words simply thanks for making it possible. I set my mind in some complex goals and the team from the UJI, the INSA Toulouse, and the SERC Chile have made everything in their hands to soften the difficulties that have been appearing during the realization of this goals. Thanks to Enrique, my tutor who understood the challenge that would suppose making a research work in Chile and offered himself to tutor me, and thanks to María José for helping me with all the adaption process that was needed for validating a work developed with a non-Spanish company. To the professors Sbarbaro, Espinoza, Morán, and Parra thank you for your support and your contribution to my work. Special thanks to my workmate Omar, you were of huge help and without your advice and ideas this work would be considerably less interesting.

Now is time to acknowledge my friends, my chosen family, the ones who asked me about my job even knowing that they wouldn't understand half the process I was working on. I hate how the distance keeps me from seeing each of you at least once per week, but I love realizing that the distance is not powerful enough to break the connection with those who matter. Special thanks to my Chorrillos gang, my roomies during the three months I spent in Chile. You had to endure my madness and cheers when the project advanced well, and you were always ready to cheer me up if I was stressed or tired. Best regards to Steffani, your critic spirit forced me to be exigent with the quality of these pages.

The last person I want to mention in the acknowledgments is my little malaka Aliki. Sometimes I still wonder what did you see in me that was worth involving yourself in a distant relationship. Both of us have our dreams, dreams that will take time, a time during which we'll be apart, time that will take courage and determination. I don't know what has the future prepared for us, but I do hope that whatever it throws on us we can face it together.

Main Text

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Chapter I. Object

The object of this project consists of carrying out a theoric study on the improvement of a flash furnace for the copper smelting, by means of the solar thermic energy in the preheating of the blast.

The oxidation reactions are modeled using mass and enthalpy balances, and several simulation models are developed for the characterization of the compositions of the incoming and the outgoing flows. In the same way, the design of the heliostat field and the central tower are determined in function of the preheating temperature and the mass flow of the blast by means of a simulation model.

This project also includes an environmental study and an economic projection for the modification of an already existing Outokumpu flash furnace, so it incorporates the SCT system technology.

Intending to bring the project closer to the reality the solar field data and operation conditions of the Chagres Anglo American Smelter (Chile) facilities are included in this work, and they establish the databases for all the simulations.

Chapter II. Reach

This project intends to deal with two of the biggest problems of the copper mining industry: the environmental impact, and the energy excess necessary to extract the mineral from the raw material.

The extraction and refining process for the copper by means through the pyrometallurgical route (using a smelting process which operates at high temperatures) is divided mainly in: extraction of the raw material, crushing and grinding, production of the copper concentrate, smelting, conversion, and electrolytic refining. This work establishes the principles for the enhancement of the smelting process, which represents 26 % of the total energy consummation in copper production.

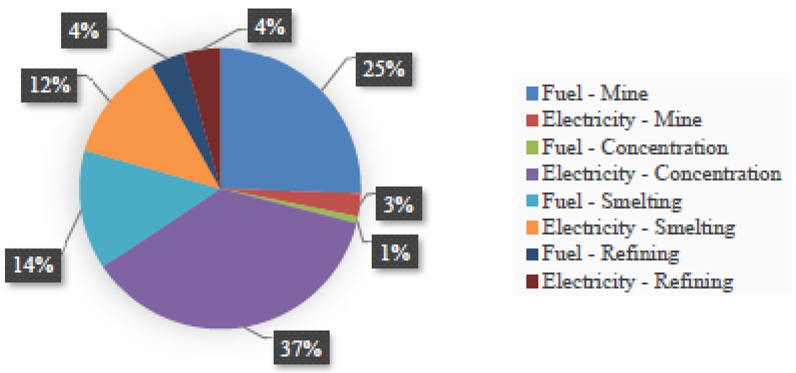

Figure II. 1: Weighted average of the specific energy consumption gave by COCHILCO [ref. 12]

The furnace technology considered in this study is the Outokumpu flash furnace (most common furnace technology worldwide). This kind of furnace uses the heat produced by the oxidation of Fe, Cu and S in order to keep the optimum operative temperature of the furnace, estimated to be around 1250 ºC, making it possible for the process to take place only with a little amount of fossil fuel, and the oxygen-enriched blast which provides the oxygen necessary for the oxidation reactions.

The main idea in this project consists of using the solar thermal energy for the preheating of the gases going inside the furnace. Some previous research indicates that preheating the blast greatly decrease the need for fossil fuel and industrial oxygen used for keeping a regular operative temperature inside the furnace. Considering the economic and environmental potential of this idea this work is developed in collaboration with the "*Solar Energy Research Center*" Chile (SERC Chile), so the preheating system can be adapted to the local industry of Chile.

Chile disposes of a well-established copper-mining industry, which struggles to keep improving the mining and refining process in order to keep pace with the edge-technology companies. The Chilean topography has the advantage of including some of the locations with higher solar radiation worldwide, therefore is only logical to consider the solar energy as a source of clean thermal energy with very little expenses (once the SCT is already operative). Another strong point for the solar energy in the Chilean mining industry is the fact that many of the mining and refining facilities are located in the boundaries of high solar radiation points (as the Atacama Desert), keeping minimum losses in transportation and storage of the thermal energy.

This project has the ambition of creating a solid theoric base for the development of solar thermal energy in the mining industry. The main innovative points of this work are:

- The development of a simulation model which describes accurately the process of flash smelting
- The study of the "Solar Central Tower system" as a source of solar thermal energy
- An environmental assessment of the Outokumpu flash furnace including and non-including the SCT system, according to the International Organization for Standardization (ISO) standards.
- An economical assessment illustrating the advantages that the preheating by the SCT system would bring to the process.
- A primary design for the overall facility including the SCT system.

Chapter III. Background

III 1. Introduction

The preheating of the flash furnace blast has been a wide subject of discussion for the professionals and experts in the mining sector, as the temperature of the oxygen has a great influence on the oxidation reactions of the smelting furnace.

In the following chapter is provided a global contextualization of the conventional copper mining process by pyrometallurgical route, giving special attention to the Outokumpu flash furnace and the reactions taking place inside the furnace during the smelting process. Besides, some details on the treatment of the off-gas from the flash smelting and the production of industrial oxygen are included in order to better understand the environmental impact of the overall smelting process.

Afterward, the basics of the current solar technology will be briefly discussed before going in deep on the thermal applications and the why the "Solar Central Tower" technology is the better adapted alternative for the conditions treated through this work.

Finally, insight into the ISO legislation establishes the basis for the environmental assessment of this work.

III 2. Pyrometallurgy of the copper

The raw ores extracted from a copper mine can be generally classified as oxide ores or sulfide ores. While the oxide ores are nowadays processed through the hydrometallurgical route, the pyrometallurgical route is still the most suitable to purify and process the sulfide ores.

In this work, the raw material going into the flash Outokumpu furnace will be supposed to be a concentrate composed mainly of chalcopyrite ($CuFeS_2$), which is a sulfide ore. Hence, in the best interest of this work, only the pyrometallurgical route is discussed in this section.

The pyrometallurgical route gets its name from the fact that the ore is purified at high temperatures (the smelting and conversion stages operate at temperatures over 1200 ºC). It's based on the oxidation reactions of the Cu, Fe, and S, which are strongly exothermic, and transform the initial ore into a highly purified form of copper (99,99% Cu by mass).

Mining, crushing and grinding

The sulfide ores extracted from the mine usually contain about 2% copper. The first stage in the processing of the copper is to crush and grind the ore until obtaining powdered ore. The most common way of doing so is using a ball mill, which separates the copper minerals away from the waste minerals.

Froth flotation

In the next stage, the powdered ore is mixed with a special paraffin oil called "collector" which makes the copper mineral particles hydrophobic without reacting with the waste minerals. Then this mixture is introduced into a bath of water containing a foaming agent responsible for creating a kind of bubble bath. Air-jets are forced up through the bath, in a way that the bubbles created by the air stream pick up the now hydrophobic copper mineral, pushing them up to the surface of the tank. The unwanted waste rock (gangue) falls to the bottom and is removed.

The enriched ore is skimmed off the surface of the mixture. The resulting product is called copper concentrate and is considered to contain about 25% copper by mass. The mixture of water, foaming agent and paraffin can be recycled.

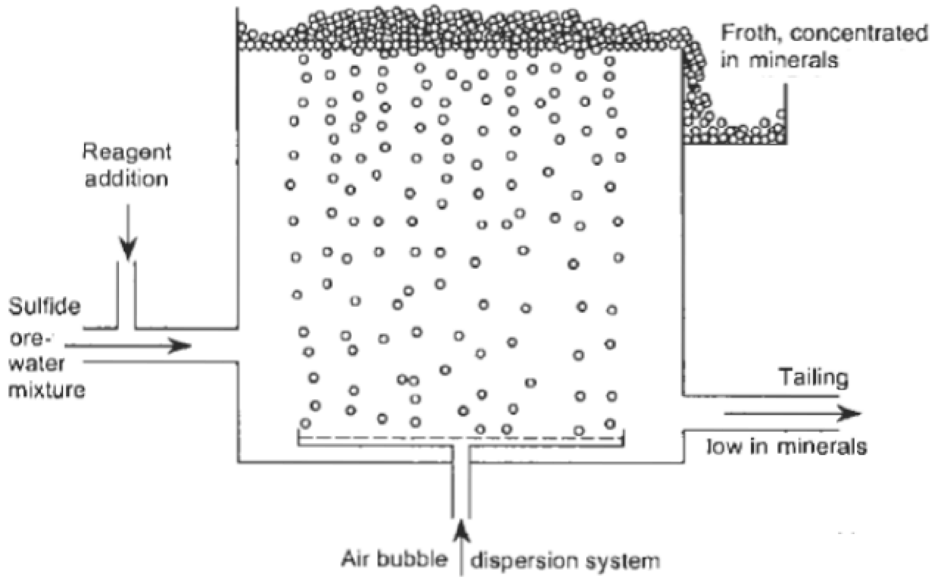

Figure III. 1: Diagram of the froth flotation process [ref. 5]

Roasting

The next stage consists in heating the concentrated ore between 500 ºC and 700 ºC in air, evaporating the water of the concentrate and starting the chemical reactions. The goal of this stage is converting the copper minerals into copper metals by changing some of the $CuFeS_2$ to copper oxide and removing some of the sulfur as sulfur dioxide. The outgoing product is called calcine.

If we take the chalcopyrite as an example, the reaction that takes place might be defined as [ref. 5]:

$$2\ CuFeS_2(s) + 3\ O_2(g) \rightarrow 2\ FeO(s) + 2\ CuS(s) + 2\ SO_2(g)$$ **(Reaction III 1)**

The environmental regulations forbid the release of SO_2 into the environment, so the companies transform it to sulfuric acid, which makes a sub-product that can be valorized.

There's a tendency in the current industry towards eliminating this stage in the production of copper, because of the following reasons:

- It has been proved that by adjusting the operational parameters of the flash furnace it's possible to reach the same results saving a considerable amount of energy.

- The flash furnace produces a steady off-gas stream that is more suitable for the conversion of SO_2 to sulfuric acid.
- Avoiding the roasting stage means economizing the inversion on the roaster equipment.

In case the roasting stage is effectively removed, drying the concentrated ore would be necessary, as the flash furnace needs the in-going concentrate particles to be free of water so the jet distributor can mix the concentrate and the flux correctly. A detailed explanation of the smelting process will be given in *section III 3*.

Smelting

The calcine (or concentrate) is now mixed with fluxes and heated over 1200 ºC, producing slag (composed mainly of SiO_2 and FeO), which is usually recycled in order to recover the remaining Cu [6], and molten matte, considered to contain about 50-70 mass-% copper. Further information about this stage will be provided in *section III 3*.

Conversion

The molten mate (composed mainly of Cu_2S and FeS) is oxidized with air to form blister copper (98% copper by mass), keeping an operative temperature of 1200 ºC in the converter.

The most common converter used in copper mining is the Pierce-Smith converter, a rotatable cylindrical furnace. The molten matte is charged into the furnace through the mouth and the Fe and S contained in the matte are oxidized by blowing air (enriched in O_2 if needed) inside the furnace. The resulting molten slag and copper are then poured out through the converter mouth.

The reactions taking place inside the converter are supposed to be [ref. 7]:

a) Elimination of iron sulfide by oxidation to iron oxide forms a slag ($FeO.SiO_2$):

$$\mathbf{2\ FeS(l) + 3\ O_2(g) + SiO_2(l) \rightarrow 2\ FeO.SiO_2 + 2\ SO_2(g)} \qquad \textbf{(Reaction III 2)}$$

b) Formation of blister copper by reduction of copper sulfide:

$$\mathbf{2\ Cu_2S(l) + O_2(g) \rightarrow 2\ Cu(l) + SO_2(g)} \qquad \textbf{(Reaction III 3)}$$

The process must be stopped once the sulfur is removed from the copper sulfide, else the copper might be oxidized to Cu_2O.

The big issue of the Pierce-Smith converter is the SO_2 escape, which is a consequence of the imperfect seal between the rotatable converter and its stationary off-gas handling system. The fact of carrying out the charging and pouring maneuvers with the converter mouth outside the gas collection hood is also a source of SO_2 emissions.

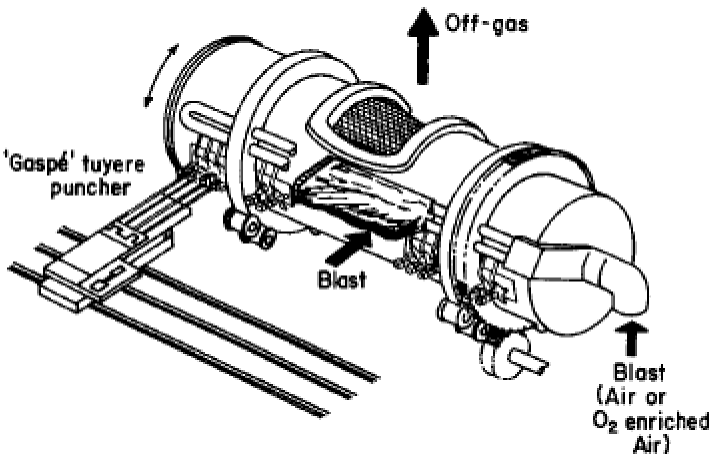

Figure III. 2: Cutaway view of horizontal side-blown Pierce-Smith Converter [ref. 7]

Anode casting

It consists of producing the anodes for the electrolytic refining. The molten blister copper obtained in the conversion is now poured into molds, creating slabs of solid blister copper over a meter tall.

Electrolytic refining

Finally, high-quality copper is produced by electrolytic refining (99.99% pure copper). Copper cathodes are hung between the anodes, forcing the copper into its ionic form Cu^{2+} in the electrolyte (copper sulfate and sulfuric acid), and then the copper ions return to being solid Cu at the cathode. The other metals in the anode (impurities) won't dissolve in the electrolyte solution, falling to the bottom of the tank.

The redox reaction taking place would be:

At the anode: $Cu(s) \rightarrow Cu^{2+}(aq) + 2\,e^{-}$

At the cathode: $Cu^{2+}(aq) + 2\,e^{-} \rightarrow Cu(s)$

Therefore, the overall mining process by pyrometallurgical route can be schematized as:

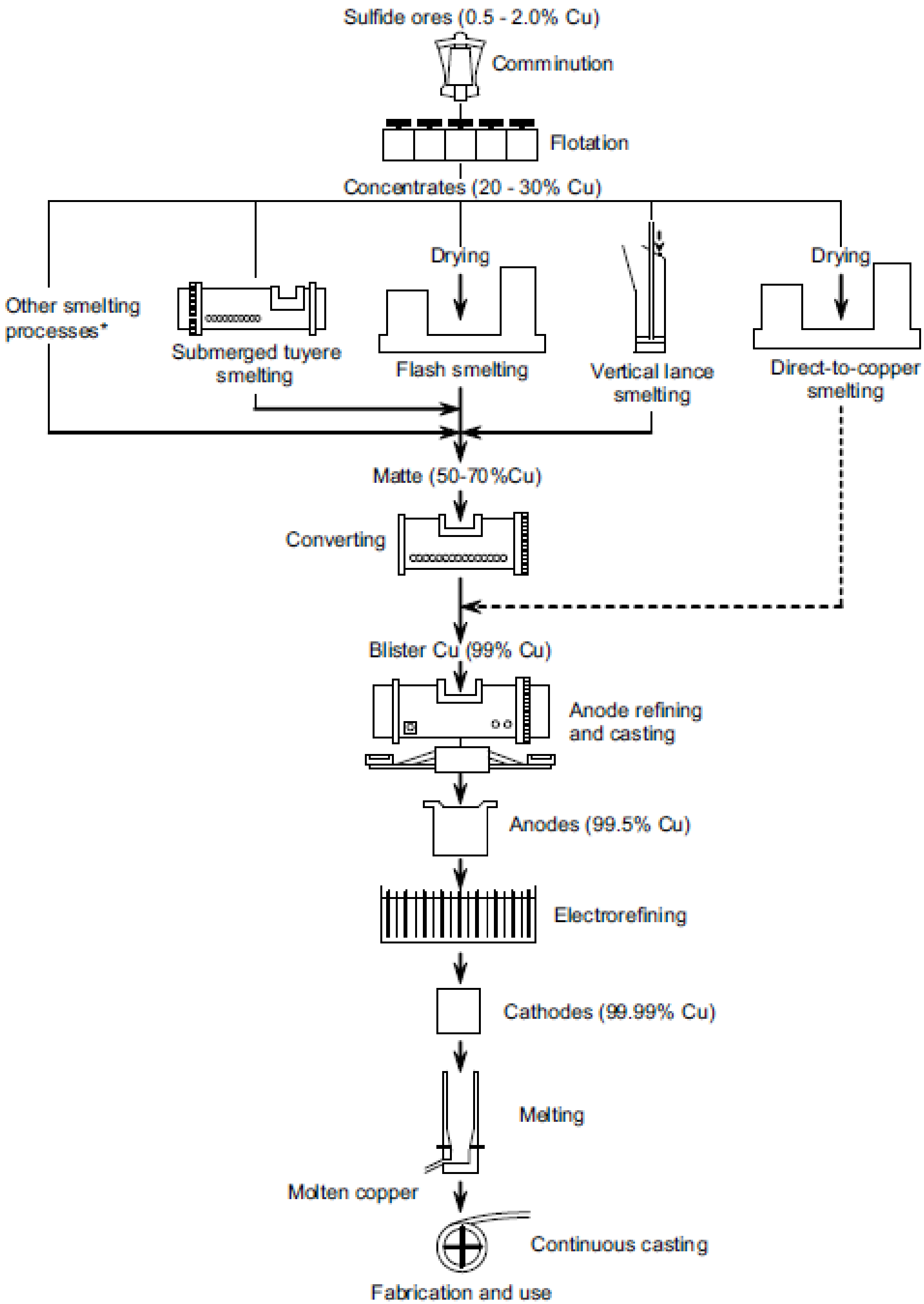

Figure III. 3: Flow diagram for the processing of sulfide ores by pyrometallurgy means [ref. 26]

III 3. Flash furnace Outokumpu

The flash smelting is a pyrometallurgical process used for smelting metal sulfide concentrates. The procedure is based on the reaction between the sulfide minerals and the O_2 of an in-going blast, which results in controlled oxidation of Fe, S, and Cu that produces a strongly exothermic reaction, increasing the temperature of the furnace up to 1200 ºC. The operational temperature of the furnace is controlled in a way it will melt the solids.

The specificity of the Outokumpu furnace is that the feed materials are injected downwards into a hot heart furnace, using hot air (enriched in oxygen or not) to oxidize and smelt its concentrates. Depending on the operational conditions a little amount of fuel might be needed to satisfy the energy needs of the furnace.

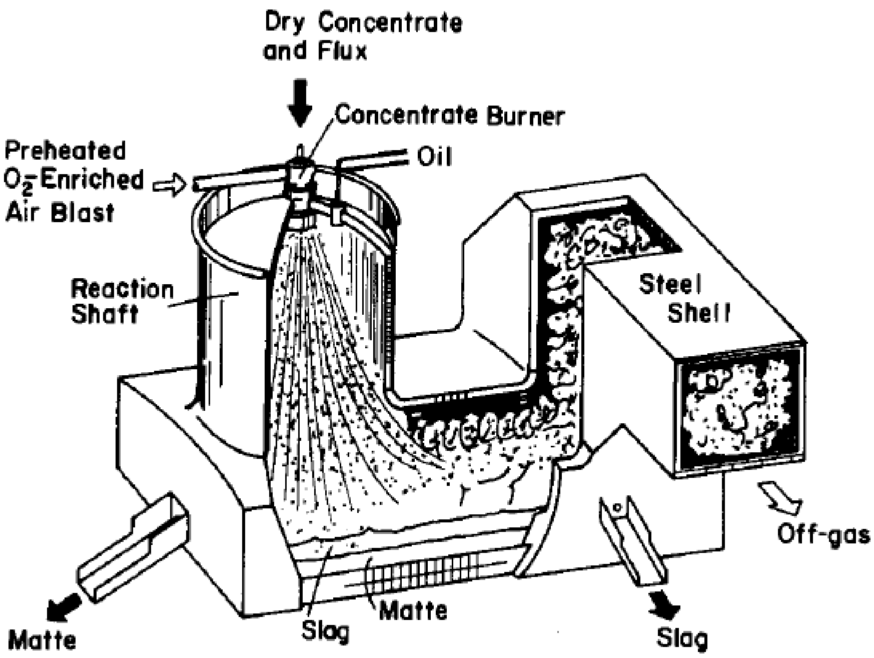

Figure III. 4 Cutaway view of Outokumpu O_2 -enriched air flash furnace [ref. 7]

The furnace is composed by:

a. The concentrate burners which combine dry concentrate and flux with the blast and direct the mixture in suspension form downwards into the furnace using a jet. One to four burners can be included in the design of the furnace.
b. A reaction shaft where the combustion and the main reactions take place.

c. A settler where the separate layers of matte and slag are settled. Because of the difference in density, the matte (higher density) will always be the bottom layer and the slag (lower density) the top layer.
d. Gas offtake that will collect the out-going gases, notably the SO_2.
e. Tap holes for removing the matte and the slag

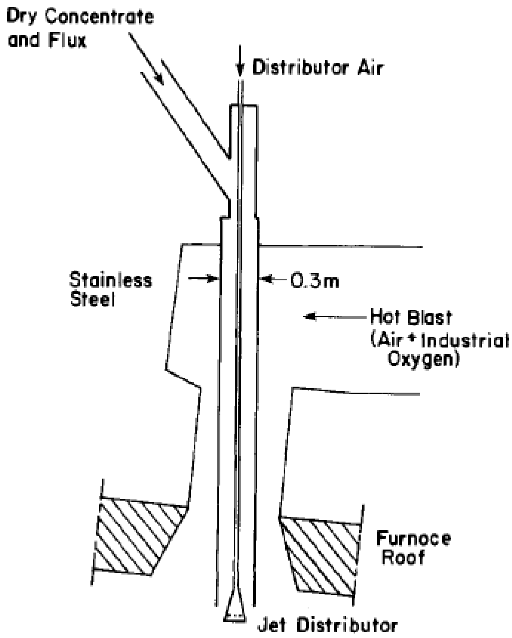

Figure III. 5: Detail of a concentrate burner [ref. 7]

Most of the furnace is contained in a steel casing about 1 cm thick. Exceptions to this are the reaction shaft roof and settler roof which are usually made of $Cr_2 0_3$-MgO refractory bricks arched, suspended or packed around refractory covered, water-cooled steel beams [ref. 8].

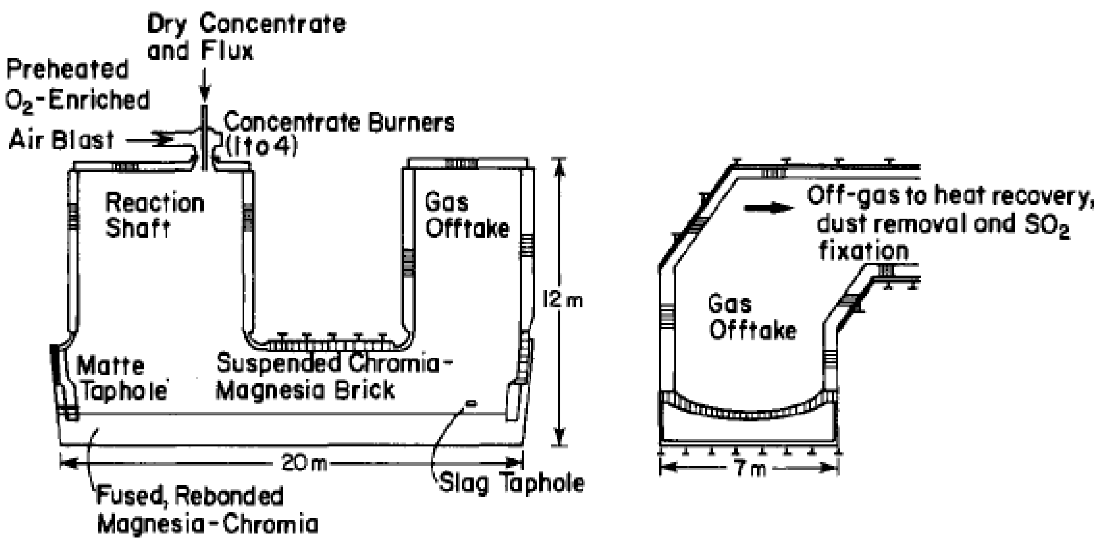

Figure III. 6: Side views of an Outokumpu Flash Furnace [ref. 7]

Outokumpu furnace flows

The feed materials and in-going flows are:

i. *Concentrate*: the composition depends on the source of the raw material, but generally it's a mixture of chalcopyrite ($CuFeS_2$), pyrite (FeS_2) and silica (SiO_2) and other minor species (such as CuS, Cu_2S, Cu_5FeS_4). The concentrate must be dry when it goes through the concentrate burners, so the concentrate particles will be correctly distributed on the jet.

ii. *Flux*: a flowing agent, necessary in the flash smelting process ass it reacts with the iron oxides creating the slag, a separate phase immiscible with the matte. The flux of most common use in the copper mining industry is the silica (SiO_2), a compound that reacts with the iron oxides producing $FeO.SO_2$, a slag with small solubility for Cu and reasonably fluid.

iii. *Blast*: the flow of air that will provide the oxygen needed for the oxidation of Fe and S. Depending of the operational conditions of the furnace it can be enriched in oxygen adding industrial oxygen to the blast.

iv. *Fuel*: some fuel can be injected into the reaction shaft or the settler if needed. It can provide localized heating in cool parts of the furnace, and it is an effective way of controlling the melting temperature

The out-going flows and materials are:

i. *Matte*: it's considered the main product, if the concentrate is mainly chalcopyrite the composition of the matte is expected to be mainly by Cu_2S and FeS with content in Cu mass between 45 % and 65 %.

ii. *Slag*: a molten layer immiscible with the matte, largely devoid of Cu. The composition may be defined as $FeO.SO_2$. Usually, the slag is recycled back to the crushing and grinding stage in order to recover the remaining minerals.

iii. *Off-gas*: the outgoing flow of hot gas, composed mainly by SO_2 and the inert gases such as N_2. This flow is treated to avoid the emission of SO_2 to the environment.

Reactions set

The experimental studies treating the flash fusion on the literature suggest that the reaction mechanism is complex and strongly dependent on the local conditions of the particles. The exact stoichiometry of the reactions is virtually unknown, however, different models of reactions have been proposed.

According to the shrinking core concept developed by Kim, Ahokainen, and Jokillakso [9] for the chalcopyrite oxidation in gas-solid suspensions, the chemical process sequence can be generally divided into three stages:

(a). Thermal decomposition of chalcopyrite ($CuFeS_2$) during the heat-up of the particles. Although the actual mechanism is not known in full details the final products can be assumed as bornite (Cu_5FeF_4), pyrrhotite ($Fe_{(1-x)}S$), free metallic iron and mono-atomic sulfur gas:

$$5\ CuFeS_2 \leftrightarrow\ Cu_5FeS_4 + 4\ Fe_{(1-x)}S + 4\ Fe + 2\ S(g) \qquad \textbf{(Reaction III 4)}$$

(b). Oxidation of the gaseous sulfur from *Reaction III 4* in a highly exothermic reaction:

$$S(g) +\ O_2(g) \leftrightarrow\ SO_2(g) \qquad \textbf{(Reaction III 5)}$$

Because of the heat created in the *Reaction III 5*, the temperature raises in all the particle. The *Reaction III 5* is supposed to start in the particle-gas interface, progressing inwards towards the core of the particle.

(c). Finally, the rest of the products of the *Reaction III 4* are also oxidized:

$$3\ Fe + 2\ O_2(g) \leftrightarrow\ Fe_3O_4 \qquad \textbf{(Reaction III 6)}$$

$$3\ FeS + 5\ O_2(g) \leftrightarrow\ Fe_3O_4 + 3\ SO_2(g) \qquad \textbf{(Reaction III 7)}$$

$$2\ Cu_5FeS_4 + O_2(g)\ \leftrightarrow\ 5\ Cu_2S +\ 2\ FeS +\ SO_2(g) \qquad \textbf{(Reaction III 8)}$$

Reaction III 7 takes place on particle surfaces. Molten sulfide droplets are formed in *Reaction III 8*, with the composition defined by the rates of *Reaction III 6 – 8*, which depends on its turn of the availability of oxygen.

If the temperature increase over 1500 K can be oxidized further into oxides, which would be against the interest of the copper extraction:

$$Cu_2S + 1.5\, O_2(g) \rightarrow Cu_2O + SO_2(g) \qquad \textbf{(Reaction III 9)}$$

$$FeS + 1.5\, O_2(g) \rightarrow FeO + SO_2(g) \qquad \textbf{(Reaction III 10)}$$

In order to separate the iron oxides some flux is added to the mixture to create the slag, resulting in the following reaction:

$$FeO + SiO_2 \rightarrow FeO.SiO_2 \qquad \textbf{(Reaction III 11)}$$

In a slightly different approach [ref. 10] Hahn and Sohn differentiate three stages in the chemical process of the flash furnace for a concentrate containing three major phases: chalcopyrite ($CuFeS_2$), pyrite (FeS_2) and silica (SiO_2). The chalcopyrite and pyrite will undergo oxidation in the furnace shaft.

First, when the concentrate particle is in solid-state and below 873 K the first chemical reactions are supposed to occur:

$$CuFeS_2(s) + \frac{15}{4} O_2(g) \rightarrow CuSO_4(s) + \frac{1}{2} Fe_2O_3(s) + SO_2(g) \qquad \textbf{(Reaction III 12)}$$

$$FeS(s) + \frac{7}{4} O_2(g) \rightarrow \frac{1}{2} Fe_2O_3(s) + SO_2(g) \qquad \textbf{(Reaction III 13)}$$

Next, once the particles are heated between 873 K and 1153 K (reported melting point of chalcopyrite), the decomposition of sulfides should take place. The overall reactions are expressed as:

$$CuFeS_2(s) + 0.5\, O_2(g) \rightarrow 0.5\, Cu_2S(s) + FeS(s) + 0.5\, SO_2(g) \qquad \textbf{(Reaction III 14)}$$

Once the particles are molten, they are supposed to be composed of Cu_2S and FeS, producing the matte. If we continue to increase the temperature the following reactions are expected to occur:

$$FeS(l) + 5\, O_2(g) \rightarrow Fe_3O_4(s) + 3\, SO_2(g) \qquad \textbf{(Reaction III 15)}$$

$$Cu_2S(l) + O_2(g) \rightarrow 2Cu(l) + SO_2(g) \qquad \textbf{(Reaction III 16)}$$

The resulting magnetite (Fe_3O_4), hematite (Fe_2O_3) and the silica (SiO_2) are expected to associate creating the slag.

However, these two models are not expected to be representative of all the different flash smelting processes, as the variation of the operational parameters may change the mechanisms of reaction. The excess of oxygen in the blast, the lack of copper in the concentrate, the presence of unusual minerals on the concentrate or the variations on the temperature are some of the factors that influence the reactions taking place.

In the interest of this work, as some of the simulations developed for testing the operational conditions of the furnace require accurate chemical reactions, the interpretation of Davenport [ref. 7] for concentrates composed by chalcopyrite, pyrite and silica will be used through the experimental calculations.

According to Davenport, all the reactions taking place inside the Outokumpu flash furnace can be effectively simplified into three main reactions:

$$\mathbf{2\ CuFeS_2 + \frac{13}{4}\ O_2(g) \rightarrow\ Cu_2S.\frac{1}{2}FeS + 1.5\ FeO + 2.5\ SO_2(g)}$$ **(Reaction III 17)**

$$\mathbf{\Delta H^o_{298} = -450\,\frac{MJ}{kg\ CuFeS_2} = -1586.25\,\frac{MJ}{kg\ O_2}}$$

$$\mathbf{FeS_2 +\ 2.5\ O_2(g) \rightarrow\ FeO + 0.5\ SO_2(g)}$$ **(Reaction III 18)**

$$\mathbf{\Delta H^o_{298} = -700\,\frac{MJ}{kg\ FeS_2}}$$

$$\mathbf{2\ FeO +\ SiO_2 \rightarrow\ 2\ FeO.SiO_2}$$ **(Reaction III 19)**

$$\mathbf{\Delta H^o_{298} = -20\,\frac{MJ}{kg\ CuFeS_2}}$$

In this set of reactions, the oxidation of chalcopyrite into mate ($\mathrm{Cu_2S.\frac{1}{2}FeS}$), and the oxidation of pyrite (FeS_2) into iron oxide is clear and easy to follow. The same can be said for the formation of the slag ($\mathrm{FeO.SiO_2}$) from iron oxide and silica. The simplicity of the model and the coherence of the results obtained using these equations makes them the logical choice for supporting the simulation models.

The *Reactions 14 and 15* provide almost all the heat necessary for keeping a steady-state in the process if enough O_2 is available inside the furnace. The temperature conditions can be regulated by modifying the ratio $R = \frac{O_2\ input\ rate}{concentrate\ feed\ rate}$, thus if the ratio increases the temperature of the furnace will increase accordingly.

Operative temperature

The reason the furnace is specifically heated over 1200 ºC is to reach a phase equilibrium where the silica interacts with the FeO creating liquid phase (slag) immiscible with the FeS.Cu_2S phase (matte). The exact operative temperature depends on the process and the concentrate composition, as it's the lower temperature allowing the slag to be fully liquid (typically between 1200 ºC and 1300 ºC). It's considered that when the slag is fully liquid the matte phase is equally liquid, as its melting point is always lower than for the slag.

In *Figure III. 7* it's possible to see how the formation of two immiscible phases only happens when enough silica (SiO_2) is included in the mixture (above 30 mas-%).

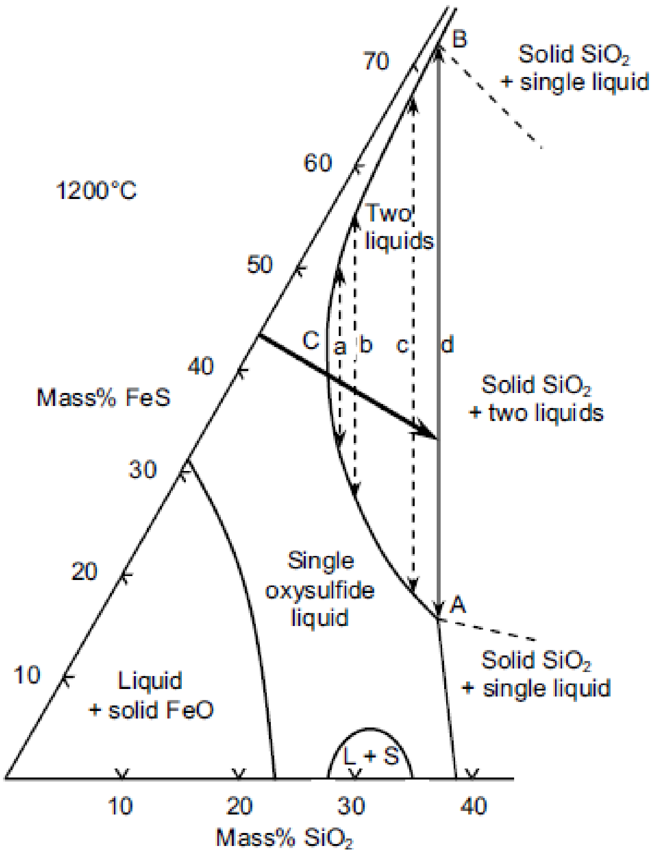

Figure III. 7: Simplified partial phase diagram for the Fe-O-S-SiO_2 system [ref. 26]

III 4. Treatment of the off-gas

Usually, the smelters have a sulfuric acid plant associated so that the off-gas stream is treated in a continuous process producing sulfuric acid (H_2SO_4), a fundamental product in the fine chemistry and hence a potential source of incomes for the mining industry. Up to 99 % of the SO_2 is removed from the off-gas flow in these facilities.

The flue gas desulphurization (FGD) systems can be categorized as:

i. Once-through: the sulfur removed is directly rejected in a waste sludge.
ii. Regenerative system: the sulfur-absorbing reagent is recovered, and the sulfur is used to produce sulfuric acid or elemental sulfur.

Both technologies can be divided into wet and dry types. In the wet processes, the gas leaving the absorbent is saturated with moisture and the wet slurry waste is produced, in contrast with the dry processes, where the gas leaving the absorbent is not saturated and the waste material is dry. Considerable differences in the SO_2 recovery efficiency can be found between the two technologies, with 50-60% in the dry processes against 93-98% in the wet ones. Because the sulfuric acid will be valorized in the economic analysis of this work, and also because the Chilean normative impose a recovery efficiency superior to 90% for the “Chagres Anglo American Smelter” factory, only the regenerable wet technology is considered in detail through this Chapter.

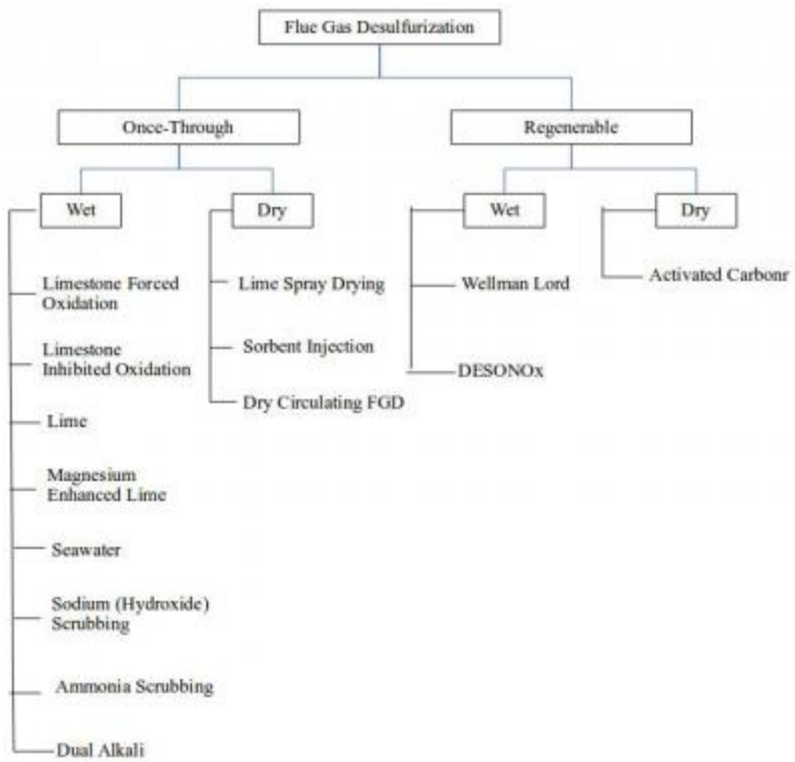

Figure III. 8: Flue gas desulphurization process [ref. 25]

The regenerable wet technology more adapted to the needs of the smelting industry is the DESONOX method, designed for the treatment of flue gas streams. This method can be described as a combined catalytic process by which nitrogen oxides and Sulphur dioxide are separated from the flue gas [ref. 25]. According to the Norbert Ohlms design [ref. 26], in a first stage, the furnace off-gas would go through a high-temperature electrostatic precipitator (ESP) for the removal of dust, solid particles and liquid droplets. The precipitators electrostatically charge the suspended particles, so they can be collected on plates or other collection devices charged with the opposite charge. The operational temperature of the furnace gases entering the ESP should be around 450 ºC, hence the off-gas (which leaves the furnace at 1250-1300 ºC) should go through a waste heat boiler, a heat recovery system where the hot gas stream is treated through a radiation and convection sections effectively reducing the temperature of the stream and producing a heated high-pressure water that can be used for the heating duties around the smelting complex.

In the Norbert Ohlms design once the gas goes through the ESP an amount of ammonia (NH_3) proportional to the nitrogen oxides (NO_x) is added to the gas stream, allowing the selective catalytic reduction (SCR) catalysts to convert the NO_x to water and nitrogen.

However, in the flash smelting process, no nitrogen oxides should be produced, so the DESONOX process could be adapted by neglecting this stage.

The following stage in the DESONOX reactor is the oxidation of the sulfur dioxide by reaction with oxygen to sulfur trioxide (SO_3) upon contact with oxidation catalysts. Then the gas stream is cooled down in several steps, making the SO_3 react with the water vapor to give gaseous sulfuric acid. The resulting H_2SO_4 drops are ionized and separated on the anode of a wet electrostatic precipitator, and finally sent through the last scrubber before a concentrated sulfuric acid (70 %) can be stocked or diluted into water.

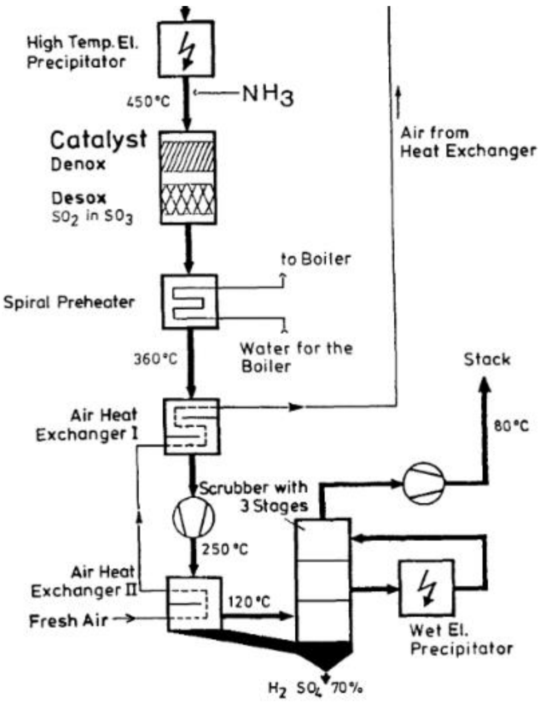

Figure III. 9: DESONOX Flow diagram [ref. 25]

A more conventional approach would be the conventional contact type acid plant. The general scheme for the contact process is [ref. 26]:

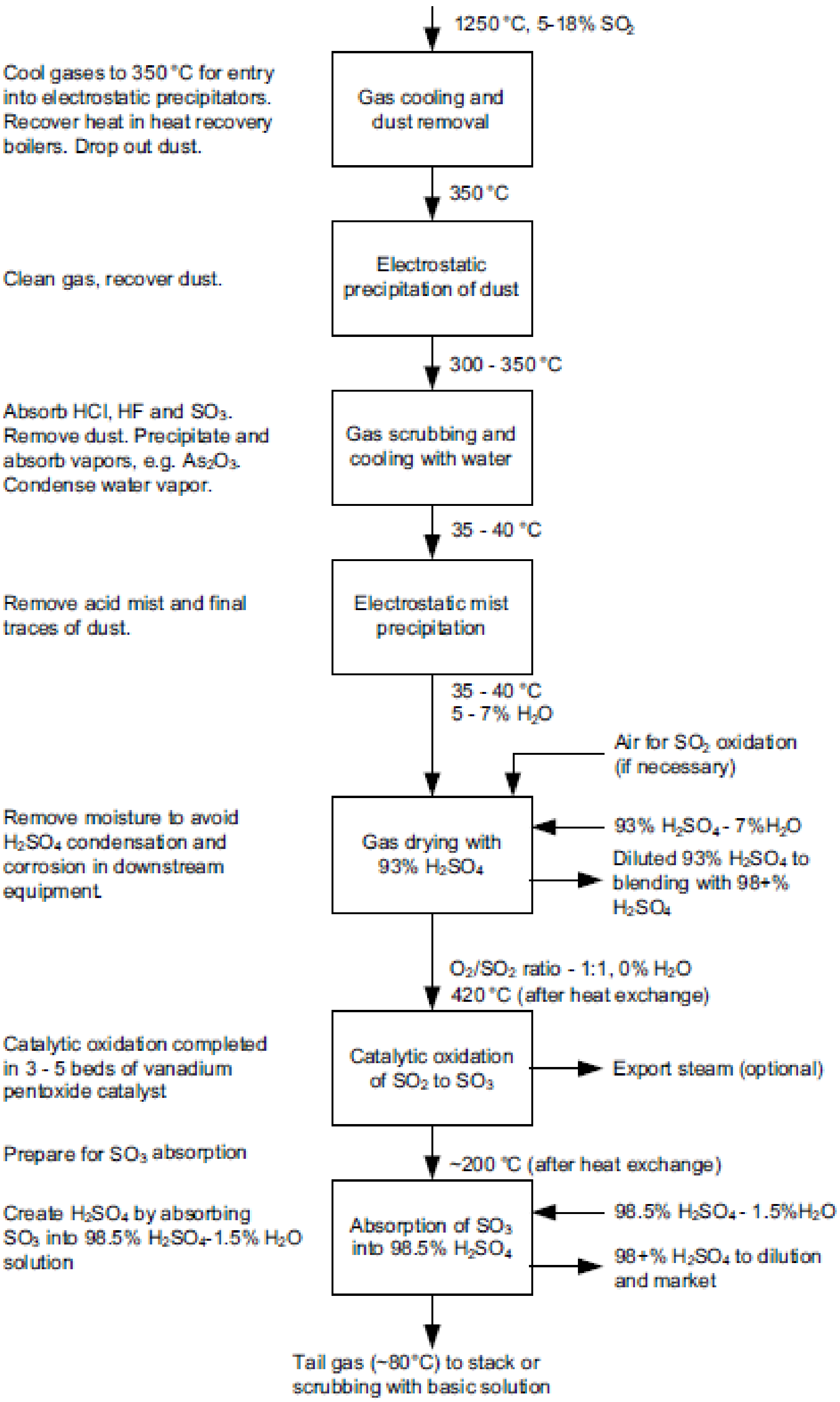

Figure III. 10: Flowsheet for producing sulfuric acid form smelting and converting gases

III 5. Production of industrial oxygen

Usually, the industrial oxygen necessary for this process is produced by cryogenic liquefaction/distillation generating 200-1000 tons of oxygen par day, with 92-99.95 vol-% purity. Nevertheless, if the expected production is bellow 200 tons oxygen per day, molecular sieve oxygen plans can generate smalls amounts of oxygen with a purity of 90-

93% vol oxygen, which can be useful for regulating the oxygen production by using an additional oxygen plant complementing the main plant.

The enriched blast is prepared by mixing the industrial oxygen and the air as they flow to the concentrate burner. The oxygen is correctly diffused using a holed pipe connected into the air conduction. The percentage of oxygen in the blast can be adjusted by butterfly valves and mass flow sensors.

III 6. Blast preheating

Nowadays the trend is employing industrial oxygen in order to avoid the use of oil for the energy supply while keeping the volume of gases in the furnace as little as possible, in a way that enables the furnace to process a bigger flow of concentrate. In other words, the current industry avoids preheating the blast, as raising the temperature also raises the volume of the gases decreasing the production of copper and sulfuric acid, the two main sources of economic incomes.

Anyway, the enrichment of the blast with oxygen can reduce the economical benefice of the process, as it's detailed in the *Budget* section. Hence in this work the equilibrium between gas volume and industrial oxygen consummation is further developed, relying on the preheating with solar energy.

III 7. Solar energy study

One of the main issues of our time is the overexploitation of natural resources and the increasing need for energy sources. The fossil fuels have been consumed over the last centuries in a way that doesn't allow the renovation of this resources, and current studies predict that we'll run out of oil in 53 years, natural gas in 54 and coal in 110 [ref. 17]. On the other side, we dispose of an external source of energy, clean and constant, thanks to the huge amount of radiation emitted by the sun.

In fact, the amount of solar energy par meter square has been estimated thanks to the law of Stefan Boltzmann and the equation of the total energy flux preservation, so the solar constant is estimated to be 1367 W/m^2.

Law of Stefan Boltzman: $M_S = \sigma T^4$ **(Equation III. 1)**

Total energy flux preservation: $\varphi_S = 4\pi R_S^2 M_S = 4\pi D_{TS}^2 E_{SC}$ **(Equation III. 2)**

It’s interesting to remark that in 2018 the European consumption is around 21480.61 TWh [ref. 20], and according to Greenpeace and the industrial association of the photovoltaic energy EPIA [ref. 19] the potential surface available just in Europe is around 3630 km^2 (houses, offices, and industries), with an average energy potential of 1122 kWh/m^2. This means that if it was possible to transform all the solar radiation arriving in Europe into energy 4072.86 TWh would be produced, one-fifth of all the energy needed. If these estimations are compared with the actual solar gross energy production in Europe, 110.8 TWh in 2016 [ref. 21], it’s evident that a huge amount of clean energy is being wasted.

Regarding the repartition of solar radiance around the world *Figure III.11* shows that Chile is one of the most interesting areas where the solar technology can be developed. In this work, the possibilities of solar thermal energy will be further analyzed as a complement of an industrial process, but the potential of the photovoltaic field is also a topic that could help to solve the electric needs of the country.

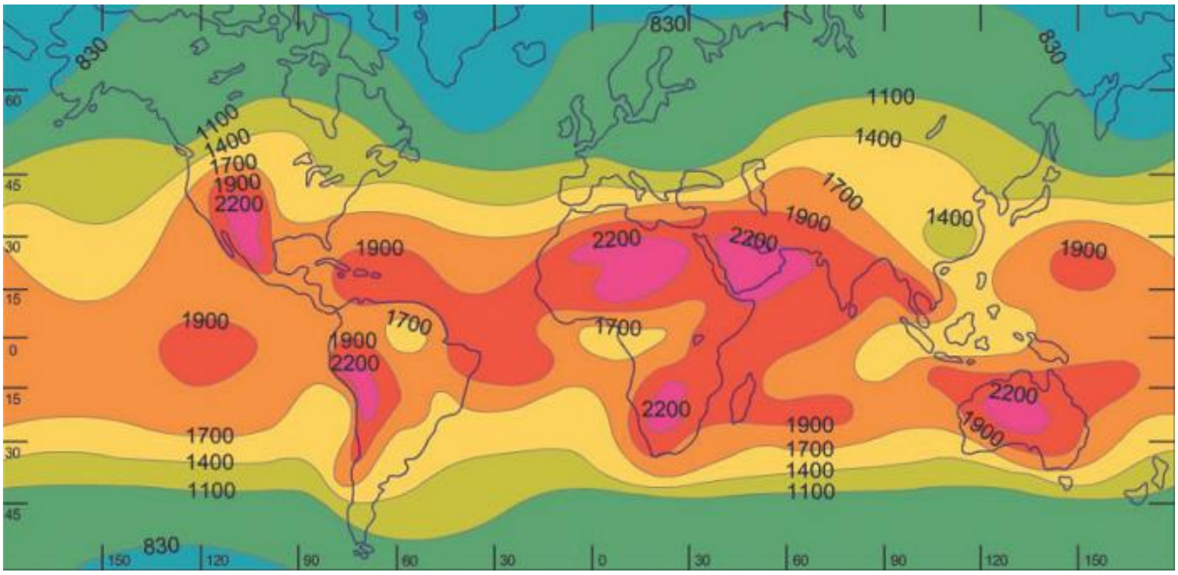

Figure III. 11: Average annual solar energy received in kWh [Encyclopedia Universalis 2005]

Although solar energy has many advantages, it’s limited by some inconveniences. The main obstacle for solar energy is that it’s only productive during the sun hours of the day, and that its efficiency depends on the weather.

In fact, solar radiation can be distinguished into three categories:

i. Direct radiation: solar radiation that has not been altered by atmospheric scattering, so it keeps a straight trajectory.
ii. Diffuse radiation: solar radiation with a modified trajectory because of the clouds, atmospheric dust or air humidity.
iii. Reflected radiation: solar radiation reflected by the surface of an object or simply the ground.

Of these three kinds of solar radiation, only the direct radiation can be used to produce solar thermal energy in a central tower system, so the parameter that is more important for the design of a central tower system is the normal direct irradiance (DNI), which will always be lower than the E_{SC}.

While radiance is the flux of radiation emitted per unit solid angle the irradiance is the radiant power received per unit area, which is nevertheless the available energy due to the direct radiation in a specific area (the mirror's surface in this work).

The solar collectors (in this work mirrors called "heliostats") must reorient their selves during the day, so they can focus or collect as much solar radiation as possible. The position of the sun depends on the time of the day and the date of the year, so the solar collectors use an automatic system that calculates the sun position using sun path diagrams like in *Figure III.12*. These diagrams are strongly dependent of the latitude and longitude where the solar energy system is installed, because the inclination of the Earth and the revolution around the Sun affects the path of the sun from the point of view of the heliostat field.

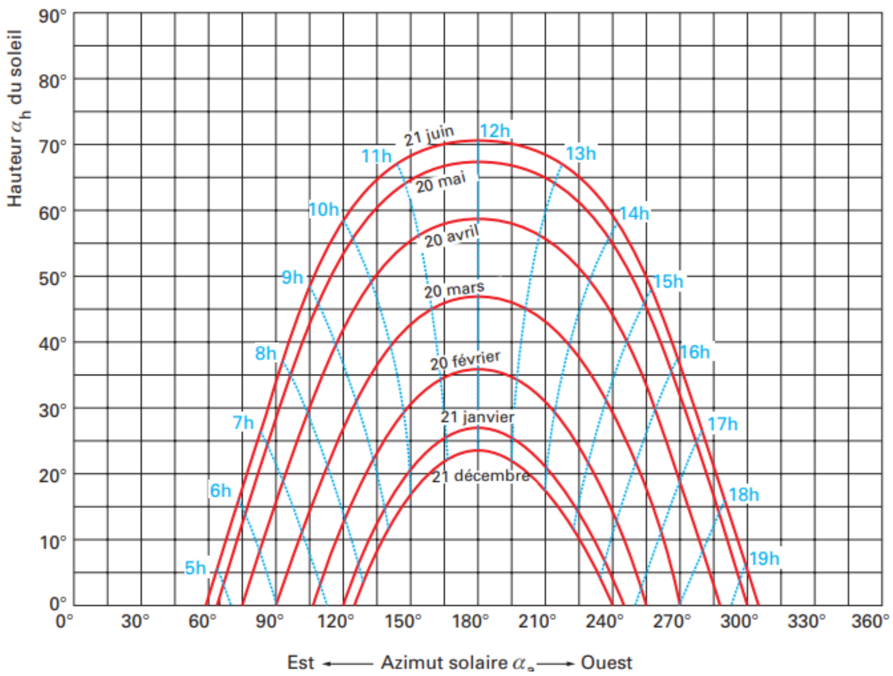

Figure III. 12: Cylindrical sun path diagram. Location at 43º latitude north, 6º longitude east [ref. 19]

III 8. Central tower systems

Depending on the kind of energy produced the solar energy technology can be divided into two:

a. Photovoltaic energy: it's based on the excitation of silicon-free electrons by the rays of solar photons. The goal of this technology is to transform solar radiation into electricity.

b. Solar thermal energy: the principle of this technology is to take advantage of the solar irradiance to increase the temperature of a calorific fluid (air, water, molten salt…), creating thermal energy.

Through this work the main goal is preheating the blast of a flash furnace, hence the solar thermal energy is further analyzed. When the goal is to produce thermal energy using solar power there are three main options:

i. Parabolic trough collector system (a in *Figure III.13*).

ii. Central tower system (b in *Figure III.13*).

iii. Compound parabolic concentrator system (c in *Figure III.13*).

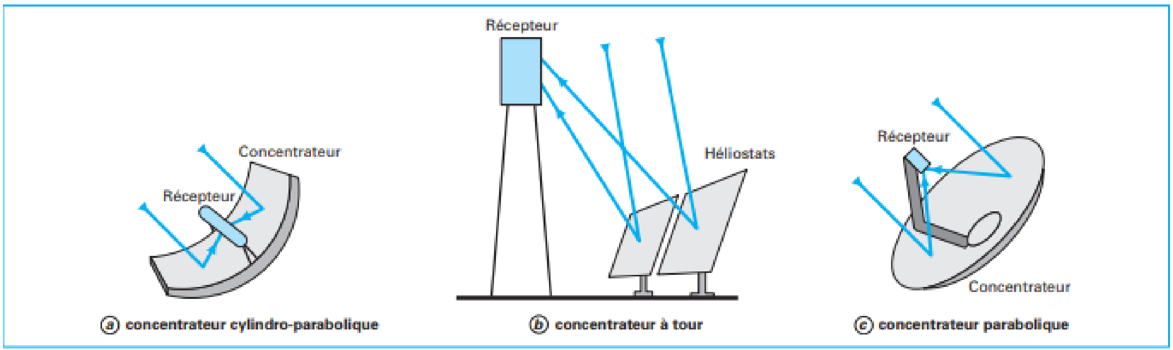

Figure III. 13: Scheme of the main families of solar concentration systems [ref. 18]

Each system has its advantages and disadvantages, so the selection of the technology is based on the energy and temperature operational capacity of each technology:

Table III. 1: Comparison of the three main solar concentration systems [ref. 18]

Characteristics of the current solar concentration systems			
Technology	**Parabolic trough collector**	**Central tower**	**Compound parabolic**
Thermic nominal yield (1)	70%	73%	75%
Power production	80 to 3000 MW_{th}	10 to 100 MW_{th}	1 to 100 kW_{th}
Operational temperature	270 to 450 ºC	450 to 1000 ºC	600 to 1200 ºC
Price of the solar field (2)	210 to 250 €/m^2 (3)	140 to 220 €/m^2	Around 150 €/m^2
Cost of the investment	2.8 to 3.5 €/W_e	3 to 4 €/W_e	10 to 14 €/W_e

(1) This yield is equal to the fraction of thermic energy received divided by DNI available
(2) Source: Solar Thermal Power Plants, EUREC-Agency, 2000
(3) This price includes the cost of the tubular receiver

In a prior study, the results show the preheating of the blast in a flash furnace would need from 4 to 10 MW_{th} in order to preheat the blast up to 600 ºC, hence the solar technology adapted to the process would be the Central tower system.

The central tower systems (also called central receiver systems, solar tower or power tower) consist of a large number of two-axis tracking mirrors (heliostats), constituting the heliostat field, and a heat exchanger (receiver) that concentrate all the energy coming from the reflection of the heliostats. This receiver can be at the top of a central power or at base of this tower (in the last case the receiver would be the target of the beam of the tower reflector at the top of the tower).

Regarding the configuration of the receiver, two main options are considered. We talk about an external receiver when cylindrical receivers are arranged outside of a surface, allowing the solar refraction for the heliostat to reach the receivers form all the points of the heliostat field.

The other option would be placing the receiver inside a cavity, installing the cavity receivers at the inner walls of a larger cavity with a smaller aperture. This reduces the flux of concentrated solar energy, as only the refraction beams from the heliostats within a cone defined by the aperture will be collected, but it greatly reduces the heat losses due to convection and radiation. When the calorific fluid is air the heat losses related to the conductivity of the wall are neglectable, because the receiver is efficiently isolated using void spaces and non-conductive materials. Also, it has been tested through experimentation that in the case of the air-heating the most efficient configuration is the cavity receiver, not surpassing a solar flux of 300 kW/m^2 [ref. 16].

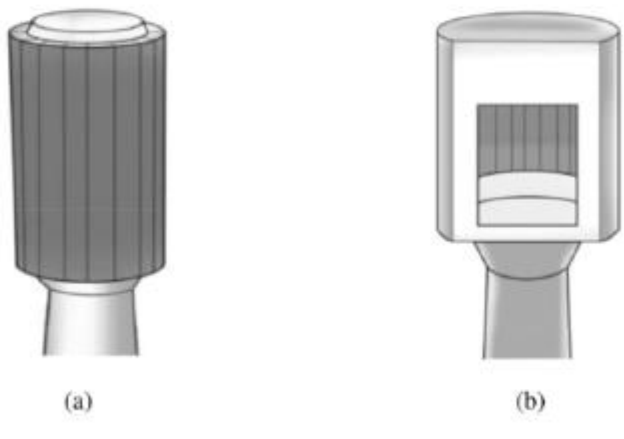

Figure III. 14: Solar receiver configuration. (a) describing an external receiver and (b) a cavity receiver [ref. 22]

The heliostats can have a surface from 10 m^2 to 200 m^2, and they are automatically oriented so they can reflect the light efficiently toward the tower receiver. Two tracking strategies are commonly used:

i. Spinning-elevation sun-tracking method: depending on the sun position the spinning axis and the elevation axis modify the angle of refraction (left scheme in *Figure III. 15*).

ii. Azimuth-elevation sun-tracking method: the azimuth axis allows the heliostat to spin horizontally, and the elevation axis is in charge of the vertical spin (right scheme in *Figure III. 15*).

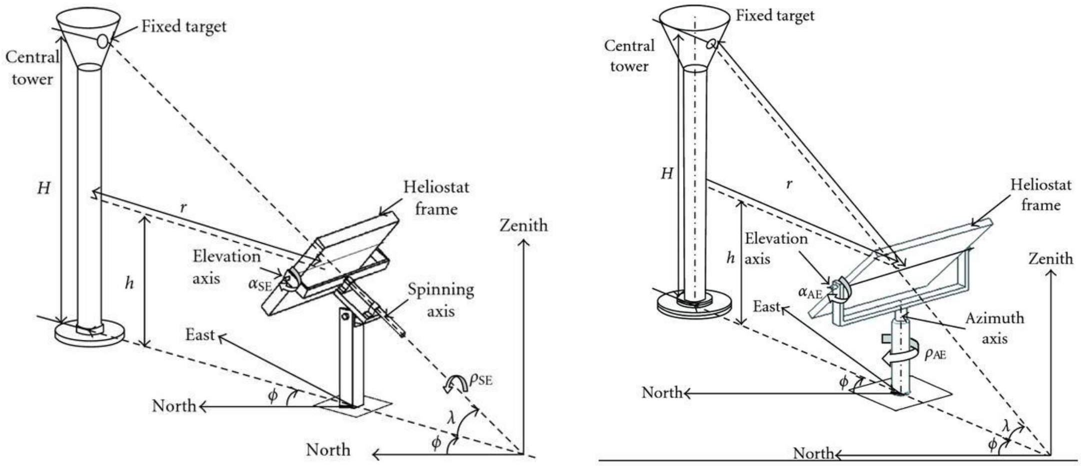

Figure III. 15: Tracking methods [ref. 15]

Depending on the location of the heliostat field two different dispositions of the heliostats are established. At mid-latitudes, the tower is placed at the edge of the heliostat field (north or south depending on the hemisphere), and at low latitudes (< 35º) the tower takes a central position (*Figure III. 16*). Else, the distribution of the heliostats and the tower height is optimized through optical calculations considering all the sources of losses: shadow effect, obstruction of the solar beam, cosine effect and reflectivity of the mirrors, the availability of the heliostats, the atmospheric absorption and the aperture of the receiver [ref. 18].

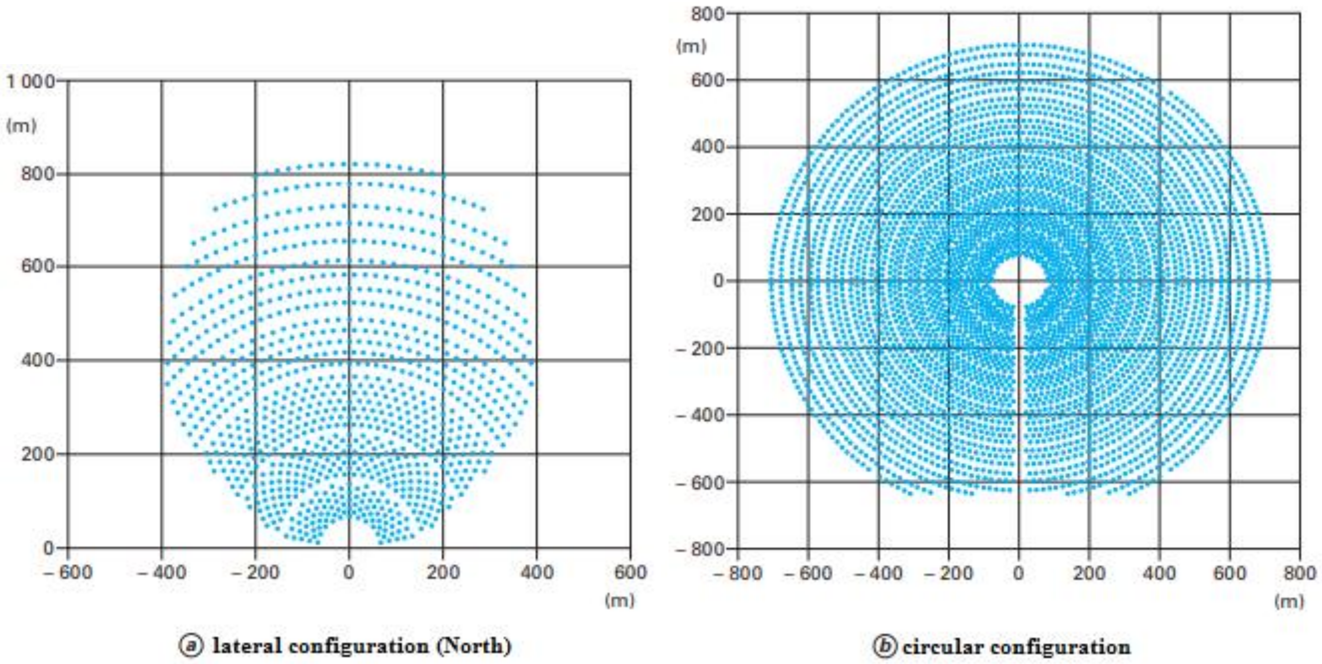

Figure III. 16: Examples of heliostat field configurations [ref. 18]

The solar central towers usually use an energy storage system based on pressurized water/steam or molten salt. In this way, the excess of energy produced in the hours of high solar irradiance can be stored and used when the available DNI is not enough for the exigencies of the heating process.

The advantage of this technology is that the system produces a huge amount of energy at high temperatures, reaching values above 1000 ºC and up 20 MW (solar tower plant Gemasolar, Torresol Energy). On the other side, large areas of land are needed for the heliostats, and the system is dependent on the weather conditions and the time of the day.

III 9. Environmental assessment

The environmental assessment in this work is based on the concept of environmental impact and life cycle of the industrial goods. An environmental impact is defined as any kind of modification of the environment, either negative or positive, totally or partially consequence of the activities of a living organism.

On the other hand, the life cycle of a product goes from the extraction of the natural resources to the elimination at the end-of-life. It divides itself into 5 stages (*Figure III. 17*): the extraction and process of raw materials; the manufacturing and processing of the product; the transportation and distribution; the use/re-use and maintenance; and finally, the final disposal.

The International Organization for Standardization (ISO) is an acknowledged international authority whose standards establish a framework for the assessment of the environmental impacts. The main goal of the ISO is to create a set of standards that the companies can voluntary follow in order to continuously improve their environmental management. The ISO organization provides with certifications to the companies that follow their environmental standards, and continuously survey the environmental management system of the companies that seek their certifications, which have become nowadays a sign of distinction. The most important and internationally acknowledged standard is ISO 14001, which specifies the requirements for an effective environmental management system (EMS). Under the framework created by this standard, and generally all the ISO 14000 family of standards on environmental management, this work follows a solid base for the environmental assessment.

The ISO defines the Life Cycle Assessment (LCA) as a technique for assessing the environmental aspects and potential impacts associated with a product by [ref. ISO 14040]:

1. Compiling an inventory of relevant inputs and outputs of a product system. In this work, the data used for the LCA is the Ecoinvent 2.2, a very complete inventory with yearly updated datasets.
2. Evaluating the potential environmental impacts associated with those inputs and outputs. This part will be done with the support of Umberto, a software specialized in the LCA according to the ISO standards.

3. Interpreting the results of the inventory analysis and impact assessment phases concerning the objectives of the study. This interpretation is the responsibility of the environmental experts, but a prior interpretation will be given in *Chapter XII*.

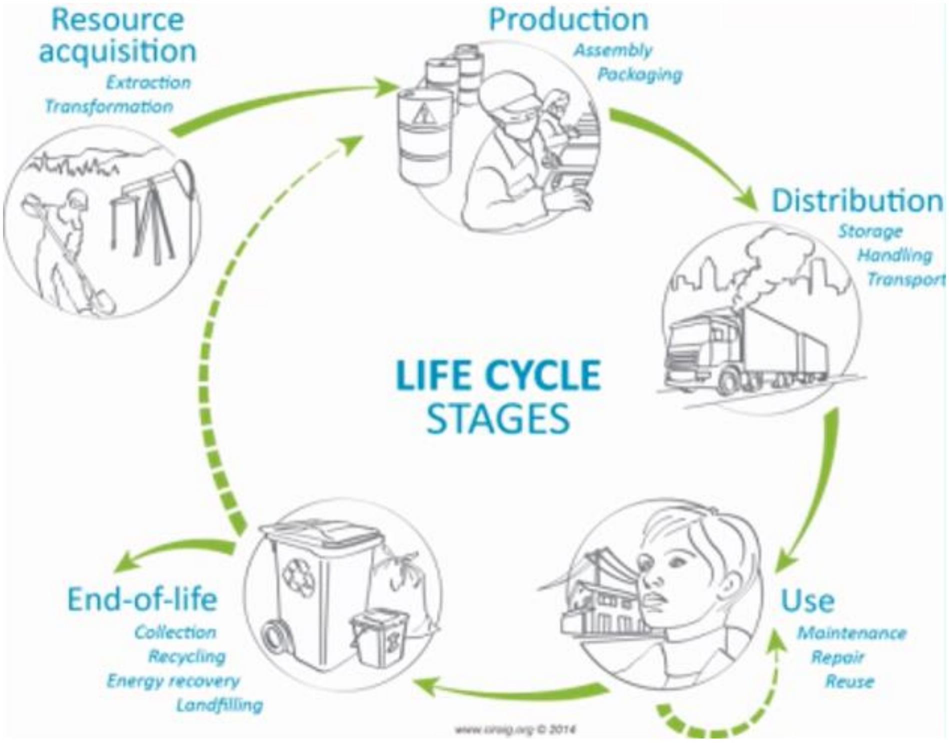

Figure III. 17: Life cycle stages

There exist two major approaches for the LCA depending on the target group. When the target group is the consumer a full-scale LCA comprising the five life cycle stages is advised, taking the cradle-to-grave LCA approach. Nevertheless, when the study is limited to a part of the overall process, like in the case of this work, a cradle-to-gate LCA can be undertaken. This means that even if all the processes from raw material extraction to the factory gate are assessed, the distribution, use and disposal stages won't be part of the analysis. For this work, the cradle-to-gate approach is more suitable, hence the smelting process will be assessed from the extraction of the copper ore to the production of copper matte, without including the matte refining and the three last stages of the life cycle of the copper.

Through this work, the main functional units for the LCA will be the carbon footprint and the Eco-indicator 99 points.

The carbon footprint estimates the equivalent of CO_2 produced by the process. As a reference point, it's interesting to know that the carbon footprint for the gasoline combustion is considered to be around 33.65 kg of CO_2 per liter, and an average passenger traveling by car emits 0.56 kg of CO_2 per km driven.

The Eco-indicator 99 consider three kinds of environmental damage [ref. 30]:

1. Human health: it includes the number and duration of diseases, and the life years lost due to premature death from environmental causes. The effects considered are: climate change, ozone layer depletion, carcinogenic effects, respiratory effects, and ionizing (nuclear) radiation.
2. Ecosystem quality: it includes the effect on species diversity, with special attention to the vascular plants and lower organisms. The effects considered are: ecotoxicity, acidification, eutrophication, and land-use.
3. Resources: it includes the surplus energy needed in the future to extract lower quality mineral and fossil resources.

The damages to the three safeguard subjects are weighted and added to one single score representing the overall environmental damage. The Eco-indicator 99 points are used as a comparative reference with other processes.

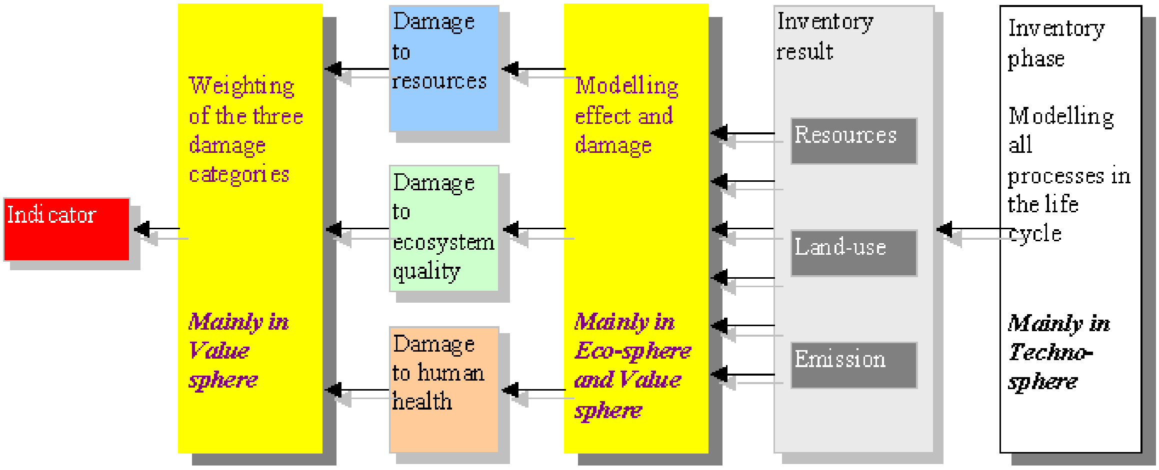

Figure III. 18: Scheme of the Eco-indicator 99 evaluation system [ref. 30]

Several approaches can be taken in Eco-indicators 99 analysis, being the three main categories [ref. 31]:

Table III. 2: Archetypes in Eco-indicators 99

Type	Time perspective	Ability to manage	Required level of evidence
Hierarchist (H)	Balance between short and long term	The proper policy can avoid many problems	Inclusion is based on consensus
Individualist (I)	short term	Technology can avoid many problems	Include only proven effects
Egalitarian (E)	long term	Problems can lead to catastrophe	Include all possible effects

In order to better evaluate the environmental impact of the smelting process several reference values are provided for the comparison in *Table III. 3*:

Table III. 3: Reference value for the Eco-indicators 99 analysis [ref. 31]

	Unit	Value
Production of rigid PVC	Points per ton	270
Production of steel high alloy	Points per ton	910
Production of copper (conventional)	Points per ton	1400
Production of paper	Points per ton	96
Heat oil (industrial furnace)	Millipoints per MJ	11
Electricity France	Millipoints per kWh	8.9

Chapter IV. Regulations y references

IV 1. Legal requirements and applied rules

Any industrial activity related with the copper mining sector within the Chilean territory is subjected to the following laws and regulations (*all the laws and legal documents will be mentioned through this work in their original language*):

Chilean laws affecting the mining activities:

- Decreto 28, establece norma de emisión para fundiciones de cobre y fuentes emisoras de arsénico, 30 de julio de 2013
- Ley del trabajo Chile, 31 de julio de 2002
- Resolución N°30 sobre exportaciones de cobre y sus subproductos, 4 de mayo de 2017
- Ley 18.248 Código de Minería, 14 de octubre de 1983
- Decreto Ley 1.349 que crea la Comisión Chilena del Cobre, 28 de abril de 1987
- Ley 18.097 de Concesiones Mineras, 21 de enero de 1982
- Estatuto Inversión Extranjera, 16 de diciembre de 1993
- Ley 19.137 sobre Pertenencias Mineras de Codelco, 12 de mayo de 1992
- Ley 20.363 (Día del Minero) , 10 de agosto de 2009
- Ley 20.649 Modifica Tributación Minera, 21 de octubre de 2010
- Ley 20.026 impuesto específico a la actividad minera, 16 de junio de 2005

- Reglamento Royalty, complemento de la ley 20.2026, 13 de diciembre de 2005

- Resolución Informe Técnico Proyectos Conexos, 17 de diciembre de 2010

- Reglamento Seguridad Minera, 7 de febrero de 2004

- Tratado Minero Chile – Argentina, 7 de febrero de 2001

- Constitución Política de la República, 22 de septiembre de 2005

Spanish laws affecting the mining activities:

- Real Decreto 294/2016, de 15 de julio, por el que se establece el procedimiento para la gestión de los derechos mineros y de los derechos del dominio público de hidrocarburos afectados por el cambio del sistema geodésico de referencia.

- Real Decreto 777/2012, de 4 de mayo, modifica el Real Decreto 975/2009, de 12 de junio, sobre gestión de los residuos de las industrias extractivas y de protección y rehabilitación del espacio afectado por las actividades mineras.

- Real Decreto 975/2009, de 12 de junio, Gestión de los residuos de las industrias extractivas y de protección y rehabilitación del espacio afectado por actividades mineras.

- Ley 12/2007, de 2 de julio, Modifica la Ley 34/1998, de 7 de octubre, del Sector de Hidrocarburos, con el fin de adaptarla a lo dispuesto en la Directiva 2003/55/CE del Parlamento Europeo y del Consejo, de 26 de junio de 2003, sobre normas comunes para el mercado interior del gas natural. Modifica el art. 121 de la Ley de Minas e introduce el 122.

- Real Decreto 647/2002, de 5 de julio, declaran las materias primas minerales y actividades con ellas relacionadas, calificadas como prioritarias a efectos de lo previsto en la Ley 43/1995, de 27 de diciembre, del Impuesto sobre Sociedades.

- Ley 34/1998, de 7 de octubre, ley del sector de hidrocarburos.

- Real Decreto 107/1995, de 27 de enero, fija criterios de valoración para configurar la sección A) de la Ley de Minas.

- Ley 43/1995, de 27 de diciembre, ley del Impuesto sobre Sociedades. Capítulo IX. Régimen especial de la minería

- Real Decreto 1116/1984, de 9 de mayo, sobre restauración del espacio natural afectado por las explotaciones de carbón a cielo abierto y el aprovechamiento racional de estos recursos energéticos.

- Real Decreto 2994/1982, de 15 de octubre, sobre restauración de espacio natural afectado por actividades mineras.

- Ley 54/1980, de 5 de noviembre, modificación de la Ley de Minas, con especial atención a los recursos minerales energéticos.

- Real Decreto 2857/1978, de 25 de agosto, reglamento General para el Régimen de la Minería.

- Ley 6/1977, de 4 de enero, ley de Fomento de la Minería.

- Real Decreto 2362/1976, de 30 de julio, por el que se aprueba el Reglamento de la Ley sobre Investigación y Explotación de Hidrocarburos de 27 de junio de 1974.

- Ley 22/1973, de 21 de julio, ley de Minas.

- ORDEN ITC/101/2006, de 23 de enero, regula el contenido mínimo y estructura del documento sobre seguridad y salud para la industria extractiva.

- Real Decreto 1389/1997, de 5 de septiembre, aprueban las disposiciones mínimas destinadas a proteger la seguridad y la salud de los trabajadores en las actividades mineras.

- Orden de 19 de marzo de 1986, establecen normas complementarias para el desarrollo y ejecución del Real Decreto 3255/1983, de 21 de diciembre, por el que se aprueba el Estatuto del Minero, en materia de seguridad e higiene.

- Real Decreto 863/1985, de 2 de abril, Reglamento General de Normas Básicas de Seguridad Minera

- Real Decreto 3255/1983, de 21 de diciembre, Estatuto del Minero.

Spanish laws affecting the solar thermic sector:

- Real Decreto 314/2006[116] por el que se aprueba el Código Técnico de la Edificación (CTE), establece la obligatoriedad de incorporar instalaciones solares térmicas y paneles fotovoltaicos en ciertas edificaciones.

- Real Decreto-ley 7/2006[119] por el que se adoptan medidas urgentes en el sector energético, desvincula la variación de las primas del régimen especial de la Tarifa media eléctrica o de Referencia.

- Real Decreto Ley 6/2009 con el fin de establecer unos mecanismos respecto al sistema retributivo de las instalaciones de régimen especial

IV 3. References

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(c). *Microsoft Word* , for the redaction and structuration of the work.

(d). *Excel* , for some figures and numerical studies.

(e). *Paint* , for the modification and adaptation of schemes and figures.

(f). *Umberto* , for the environmental assessment .

(g). *Autocad* , for the design plans.

Chapter V. Definitions, abbreviations and translations

Nomenclature

Scalars

Abs	: absorbance
$R_{opt\ ref}$	: apparent optical efficiency
D_{TS}	: average distance between the Sun and the Earth ($149.6 \cdot 10^9$ m)
R	: constant of perfect gases ($8.31 \frac{Pa \cdot m^3}{mol \cdot K}$)
σ	: constant of Stefan Boltzman ($5.67 \cdot 10^{-8}$ W/m^2·K^{-4})
CPI	: Consumer Price Index = 2.5%
ρ	: density (kg/m^3)
D	: domain
W_e	: electrical energy (J)
M_S	: energetic emittance (W/m^2)
H	: enthalpy (J)
C_g	: geometric concentration ratio (m^2/m^2)
g	: gravity constant (9.8 J/m·kg)
Q	: heat (J)
z	: height (m)
R_{opt}	: heliostat field optical efficiency
R_{int}	: intercept factor
U	: internal energy (J)
E_C	: kinetic energy (J)
L	: length (m)
W_m	: magnetic energy (J)
m	: mass (kg)
F	: molar flow (mol/h)
i_n	: nominal interest = 4%
P_n	: normal pressure (101320 Pa)
T_n	: normal temperature (273.18 K)

E_p : potential energy (J)

P : pressure (Pa)

$R_{Cu/S}$: ratio Cu/S

i_r : real interest = i_n/IPC = 1.6%

E_{SC} : solar constant (1367 W/m^2)

φ_S : solar flow (W)

Φ_{solar} : solar flow par surface unit (W/m^2)

R_S : solar radius (686000 km)

h : specific enthalpy (J/kg)

C_p : specific heat (J/K·kg)

u : speed (m/s)

S : surface (m^2)

T : temperature (K)

$\varepsilon_{receiver}$: thermal emissivity of the receiver

v : volume (m^3)

G : volumetric flow (Nm^3/h)

η : yield

Abbreviations

Capital letters

IVA : Added Value Tax

AW : Atomic Weight (g/mol)

BEC : Budget Execution and Implementation

CF : Cash Flow

CC : Contractor's Cost

DNI : Direct Normal Irradiance (W/m^2)

PPEE : Dry Electrostatic Precipitators

FGD : Flue Gas Desulfurization

FFF : Fusion Flash Furnace

ESP : Electrostatic Precipitator

EMS : Environmental Management System

GC : General Cost

IB	: Industrial Benefit
ISO	: International Organization for Standardization
LCA	: Life Cycle Assessment
MW	: Molar Weight (g/mol)
PVA	: Present Value of Annuity
DESONOX	: Process for the Nitrogen oxides and Sulphur dioxide
R	: Ratio
RT	: Return Term
SCT	: Solar Central Tower
SERC	: Solar Energy Research Center

Translations

Aggregates	: accesorios
Tap Holes	: agujeros de salida
Amortization	: amortización
Gross profit	: beneficio bruto
Net profit	: beneficio neto
Reaction shaft	: cámara de reacción
Heliostat field	: campo de heliostats
Boiler capacity	: capacidad de caldera
Melting capacity	: capacidad de fundición
Total furnace charge	: carga total del horno
Scrap	: chatarra
Gas off-take	: chimenea
Copper	: cobre
Blister copper	: cobre blíster
Fitting 90º	: codo 90 º
Concentrate	: concentrado
Flue	: conducción
Conductions	: conducciones
Converter	: convertidor

Conversion : conversión

Settler : crisol de sedimentación

Scrubber : depurador

Slag : escoria

Foaming agent : espumante

Froth flotation : flotación por espuma

Cash Flow : flujo de caja

Anode casting : forjado anódico

Flux : fundente

Smelting : fundición

Overhead expenses : gastos generales

Anode furnace : horno anódico

Hydrometallurgy : hidrometalurgia

Flash furnace : horno flash

Added Value Tax : Impuesto de Valor Añadido

Corporation tax : impuesto de sociedades

Initial investment : inversión inicial

Liquidity : liquidez

Manpower : mano de obra

Sun path diagram : mapa solar

Matte : mata

Molten matte : mata fundida

Ore : mena

Sulfide ore : mena de sulfito

Mining : minería

Mine : mina

Grinding : molienda

Ball mill : molino de bolas

Paving : pavimentar

Return Term : período de retorno

Pyrometallurgy : pirometalurgia

Slab : plancha

Budget execution and implementation : presupuesto de ejecución del material

Contractor's cost : presupuesto de ejecución por contrata

Exploitation budget : presupuesto de explotación

Burner : quemador

Receiver : receptor

Electrolytic refining : refinamiento electrolítico

Yield : rendimiento

Blast : soplado

Internal Rate of Return : tasa interna de rentabilidad

Roasting : tostado

Crushing : trituración

Pipe : tubo

Present Value of Annuity : valor actual neto

Economic profitability : viabilidad económica

Chapter VI. Design requirements

VI 1. Outokumpu flash furnace

The design, operative conditions, and design limitations of the *Chagres Anglo American Smelting facility in Chile* have been adopted and completed with data from the bibliography in the analysis of this work. In the best interest of the work, the simulation results are obtained using the operational mode described below, so it's possible to establish a comparative base for the simulations developed in the "Results Chapter".

Table VI. 1: limit values for the furnace capacity

Melting capacity	Tons concentrate/year	610000
	Tons concentrate/h	75
Total furnace charge	Tons/h	90
Boiler capacity	Nm^3/h	35000

In *Table VI. 1*, the limit values for the capacity of the design are specified. Over these conditions, the safety of the process isn't guaranteed, although it's possible to increase the gas flow through the furnace over 35000 Nm^3/h if the feed rate decrease, only if the total volume of all the phases inside the furnace stays within the safety limits. In the current industry, the flash furnaces usually work at a feed rate close to the melting capacity, that's why in this work the feed rate of the process will be fixed at 75 tons of concentrate per hour. The total charge of the furnace is equal to the addition of the concentrate, the fluxes, and the recycled dust.

The initial goal of this project will be preheating the blast with 75 tons of concentrate per hour, with the restrictions of creating a 60% pure matte and not surpassing the value of 35000 Nm^3/h for the flow of gases. As the studies developed later on in this work show, increasing the temperature of the blast and using fossil fuels expand the gases inside the furnace. Hence, in a prior study, the furnace is forced to work in the limit conditions of feed rate, and the evolution of the key parameters for the understanding of the furnace is analyzed in relation with the temperature of the blast.

For the purpose of being able to fully understand the process, the simulations will run until eliminating the need of industrial oxygen in the blast, even if doing so makes the volume of gases overpass the boiler capacity. However, in the analysis of the Solar Central Tower system, only the operational modes respecting the furnace capacity are evaluated.

Table VI. 2 illustrate the behavior of a real Outokumpu Flash Furnace using a concentrate with a ratio Cu/S of 1. This is, in fact, the case of the Chalcopyrite concentrate, so the results should be consistent with the hypotheses and theories developed in the creation of the simulation equations.

$$R_{Cu/S} = \frac{mass\ of\ copper\ in\ the\ concentrate}{mass\ of\ sulfur\ in\ the\ concntate}$$ **(Equation VI 1)**

Table VI. 2: Operational modes of the flash furnace (Charles Anglo American technical date)

FLAHS FURNACE (24 Hours cycle)						
Total charge Burner	Tons/day	1 905	2 046	2 173	2 067	2 001
	Tons/hour	79.4	85.2	90.5	86.1	83.4
Blast In-take	Nm3/h	16 218	19 016	20 095	14 790	14 681
	% vol O2	69.2	66.2	69.1	79.8	77.5
Temperature Reaction shaft	°C	1 415	1 439	1 468	1 415	1 409
Heat losses Reaction shaft	Mcal/h	900	900	900	900	900
Fuel Settler	Nm3/h	897	603	234	832	909
Slag Settler	tpd	708	845	975	859	826
	% Cu	2.1	2.1	2.1	2.9	4.9
	°C	1 300	1 300	1 300	1 300	1 300
Matte Settler	tpd	869	856	828	875	859
	% Cu	63.1	62.8	62.8	64.5	63.9
	°C	1 260	1 260	1 260	1 260	1 260
Gases	Nm3/h	28 775	27 418	23 398	26 354	27 221

Settler	°C	1 400	1 400	1 400	1 400	1 400
Heat losses Settler	Mcal/h	3 200	3 200	3 200	3 200	3 200
Fuel Up-take	Nm3/h	33	41	68	48	43
Heat losses Up-take	Mcal/h	700	700	700	700	700
In-gases Steel shell (all except comb)	Nm3/h	29 106	27 868	24 232	26 901	27 701
	% vol SO2	31.1	35.8	45.1	34.7	32.2
	°C	1 350	1 350	1 350	1 350	1 350
Steam Steel shell	tph	25.7	25.0	22.8	24.5	24.7
In-gases PPEE	Nm3/h	34 732	33 911	30 400	32 907	33 795
	°C	380	380	380	380	380
Off-gases PPEE	Nm3/h	36 223	35 403	31 891	34 397	35 286
	°C	360	360	360	360	360
In-gases Mixing chamber	Nm3/h	36 223	35 403	31 891	34 397	35 286
	% vol O2	7.1	7.3	7.8	7.7	7.7
	% vol SO2	23.8	26.8	32.6	25.8	24.2
	°C	350	350	350	350	350

It can be observed that the volume of in-gases going to the settler (blast) usually goes around 28 Nm^3/h in a process without any kind of preheating and around 600 Nm^3/h of fuel (540 kg/h if we consider $\rho_{gas} = 0.9 kg/m^3$) when the feed rate is equal to 85 ton/h, therefore 6.43 kg of fuel per ton of concentrate. In these conditions, the purity of the matte is around 62 mass-% in copper.

Now using the simulation model, a similar case is assessed, where the feed rate is kept constant at 75 ton/h, the purity of the matte is fixed on 60 mass-% but the fuel supply is increased up to 10 kg of fuel per ton of copper.

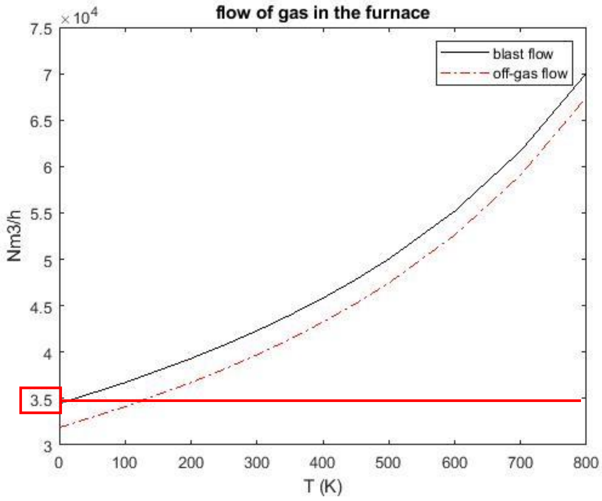


Figure VI. 1: Evolution of the gas volume with the temperature of the blast when 10 kg fuel introduced per ton of concentrate

The first phenomenon that can be observed is that the volume of blast flow is over the boiler capacity even without preheating, which means that the amount of combustible used in the operation increases greatly the volume of the gases. In fact, the use of fuel over 6 kg per ton of concentrate makes the system work over the design limitations.

As a matter of fact, all the flows in this work are expressed in Nm^3, which means that they don't take into consideration the real temperature and pressure inside the furnace. In the real thermodynamic conditions, the volume of the gases is expanded, but this fact is already considered in the design limitations.

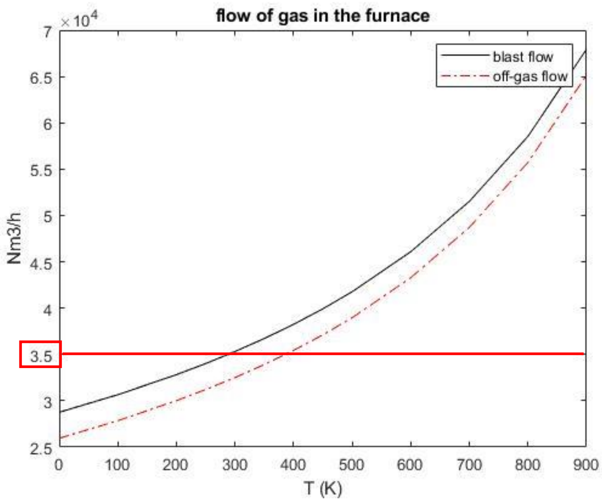


Figure VI. 2: Evolution of the gas volume with the temperature of the blast when 6 kg fuel introduced per ton of concentrate

As expected from the real operation data the simulation works under the design conditions until going over the 300 K, which means that no preheating would be possible without a further reduction on the employment of fuel. It can be observed how the volume of the blast strongly depends on the temperature.

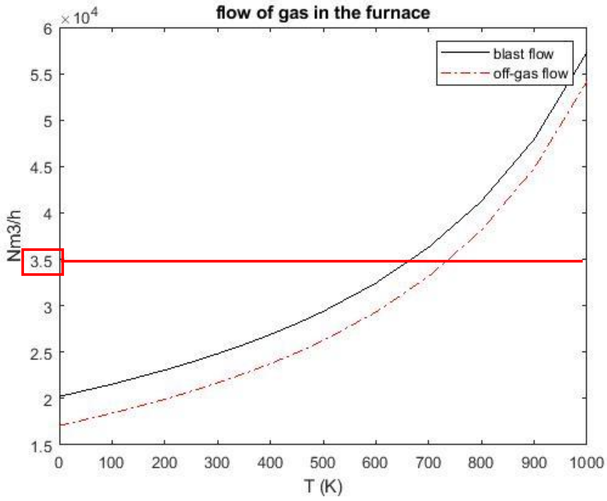


Figure VI. 3: Evolution of the gas volume with the temperature of the blast when no fuel is used

In *Figure VI. 3* it's finally possible to observe a scenario where the preheating is respects the design limitations of the furnace, with the additional advantage of removing the need for fuel for regulating the temperature of the furnace.

VI 2. Conductions

The study of the hydraulic conditions inside the conductions is not the goal of this work. However, *Table VI. 1* shows the linear speed as a parameter for determining the viability of the conductions chosen for the design of the SCT system.

Table VI. 1: Canalization's linear speed

Flow through the pipe (m^3/h)	Diameter pipe (m)	Transversal area pipe (m^2)	Linear speed (m/s)
35000	0.61	0.29	33.27

The linear speed is reasonable for the air if we consider a maximum speed of 100 m/s before putting in risk the control and safety valves. No risk of explosion as the blast doesn't contain any explosive species.

VI 3. Central Tower Systems

Because the design of the Central Tower System is strongly dependent of the needs of the flash furnace, it's no possible to obtain the technical information of an already existing facility which is effectively adapted to the case analyzed in this work. In consequence, a simple methodology has been implemented for the creation of a theoric design of a solar field adapted to the needs of the Charles Anglo American flash furnace, operating in the specific conditions considered in this work.

The details of the theoric development for the design of the solar field are written down in *Chapter VII 4*.

For the design of the heliostat, it's adopted in this work the model proposed by the Stellerborsch University [ref. 32] (*Appendix IV*). According to this model, the mirror surface of one heliostat would be of 9 $m^{2.}$ and the tracking system corresponds to the Azimuth-elevation sun-tracking method. If the heliostats are 9 m^2 and the mirror area is of 10201 m^2 (Chapter VIII 5) then there would be necessary 1134 heliostat.

The coordinates of the *Chagres Anglo American Smelter* facility are:

- Longitude: O70°38'50.06"
- Latitude: S33°28'21.68"

According to *Chapter III 8*, being the facilities located on a latitude inferior to S35ª, the optimal disposition for the tower is a central position in the heliostat field.

Figure VI. 4:Location of the Chagres Anglo American Smelter

Chapter VII. Analysis result

This chapter is composed of a discussion of the simulations modeling the smelting process and the design of the solar field, and analyzing the processes used to treat the off-gas.

VII 1. Process modeling

In order to create a mathematic consistent model several elemental mass balances have been developed, all along with the energy balance and some restrictions and hypothesis that allow the determination of all the unknown variables.

The compounds considered for the balance equations are:

- Reactants: $CuFeS_2$ as concentrate (fixed value of one ton); SiO_2 as flux; O_2 and N_2 as the variable composition of the blast; and fuel (fixed value as input for the simulation).
- Products: Cu_2S and FeS in the matte; FeO and SiO_2 in the slag; SO_2, N_2, CO_2, and H_2O in the off-gas.

Considering that the chalcopyrite and fuel mass are adjustable input parameters in the simulation (all the calculations suppose a $CuFeS_2$ feed of 1 ton and the two values for the fuel mass used for the analysis in this work are 0 kg and 10 kg), for the moment a total of ten variables that must be determined by the matrix calculations.

Moreover, to force the system to develop matrix calculations that describe steady-state flash smelting producing matte of a specified grade (60 mass-% in this work), an additional variable will be considered: the mass matte.

The following hypotheses have been established for the creation of the calculations matrix:

Hypothesis

i. The pressure of all the flows and the pressure inside the furnace stay constant and equal to 1 bar.
ii. The initial temperature of all the species is the environment temperature, assumed to be 298.15 K, beside the temperature of the blast which depends on the preheating.

iii. The operational temperature of the furnace is constant at 1500 K.
iv. The SiO_2 is assumed to behave as if it were an element in the sense that the silicon-oxygen bond is not broken during the smelting [ref. 7].
v. The enthalpies and specific heat of all the species will be depending exclusively on the temperature, as the pressure and the volume in the furnace are constant.
vi. The heat loss for the Outokumpu flash furnace is assumed to be of 650 MJ/ton of concentrate [ref. 7].
vii. All the oxygen present in the blast is consumed in the oxidation reactions.
viii. The ratio of SiO_2 in the slag is supposed to be 0.3/0.7 [ref. 9].
ix. Concentrate feed rate about 75 tons of concentrate per hour.
x. The matte grade is considered constant and equal to 60 mass-% of Cu.
xi. In the real process, some of the copper stays in the slag and must be treated for recovery, but in order to simplify the model, it will be assumed that all the copper in the concentrate goes effectively to the matte (Cu_2S).
xii. The concentrate is composed exclusively by chalcopyrite ($CuFeS_2$), hence the matte grade is 34.6 mass-% in Cu.

Every steady-state operation must be balanced in mass and energy according to the following equations:

Mass balance in a geometric volume D

This first principle, which simply states that the sum of mass for any chemical element going into a defined domain (as the interior of the furnace) will be the same at the entrance that at the exit, can be mathematically expressed as:

$$\boldsymbol{m}(\boldsymbol{D}) = \iiint_{\boldsymbol{D}} \boldsymbol{\rho}.\,\boldsymbol{dv}$$ **(Equation VII 1)**

Which can be further developed for each chemical element participating in the flash smelting operation:

Cu

mass Cu_2S in matte · % Cu in Cu_2S = mass CuFeS2 · % Cu in $CuFeS_2$ **(Equation VII 2)**

· % Cu in Cu_2S = 80

· % Cu in $CuFeS_2$ = 34.6

mass matte · mass Cu in matte = mass Cu_2S · Cu in Cu_2S **(Equation VII 3)**

· % Cu in matte = 60

Matte

mass matte = mass Cu_2S + mass FeS **(Equation VII 4)**

Fe

mass $CuFeS_2$ · % Fe in $CuFeS_2$ = mass FeS · % Fe in FeS

+mass FeO · % Fe in FeO **(Equation VII 5)**

· % Fe in $CuFeS_2$ = 30.4

· % Fe in FeS = 64

· % Fe in FeO = 78

S

mass $CuFeS_2$ · % S in $CuFeS_2$ = mass Cu_2S · % S in Cu_2S + mass FeS · % S in FeS

+ mass SO_2 * % S in SO_2 **(Equation VII 6)**

· % S in $CuFeS_2$ = 35

· % S in Cu_2S = 20

· % S in FeS = 36

· % S in SO_2 = 50

O

mass O_2 = mass FeO · % O in FeO + mass SO_2 · O in SO_2 + mass CO_2 · % O in CO_2

+ mass H_2O · % O in H_2O **(Equation VII 7)**

· % O in FeO = 22

· % O in SO_2 = 50

· % O in CO_2 = 73

· % O in H_2O = 89

SiO2

mass SiO_2in = mass SiO_2out **(Equation VII 8)**

mass SiO_2out = mass FeOout · ratio of SiO_2 in the slag **(Equation VII 9)**

N

mass N_2in = mass N_2out **(Equation VII 10)**

C

mass fuel · % C in fuel = mass CO_2 · % C in CO_2 **(Equation VII 11)**

· % C in fuel = 87 [11]

· % C in CO_2 = 27

H

mass fuel · % H in fuel = mass H_2O · % H in H_2O **(Equation VII 12)**

· % H in fuel = 13 [11]

· % H in H_2O = 11

The mass percentage of an element in a chemical compound can be easily determined as:

$$\%\ \boldsymbol{element\ in\ compound} = \mathbf{100} \cdot \frac{AW\ element \cdot number\ of\ atoms}{MW\ compound}$$ **(Equation VII 13)**

· % element in compound = mass percentage of an element in a chemical compound

All the mass percentages of the elements in the compounds, as well as the enthalpies used in this work, are detailed in *Appendix I*.

Using *Equations VII 2 to VII 12* the calculations matrix is composed of a system of 10 equations for eleven variables. An additional equation is needed for the system to have a unique solution; hence the energy balance must be established.

Energy balance

Combining the first and second principle of the thermodynamics it's possible to establish an equation that considers the internal energy; the kinetic energy; the potential energy; the mechanical work; the heat exchange; the electrical energy; the magnetic energy; and the incoming and outgoing mass flow energy:

$$\boldsymbol{dU + dE_C + dE_p + PdV = \sum_{i=1}^{n} \delta Q_i + \delta W_e + \delta W_m + \sum_{j=1}^{n} dm_j} \left(\boldsymbol{h_j + \frac{u_j^2}{2} + gz_j}\right)$$ **(Equation VII 14)**

For a steady state process in a constant volume without electrical or magnetic forces involved the previous equation can be simplified. Moreover, if the kinetic and potential energy related to the mass flow is considered negligible the Equation VII 14 can be rewritten as:

$$0 = \sum_{i=1}^{n} \delta Q_i + \sum_{j=1}^{n} dm_j \left(h_j\right) \rightarrow Q_{loss} + \sum m_{out}\, h_{out} = \sum m_{in}\, h_{in}$$

$\rightarrow\ \boldsymbol{Q_{loss}} + \sum \boldsymbol{H_{products}} = \sum \boldsymbol{H_{Reactants}}$ **(Equation VII 15)**

$$\sum H_{products} = H_{Cu_2S} + H_{FeS} + H_{FeO} + H_{SiO_2 out} + H_{SO_2} + H_{N_2 out} + H_{CO_2} + H_{HO_2}$$

$$\sum H_{reactants} = H_{CuFeS_2} + H_{SiO_2 in} + H_{O_2} + H_{N_2 in} + H_{oil}$$

$$Q_{loss} = \frac{heat\ loss\ par\ hour\ (\frac{MJ}{h})}{concentrate\ feed\ rate\ (\frac{tons}{h})}$$

Adding the *Equation VII 15* to the calculations matrix it’s possible to determine the mass of each species in the process.

Calculation of characteristic parameters

For this work several parameters are analyzed as a measure of the influence of the preheating of the blast on the performance of the process. These parameters are:

i. Mass flow of air obtained from the environment (kg/h)

$\boldsymbol{m_{air}} = \boldsymbol{m_{N_2 out}} / \boldsymbol{N_{in\ the\ air}}$ with $\boldsymbol{N_{in\ the\ air}} = \mathbf{0.77}$ **(Equation VII 16)**

ii. Mass flow of industrial oxygen needed (kg/h)

$\boldsymbol{m_{O_2\ ind}} = \boldsymbol{m_{O_2\ out}} - \boldsymbol{m_{air}} \cdot \boldsymbol{O_{in\ the\ air}}$ with $\boldsymbol{O_{in\ the\ air}} = \mathbf{0.23}$ **(Equation VII 17)**

iii. Total mass flow of the blast (kg/h)

$\boldsymbol{m_{blast}} = \boldsymbol{m_{O_2\ ind}} + \boldsymbol{m_{air}}$ **(Equation VII 18)**

iv. Percentage of oxygen in the blast

$\%\boldsymbol{O} = \boldsymbol{m_{O_2\ in}} / \boldsymbol{m_{blast}}$ **(Equation VII 19)**

v. Volumetric flow of the blast (Nm^3/h)

$$P_n \cdot G_{blast} = F_{blast} \cdot R \cdot T_n \rightarrow D_{blast} = \left(F_{O_2\ in} + F_{N_2\ in}\right) \cdot R \cdot \frac{T_n}{P_n}$$

$\rightarrow\ \boldsymbol{G_{blast}} = \left(\frac{m_{O_2\ in}}{MW_{O_2}} + \frac{m_{N_2\ in}}{MW_{N_2}}\right) \cdot \boldsymbol{R} \cdot \frac{\boldsymbol{T_n}}{\boldsymbol{P_n}}$ **(Equation VII 20)**

vi. Volumetric flow of the off-gas (Nm^3/h)

$$G_{off-gas} = \left(\frac{m_{SO_2\,out}}{MW_{SO_2}} + \frac{m_{N_2\,out}}{MW_{N_2}} + \frac{m_{H_2O out}}{MW_{H_2O}} + \frac{m_{CO_2\,out}}{MW_{CO_2}}\right) \cdot R \cdot \frac{T_n}{P_n} \quad \textbf{(Equation VII 21)}$$

vii. Energy needed to heat the blast up to a given temperature (MW)

$$Q = m_{O_2\,in} \cdot C_{p\,O_2} \cdot (T_{blast} - T_{env}) + m_{N_2\,in} \cdot C_{p\,N_2} \cdot (T_{blast} - T_{env}) \quad \textbf{(Equation VII 22)}$$

It's important to remark that the specific heat variates in function of the range of temperatures, and its value should be adapted.

VII 2. Treatment of the SO_2

The off-gases produced in the Outokumpu flash furnace are rich in SO_2 a contaminant compound dangerous for the environment and human health. Because of the contaminant nature of the SO_2 several regulations have been stablished for the mining industry, hence the off-gas flow of the flash furnace must be treated in order to reduce the content in SO_2. According to the "Decreto 28" the current legal code in Chile limits the SO_2 emissions for "Chagres Anglo American Smelter" factory is fixed in 14400 ton/year (*Table VII. 1*).

Table VII. 1: Emissions boundaries for Chilean smelting factories [ref. 24]

Fuente emisora	SO_2 (ton/año)	As (ton/año)
Altonorte	24.000	126
Caletones	47.680	130
Chagres	14.400	35
Chuquicamata	49.700	476
Hernán Videla Lira	12.880	17
Potrerillos	24.400	157
Ventanas	14.650	48

On the other hand, according to the decree 28, all the smelting factories and enforced to remove and treat at least 95 mass% of the total SO_2 production [ref. 24]. In the case of the flash furnace considered in this work, the total production of SO_2 is around 9052 Nm^3/h, or 25.86 ton/h (Chapter VI). Considering that the factory is working 365 days per year 24 hours an amount of 226533.6 tons per year would be produced, and so a treatment reducing this quantity in the 93.6 mass% must take place for the factory to operate under the boundaries established by the Chilean government.

Taking into account these facts and considering a recovery efficiency of 95 mass% when using the DESONOX process, the study developed in *Chapter VIII. 3* shows the H_2SO_4 production and the final emissions of SO_2.

VII 3. Solar irradiance

The data considering the direct solar irradiance corresponds to the "Chagres Smelter Anglo American" [ref. 23], the location of the facilities with the flash furnace considered in this work. The time of the year chosen is October, as the average DNI during this month is 337.9 W/m^2, close to the average DNI of the whole year (321.94 W/m^2). The reason why the average annual values haven't been used in this study is that the path followed by the DNI average curve is not characteristic of the tendencies of the DNI evolution during a normal day, creating uncertainty in the results. Hence it has been considered more accurate to use the DNI data of an actual month of the year with an average daily DNI similar to the annual daily average.

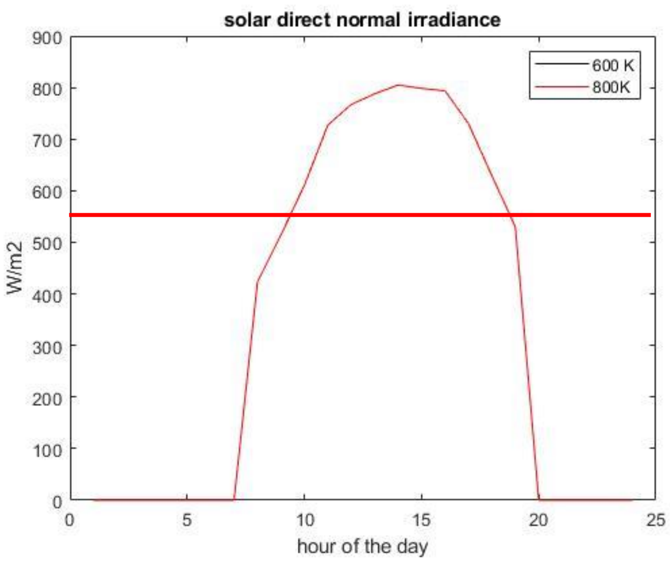


Figure VII. 1: Solar normal irradiance

The SCT system is designed for working without storage system during the hours of maximum solar radiation (DNI > 550 W/m^2), which means being generally operative from 11 am to 5 pm, making an average of 6 working hours. During the meantime, the smelting system is considered to work under conventional conditions (enriched blast and fuel supply).

In the real industry, there would be a storage system based on molten salts or water, making it possible to keep using solar thermal energy without interruptions.

VII 4. Solar thermal energy

For the evaluation of the solar thermal energy needed several parameters are needed for the analysis of the performance of a Central Tower System. First of all, the design of the heliostat field must be established considering the expected mass flow for the blast, the target temperature and the energy needed to heat the mass flow to this temperature. Likewise, a reference DNI must be provided for the design of the heliostat field.

Thanks to the simulation modeling the flash furnace, and considering the study developed in the *Chapter VIII* regarding the optimal working conditions for the preheating system, the following parameters can be stablished for the design of the Central Tower System:

Table VII. 2: Parameters of the flash furnace

Conditions of the flash furnace	
Temperature in-flows	298 K
Temperature blast preheated	600 K
Temperature furnace	1500 K
Feed rate concentrate	75 tons/h
Feed rate fuel	0 tons/h

Table VII. 3: Parameters for the heliostat field design

Parameters for the heliostat field design	
Blast mass-flow	12 kg/s
Reference DNI	900 W/m^2

Temperature blast inlet	288 K
Temperature blast outlet	600 K
Energy needed for the preheating	4 MW
Concentration ratio	300

One of the most important parameters for the design of the heliostat field is the concentration ratio (C_g), which is the ratio between the reflective surface of the mirrors and the surface of the receiver.

$$C_g = \frac{S\ heliostats\ (m^2)}{S\ receiver\ (m^2)} \quad , \quad 200 < C_g < 350 \quad \text{[ref.16]} \qquad \textbf{(Equation VII 23)}$$

The value of C_g should allow the system to operate close to the optimal solar flux (300 kW/m^2), that's why after an iterative process the value of 300 is assigned to C_g.

In an attempt to keep the model as simple as possible, it has been assumed that the temperature of the wall of the receiver is the same as the temperature of the blast outlet. The optical limitations of the solar reflection must be included in the model; hence two additional parameters are considered in the model:

- Heliostat field optical efficiency (R_{opt}) = it takes into account the blocking (from the mirror to the tower), shadowing (form the sun to the mirror), the direct physical interception and the reflectivity of the heliostat. It also includes manufacturing and installation errors.
- Intercept factor (R_{int}) = ratio of solar radiation that reaches the heliostat and reaches the receiver.

$$R_{opt\ ref} = R_{int} \cdot R_{opt} \qquad \textbf{(Equation VII 24)}$$

The receiver is conceived as an object with the best possible absorbance, but nowadays any receiver has successfully reached the absorbance of a black body. In consequence, an absorbance of 0.91 will be assumed. On the other side, because of the high temperatures reached by the receiver the emittance must be considered as a source of energy losses.

Finally, in order to obtain the dimensions of the heliostat field an iterative process is implemented, where the following equations are solved in function of the area of the receiver (considered a square with a side of length L), until justifying the heat balance:

(Set of equations VII 1):

$$Q_{air} = m_{air} \cdot C_{p\,air} \cdot (T_{blast} - T_{amb})$$

$$S_{receiver} = L^2$$

$$S_{receiver} \cdot C_g = S_{heliostats}$$

$$Q_{input\,energy\,receiver} = \mathrm{R_{opt\,ref}} \cdot \mathrm{DNI} \cdot S_{heliostats}$$

$$Q_{absorbed\,receiver} = Abs \cdot Q_{input\,energy\,receiver}$$

$$Q_{loss\,receiver} = Abs \cdot \varepsilon_{receiver} \cdot Q_{input\,energy\,receiver} \cdot \sigma \cdot (T_{receiver}^4 - T_{amb}^4)$$

$$Q_{useful\,receiver} = Q_{absorbed\,receiver} - Q_{loss\,receiver}$$

Condition for the iteration: $\boldsymbol{Q_{useful\,receiver} - Q_{air} = 0}$

Using this method is possible to deduce the $S_{receiver}$ and the $S_{heliostats}$, the parameters that define the design of the Solar Central Tower system.

In order to evaluate the performance of the system in terms of yield the following parameters are determined:

Set of equations VII 2:

$$\eta_{receiver} = \frac{Q_{useful\,receiver}}{Q_{input\,energy\,receiver}}$$

$$\eta_{system} = \frac{Q_{useful\,receiver}}{\mathrm{DNI} \cdot S_{heliostats}}$$

$$\Phi_{solar} = DNI \cdot C_g / 10^6$$

The $\eta_{receiver}$ indicates the performance of the receiver, how much of the energy arriving at the equipment is effectively transmitted to the blast. On the other side, the η_{system} is only the ratio between how much energy arrives at the blast in function of the energy reflected by the heliostats. The difference between both yields is that the $\eta_{receiver}$ consider the energy lost because of the heliostats blocking the light reflected by other heliostats, the shadow effect, the cosine effect and the reflectivity of the mirrors, the availability of the heliostats, the atmospheric absorption and the aperture of the receiver.

It should be noticed that according to the definition of the yield of the receiver and the yield of the SCT system, the $\eta_{receiver}$ should always be superior to the η_{system}, as $\eta_{receiver} = \eta_{system}/R_{\text{opt ref}}$ and $R_{\text{opt ref}}$ is always less than 1. This fact is consistent with the interpretation of both parameters, as the η_{system} doesn't consider the fraction of the energy lost from the heliostat surface until the light radiation reaches the receiver.

Because the results obtained when removing the fuel supply look promising, the solar study analyses only the scenario where no fuel is included in the energy matrix. The discussion and presentation of the results are detailed in *Chapter VIII. 4*.

Chapter VIII. Final results

VIII 1. Preheating the blast

In this section, the influence of the preheating on the process will be assessed. The energy supply for the smelting flash furnace is provided by an equilibrium of three sources of energy:

-The fuel.

-The oxygen in the blast.

-The enthalpy of the blast.

The goal of preheating the blast would be to increase the enthalpy of the gas flow, sparing the fuel and the industrial oxygen as much as possible. The main problems with this strategy are that we also need energy in order to preheat the blast, and that when the temperature of the gas increases the volume of this gas will increase accordingly. The issue of the energy is solved by supplying solar thermal energy, but the expansion of the gases constitutes a design limitation which should be solved with further research for making the solar preheating fully profitable.

At a fixed concentrate feed mass (75 tons per hour) and fuel mass (10 kg in the following examples) the main parameters changing with the temperature of the blast are: the mass of air needed in the process, the amount of industrial oxygen used to enrich the blast, and the energy needed for the preheating. Another important factor on the simulations is that the matte grade is fixed in 60 mass-% of Cu.

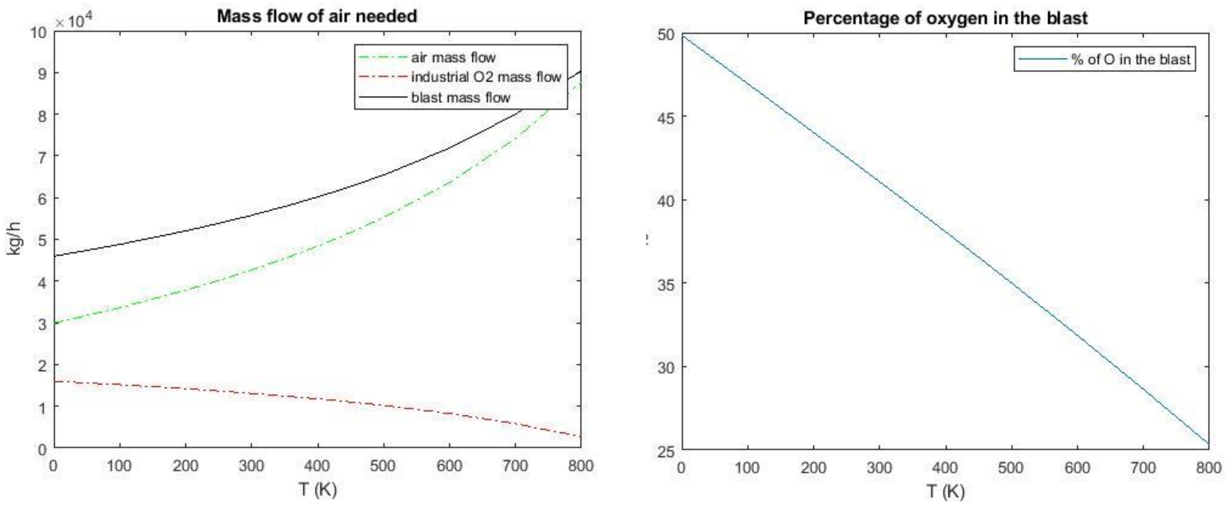


Figure VIII. 1: Evolution of the mass of air and the industrial oxygen needed to keep a steady state in the furnace depending on the temperature of the blast

As expected, increasing the temperature of the blast allows the system to work without additional industrial oxygen. However, the amount of air used in the process increases almost to the double of its value when going from 298 K to 600 K, and in consequence, the mass of the blast also increases. The main consequence of this fact is that, with a limited volume of the furnace, the bigger is the mass and volume of gases the lower will be fusion capacity of the smelter, hence the production of copper will be limited.

Logically, when the mass of air increases and the mass of industrial oxygen is reduced the composition of the blast decrease progressively until reaching the ambiance air composition (23 % mass content in O_2). Because of this, the mass of N_2 would considerably increase but, as the N_2 is considered to act as an inert gas, the influence of this fact is minor for the operation of the flash furnace.

The following figure shows the evolution of the required energy for the preheating in relation to the target temperature. This parameter has great importance for the design and operational mode of the central tower system detailed in *Sections VI 2 and VII 3*.

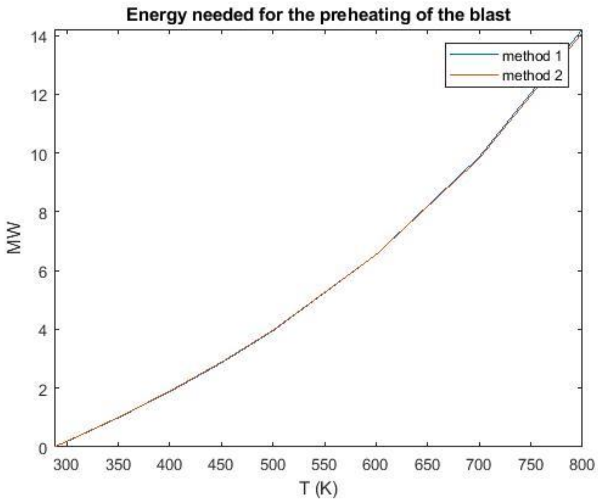


Figure VIII. 2: Energy needed in the preheating to reach a given temperature

Considering that the in-going gas is at ambiance temperature (298.15 K), the energy needed to eliminate the need for industrial oxygen for our system is of 14 MW. This amount of energy can be reached using solar thermal energy if the conditions are appropriate, but with the current technology, it wouldn't be possible to use exclusively solar energy for the full day. In the hours of low solar radiance, a complementary energy system should be included, else the system could work as in the conventional smelting. This idea will be further developed in *Sections VIII 2, VIII 4 and VIII 5.*

The *Table VIII. 1* shows the composition of the different mass flows involved in the copper smelting for a feed rate of 75 tons of concentrate par hour and 10 kg fuel/ton of concentrate. They show the requirements for a process where the oxygen reacts completely with the chalcopyrite.

Table VIII. 1: Composition smelting with fuel

T (K)	O_2 (kg/h)	N_2 (kg/h)	SiO_2 (kg/h)	Cu_2S (kg/h)	FeS (kg/h)
298.15	22902.00	32791.73	8725.27	32437.50	10812.50
500.00	22902.00	42522.41	8725.27	32437.50	10812.50
800.00	22902.00	67565.08	8725.27	32437.50	10812.50

T (K)	matte (kg/h)	FeO (kg/h)	SO_2 (kg/h)	CO_2 (kg/h)	H_2O (kg/h)
298.15	43250.00	20358.97	31740.00	2416.67	886.36
500.00	43250.00	20358.97	31740.00	2416.67	886.36

800.00	43250.00	20358.97	31740.00	2416.67	886.36

The *Table VIII. 1* shows that almost all the species are independent of the temperature (because the complete reaction with a fixed feed rate has several mass exigences in order to respect the mass balance equations). The exception is the nitrogen, which goes into the furnace as an inert gas, because the difference in the evolution of the enthalpy of the nitrogen serves for equilibrating the enthalpy balance. The mass of nitrogen increases proportionally with the mass of air mixed with the industrial oxygen, but the amount of oxygen needed is always the same, as it always takes the same amount of oxygen to completely oxidize the copper concentrate.

The following table shows the main results characterizing the smelting process:

Table VIII. 2: Results smelting with fuel

T (K)	blast (kg/h)	O_2 ind (kg/h)	V blast (Nm^3/h)
298.15	55694.00	13107.00	42247.00
500.00	65424.00	10201.00	50029.00
800.00	90477.00	2720.00	70055.00

T (K)	V off-gas (Nm^3/h)	% O_2	Q (MW)
298.15	39660.00	41.12	0.00
500.00	47441.00	36.55	3.98
800.00	67467.00	25.32	14.10

With an input of 10 kg fuel/ton of concentrate, the restriction of the boiler capacity is never respected. In consequence, the fuel input should be reduced in order to make the process respect the restrictions of the design. However, it's evident that using fuel to satisfy the energy needs of the process strongly increase the volume of the blast flow, hence if the solar thermal energy is used in the process the fuel supply should be reduced as much as possible.

An alternative approach to the characterization of the smelting process would consist of providing the boiler capacity (35000 Nm^3/h) as an imposition in the simulations, and then evaluating the maximum feed rate which would respect this condition. By this approach, it's possible to assess the maximum productivity of the flash furnace depending on the preheating of the blast.

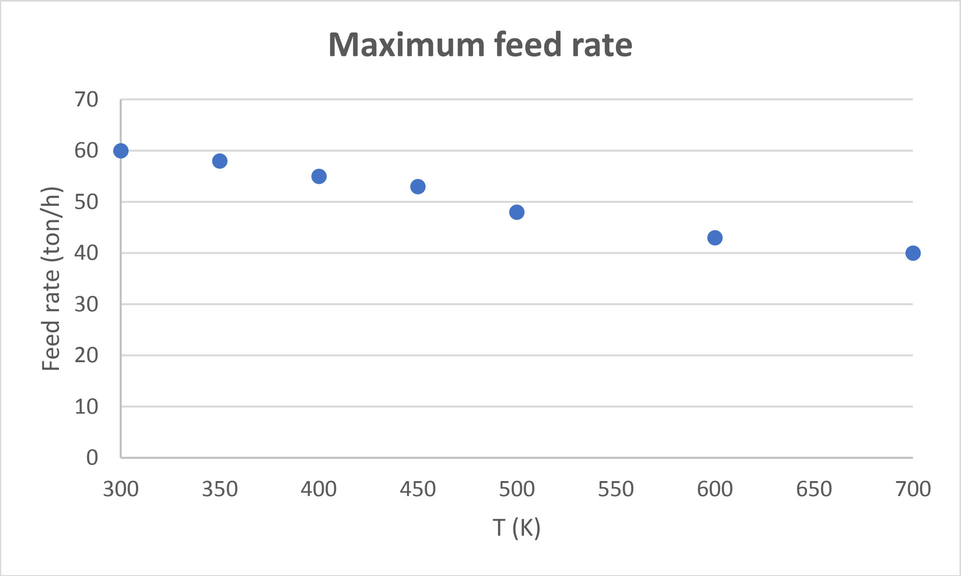


Figure VIII. 3: Maximum feed rate depending on the temperature

Keeping in mind that the complete removal of the industrial oxygen happens at 800 K, it should be noticed that the maximum feed rate decreases in more than the 30 % of the value without preheating the blast. This suggests a huge loss of profit (*Chapter XI*), in consequence, there should be further research in order to solve the problem of the volume of the gases. Anyway, preheating at lower temperatures is still an interesting possibility because of its potential in saving energy and resources.

VIII 2. Removing the fuel in the energy supply

For the following section, the possibility of completely avoiding the use of fossil fuel is analyzed. It should be noticed that without the combustion reaction no H_2O or CO_2 is produced in the smelting process.

As it was done in the previous section, the analysis is focused on the mass of air, the mass of industrial oxygen and the energy required for the preheating. All the input parameters, besides the fossil fuel input, remain unchanged on the following simulations.

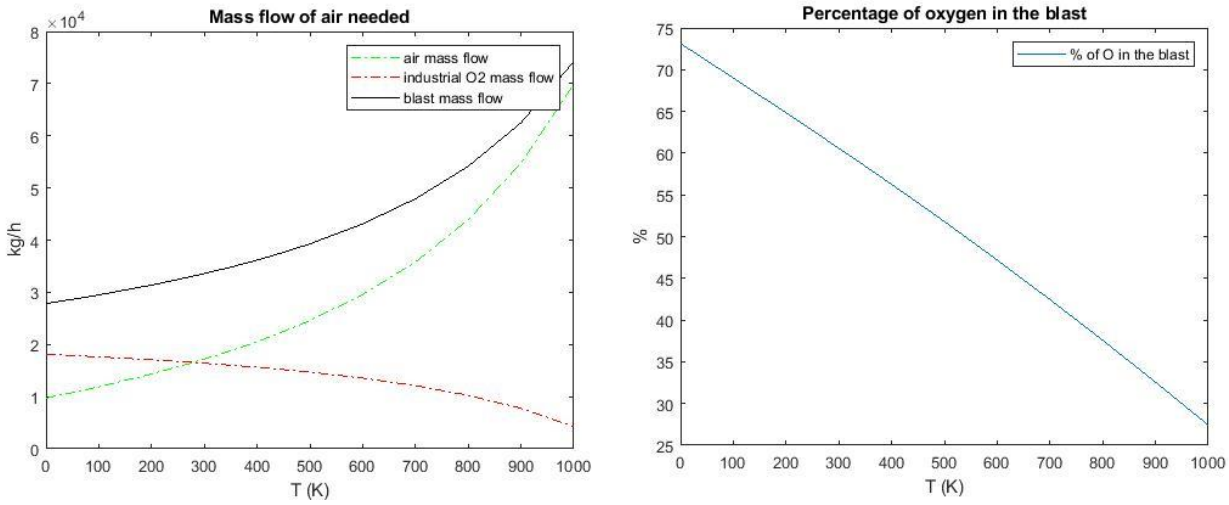


Figure VIII. 4: Evolution of the mass of air and the industrial needed to keep a steady state in the furnace depending on the temperature of the blast if no fuel is used for the process

The main difference when comparing with the previous operational mode is that much less mass of air is required, hence the volume of gas is greatly reduced at low temperatures (from 300 K to 700 K). However, because of the energy needs of the system, a higher temperature is needed for completely removing the industrial oxygen. This suggests that a mixed operational mode may be suitable for the correct operation of the furnace, at a temperature of 1000 K may expand the gas too much and threat the safety of the process.

It should be noticed that the removal of the fuel makes it necessary to reach higher temperatures in the preheating before being able to work without industrial oxygen supply. When there was a supply of 10 kg of fuel per ton of concentrate preheating the blast up to 800 K was enough, but in this scenario, the preheating should continue until reaching the 1000 K, which would be much more energy demanding.

Another consequence of the removal of fuel in the furnace is that the blast is greatly enriched in O_2 without increasing excessively the industrial oxygen total mass flow. This is beneficial for the process, as it allows a higher production (the concentrate can take the place left by the gases) while keeping a low consumption of industrial oxygen and even saving energy in the air collectors.

As shown in *Figure VIII. 5* the energy needed for the preheating of the blast is reduced for the lower temperatures, because the blast mass is reduced when removing the fossil fuel. However, if the industrial oxygen is removed completely the energy required for the preheating goes up to 16 MJ, an energy level that would increase the cost of the inversion needed in order to include the solar thermal energy in the process (*Section VI 2 and Budget*). This reinforces the idea that a half-way solution should be adopted, as preheating the blast just up to 600 K brings a reduction of 18 % of the mass of industrial oxygen required in the smelting process, and complete removal of the fossil fuel. This would mean a considerable save of resources without needing an excessive solar energy consummation (around 4 MW at 600 K).

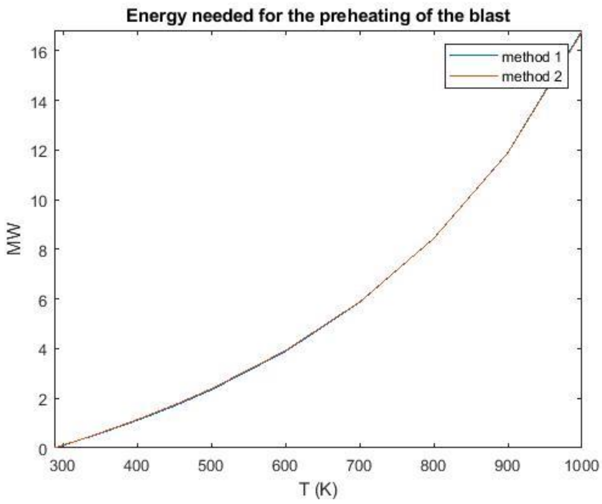


Figure VIII. 5: Energy needed in the preheating

As done in the previous section the *Table VIII. 3* shows the mass flows of main species involved in the smelting of sulfide concentrate.

Table VIII. 3: Composition smelting with fuel

T (K)	O_2 (kg/h)	N_2 (kg/h)	SiO_2 (kg/h)	Cu_2S (kg/h)
298.15	20348.97	13193.14	8725.27	32437.50
600.00	20348.97	22761.19	8725.27	32437.50
1000.00	20348.97	53874.86	8725.27	32437.50

T (K)	FeS (kg/h)	matte (kg/h)	FeO (kg/h)	SO_2 (kg/h)
298.15	10812.50	43250.00	8725.27	31740.00

600.00	10812.50	43250.00	8725.27	31740.00
1000.00	10812.50	43250.00	8725.27	31740.00

As supposed, there isn't any production of H_2O or CO_2 if the fuel supply is removed, as those are the products of the combustion. On the other hand, it can be observed how the flow of nitrogen is lower than in the fuel scenario, causing a reduction of the mass of air needed in the process.

Table VIII. 4: Results smelting with fuel

T (K)	blast (kg/h)	O_2 ind (kg/h)	V blast (Nm^3/h)
298.15	33542.00	16408.00	24789.00
600.00	43110.00	13550.00	32440.00
1000.00	74224.00	4256.00	57320.00

T (K)	V off-gas (Nm^3/h)	% O_2	Q (MW)
298.15	21655.00	60.67	0.00
600.00	29306.00	47.20	3.93
1000.00	54186.00	27.42	16.76

Over 600 K the volume of the blast surpasses the boiler capacity, hence the operative limit for the Charles Anglo American flash furnace would be a preheating of 3.93 MW. This can be considered the maximum profitability preheating up to 600 K, as it represents the maximum feed rate (in this case 75 ton/h) respecting the boiler capacity limitation.

An alternative approach would come from fixing the boiler capacity up the maximum value 35000 Nm3/h in order to check which would be the maximum feed rate possible. In the real industry, this would be the actual feed rate, as increasing the production of copper would bring the maximum economical benefice, even despite the major environmental impact.

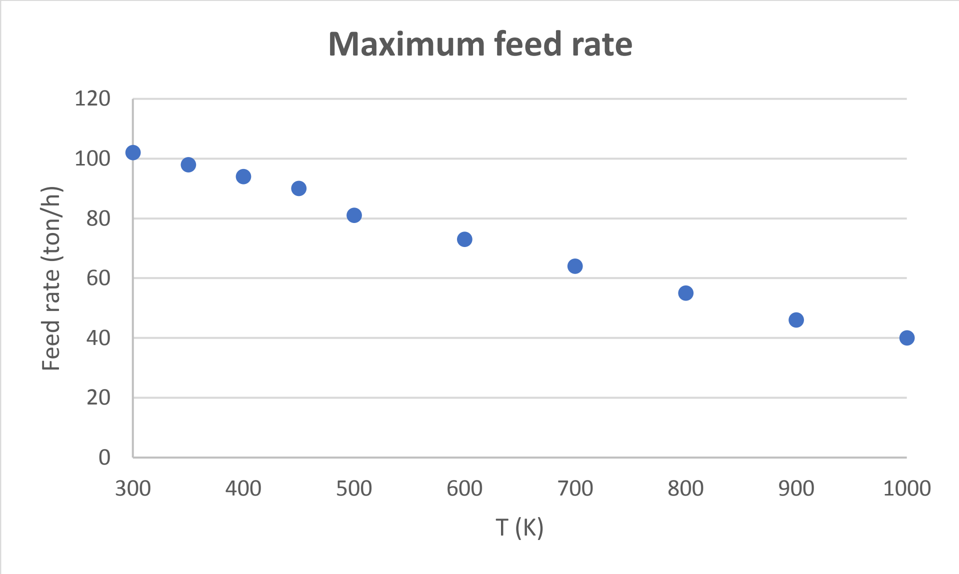


Figure VIII. 6: Maximum feed rate depending on the temperature

As in the previous case, the preheating reduces the maximum feed rate. Further research should be done in the sector of copper mining, in order to take advantage of the fuel and oxygen savings because of the preheating without losing productivity.

On the other side, the removal of the fuel enhances productivity in relation with the *Section VIII 1*. In other words, if the blast is enriched with enough O_2 it's possible to remove the fuel from the smelting process without preheating the blast, and in this case, the flash furnace would work at its maximum productivity.

VIII 3. Maximum capacity of the furnace

If the smelting process is taken in place without preheating and fuel supply the volume of the gases is brought to the minimum, allowing the maximum feed rate, and hence the maximum production of copper.

Table VIII. 5: Maximum copper production depending on the preheating of the blast (without fuel)

T (k)	Feed rate (ton/hour)	O_2 industrial (kg/h)	Annual processing capacity (tons $CuFeS_2$)	Annual production of Copper (tons)
1000	40	3316	350400	105120

900	46	5153	402960	120888
800	55	7519	481800	144540
700	64	10664	560640	168192
600	73	13550	639480	191844
500	81	15870	709560	212868
450	90	18626	788400	236520
400	94	19850	823440	247032
350	98	21075	858480	257544
300	102	22300	893520	268056

The *Table VIII. 5* shows how the production of copper increases with the employ of industrial O_2 and decreases with the preheating. Logically, this is the source of a great economical income, even if it comes with a major environmental impact.

Further research should deal with the decrease of the production caused by the preheating, so the SCT improvements in the smelting process can be economically competitive with the enrichment of the blast.

VIII 4. Treatment of the SO_2

As explained in the *Chapter III*, using the DESONOX process a recovery efficiency of 95 mass% can be assumed, and so the following results are up for the economic and environmental analysis in a no fuel scenario:

Table VIII. 6: In data if 95 mass% is assumed

T (K)	V off-gas (NM3/h)	% SO_2 in volume before → after treatment	SO_2 flow before →after treatment (ton/h)	H_2SO_4 (ton/h)
298.15	21655.00	51.28 → 2.56	31.74 → 1.59	30.15
600.00	29306.00	37.89 → 1.89	31.74 → 1.59	30.15
1000.00	54186.00	20.49 → 1	31.74 → 1.59	30.15

Considering that, if the oxidation of the concentrate is total, the SO_2 produced in the smelting process is only dependent of the feed rate, the SO_2 in the off-gas would constant and equal to 31740 kg/h if the feed rate is 75 tons/h. Therefore, if the recovery efficiency is considered constant, it's logical if the SO_2 stays also unchanged independently of the temperature.

As specified in *Chapter VII 2* the maximum SO_2 emissions allowed for the Chagres smelting facility is 14400 tons per year. When applying the DESONOX treatment the emissions go down to 1.59 tons per hour, 13902 tons per year, which means that the smelting operation would respect the environmental legislation.

One of the main interests in this process is the production of sulfuric acid, a chemical product which is valorized later on *Chapter XI.* In the scenario presented in this work, the production would be 30.15 tons/h, 264114 tons per year, representing a source of incomes valorized on $66,028,500.00 per year.

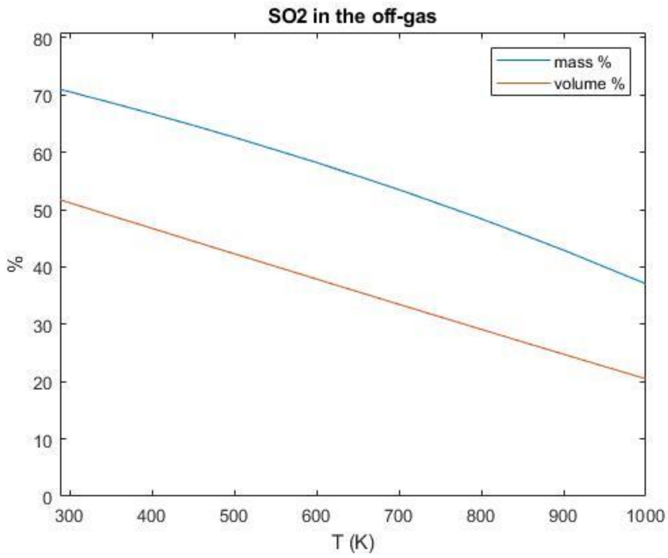


Figure VIII. 7: Evolution of the composition in the off-gas

The *Figure VIII. 7* shows the dilution of the SO_2 because of the preheating. According to the data of *Table VIII. 5* preheating just up to 600 K would decrease the content of SO_2 down to 1.89 vol-%, diminishing the environmental impact.

VIII 5. Solar thermal energy

In this section, the performance and main parameters of the SCT system are assessed by means of the equations detailed in *Chapter VII 4*. As explained in the previous sections, the optimum operational point for the improved smelting system would be in an intermediate preheating point, considered through this work to be around 600 K. However, in this section it's also considered the scenario of the SCT system designed for an expected blast preheating of 800 K, in order to facilitate the understanding of the operation.

Table VIII. 7: Design parameters

T (K)	$S_{heliostats}$ (m^2)	$S_{receiver}$ (m^2)	Work hours
600	10201	34	11 to 17
800	24226	80.75	11 to 17

T (K)	$\eta_{receiver}$	η_{system}	Q_{useful} (MW)
600	0.86	0.5	4
800	0.77	0.44	8.5

The SCT system is designed in function of the expected Q_{useful}, which depends directly on the mass flow of the blast and the temperature of the preheating. The more energy per unit of time is needed, the bigger the heliostat field should be. This is evident when comparing the ratio between the Q_{useful} and the $S_{heliostats}$:

- If $T_{preheating} = 600\ K \rightarrow R_{600} = \frac{S_{heliostats}}{Q_{useful}} = 2550.25 \frac{m^2}{MW}$
- If $T_{preheating} = 800\ K \rightarrow R_{800} = \frac{S_{heliostats}}{Q_{useful}} = 2850.118\ \frac{m^2}{MW}$

The ratios are numerically close, as the ratio between the surface of the field and the useful heat received is always around 2500 $\frac{m^2}{MW}$. In fact, the difference between the ratios is reflected in the yield of the system and the yield of the receiver:

- $\frac{R_{600}}{R_{800}} = 0.89$
- $\frac{\eta_{system,800}}{\eta_{system,600}} = 0.88$
- $\frac{\eta_{receiver,800}}{\eta_{receiver,600}} = 0.89$

All these relations show that when increasing the energy that the system is expected to supply the surface of the mirrors increases consequently, and so does the heat losses of the system, producing a fall on the receiver and system yield of the installation.

Once the design of the heliostat field is established, a set of calculations is used to analyze the performance of the Central Tower System depending on the hour of the day.

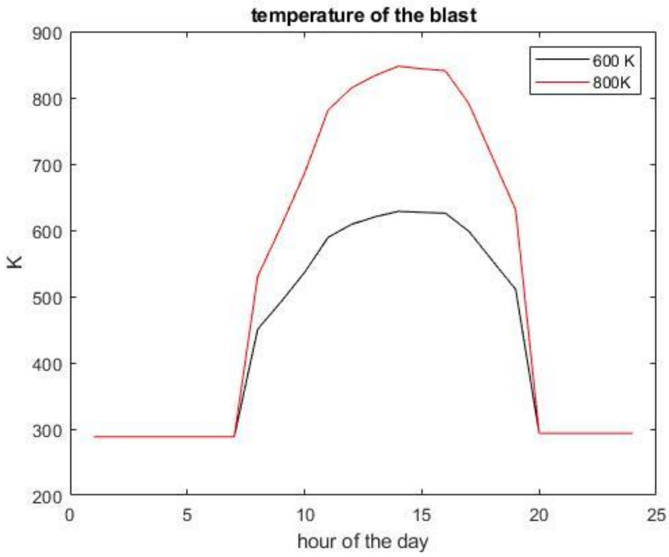


Figure VIII. 8: Temperature of the blast

The *Figure VIII. 8* shows how the temperature of the blast variates depending on the hour of the day. The SCT system is designed with the idea of providing as much energy as the blast needs for reaching the expected temperature, but without wasting energy. This means that during the hours of major solar irradiance the blast reaches the desired temperature, but when the DRI is under 550 W/m^2 the system doesn't produce enough energy and an alternative operational mode should take place in the flash furnace.

By this method, the flash furnace would be able to work with an effective preheating an average of 6 hours per day. The alternative would be using a storage system, in which case the heliostat would be over-dimensioned, producing more thermal energy than the blast needs to reach the target temperature, and the surplus energy would be stored and used during the hours of low solar irradiance.

It's possible, when comparing with the *Figure VII. 8*, to see that the DRI and the temperature of the blast follow the same path, as the source of the energy used for preheating the blast is the solar irradiance.

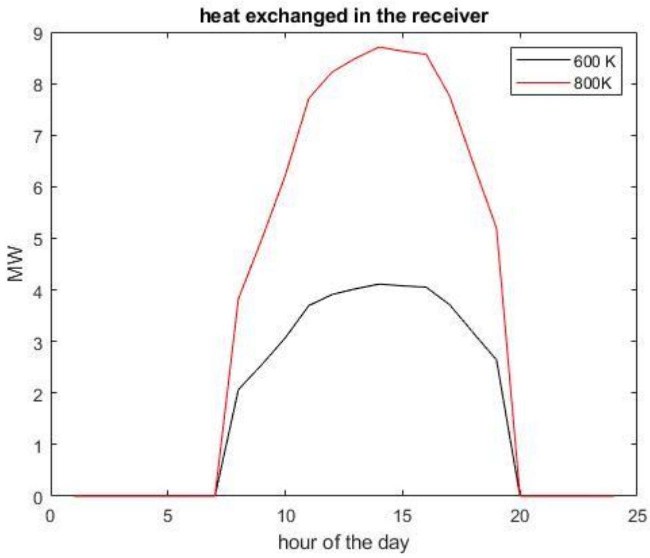


Figure VIII. 9: Energy received

The energy produced by the SCT system in the working hours corresponds to the energy needed to preheat the air in the blast, 3.93 MW for reaching the 600 K and 8.5 MW for reaching the 800 K. To illustrate the case where a storage system was included, the heliostat field would be over-dimensioned so the energy curve corresponding to the 800 K preheating would be applied for a 600 K preheating. The difference of energy between the two curves would correspond to the energy stored (minus heat losses), and it would be the available energy during the low irradiance hours, making it possible to work in blast preheating conditions permanently.

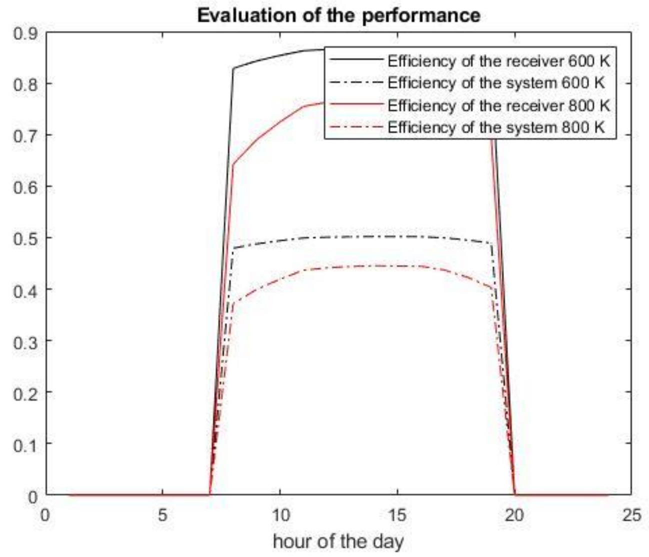


Figure VIII. 10: Evaluation of the performance

As commented previously the Figure VIII. 10 shows clearly how the yield decreases when enlarging the heliostat field. Therefore, it could be said that the preheating at lower temperatures allows better energy efficiency.

VIII 6. Final conclusions

The industry and business of copper involve great amounts of money, and enhancing the smelting process could bring millions of dollars to the smelting companies. Another factor to consider is the reduction of the environmental impact, which according to the studies in *Chapter XII* could be done by removing the fuel supply and reducing the consummation of industrial oxygen. In this work the preheating of the blast has been discussed, being the main conclusions:

About the optimal operational mode for the Outokumpu Flash Furnace, it could be said that it depends mainly of the composition on the concentrate and the targeted grade of the matte. However, generally, the optimal working temperature is around 1250 ºC, depending on the melting point of the slag. If the goal is increasing the production the best solution is enriching the blast in order to take full profit of the heat produced by the oxidation reactions, reducing the fuel supply and avoiding the preheating. On the other hand, if a constant feed rate is fixed, the blast should be preheated as much as possible without going over the boiler capacity, enhancing the smelting process by reducing the fuel and industrial oxygen consummation.

Although in this work a simplified model was considered for the understanding of the Outokumpu Flash Furnace, an extended study should be done for every smelting system intending to use the SCT for the enhancement of the process. This study should consider the real composition of the concentrate (not only chalcopyrite but also pyrite, iron…), the design of the furnace, the composition of the blast, the optimal temperature for the furnace, and a more realistic approach for the set of reactions inside the reaction shaft.

Another field of great importance for enhancing the smelting process and the SCT system is a full study of the pressure loss in the conductions, the speed and mass flow of the gas going through the pipes, and the influence of the high temperatures on the conductions.

If the dust from the off-going gases was pulled apart from the gases without cooling down the gas stream, it would be possible to take profit of the heat for drying the concentrate or preheating the blast. This would mean enhancing the electrostatic precipitators so they can work at high temperatures, and creating a continues process to collect the dust without interrupting the gas flow.

Regarding the SCT system, there are still many aspects that should be considered in the design of the heliostat field and the receiving tower. The position and distribution of the heliostats need further consideration, adapting the system to the location of the copper refinery, and the tracking system should be adapted to the local sun path. Also, the performance of the heliostat field can be improved by increasing the reflective surface per mirrors (the 9 m^2 per mirror considered in this work is among the smaller designs in the market).

As for the receiver of the tower, it should be composed by a material with high heat capacity, able to pass on the thermal energy received to the air. It should be located inside a cavity, reducing the convection and radiation losses.

An important matter not developed in this work is the storage for the SCT system. Designing an effective storage system would allow the furnace to work permanently in favorable conditions. This subject also opens some interesting possibilities for the potential of the solar thermal energy in the copper industry, as would be using the copper concentrate as a substitute of the molten salts for the storage of thermal energy.

The planning for the creation of the SCT system and its adaptation to the furnace would need more attention, in this work only a general assessment is included. It should be considered the local geography, the price of the delivery for the materials and the possible incontinences.

Summarizing, for the future of the flash smelting resides in the enhancing of the smelting furnace, the research should be focused on reducing the volume of gases inside the furnace and taking full profit of the blast preheating. Other interesting improvements would involve the off-gas collection, the SO_2 treatment and the exploitation of the heat from the off-going gases. The Figure VIII. 12 illustrates the main ideas and elements of this project:

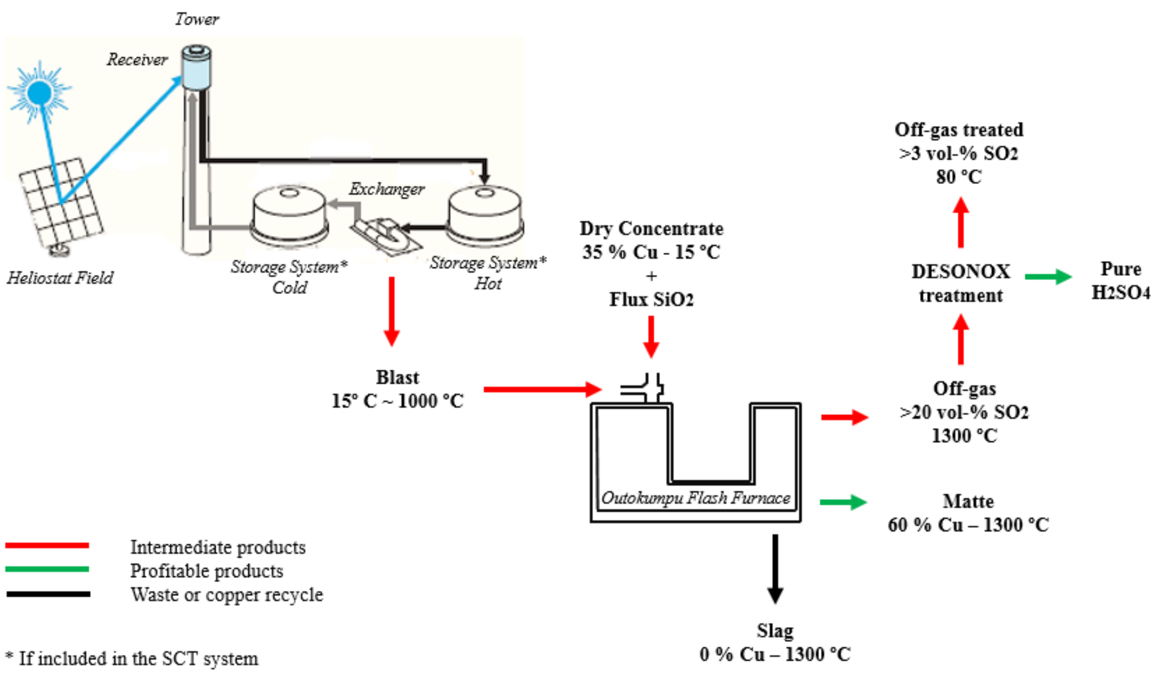


Figure VIII. 11: Scheme of the project.

Chapter IX. Planning

In this chapter, it's discussed the planning for the construction and installation of the SCT system, as well as the adaptation of the conventional smelting system. The distribution of the time is made taking into account that heliostat field and the tower are generally considered different projects.

The site improving for the 10201 m^2 is quite simple, it only consists in flattening the field and measuring the distances between the heliostats. The next stage would be preparing the civil work for the installation of the mirrors, but because of the big extension of the field, it's possible to start setting up the structures on the already flattened field while the site improving continues taking place. With the same idea, once the structure for the heliostat is ready the mechanical structure that will hold the mirror is installed.

As for the tower, it consists of building a complex civil work, it would take at least one year and it would include the civil work, the paving and the construction of the whole structure. It's by far the more complex part of the civil work for the creation of the SCT system.

The setting of the mirrors is done once the tower civil work and the heliostat field are finished, because it involves working with very fragile and expensive materials, and it demands caution. Meanwhile, it can be installed the receiver of the tower, which would take a short period of time as the receiver is already designed at command by an external specialized company.

Finally, the rest of the connecting work, the installation of the electric and control system, and the testing and commissioning should take around 180 days in total.

Using the *Table IX. 1* a Gantt chart is joined in *Figure IX. 1* in order to clarify the planning of the overall project.

Table IX. 1: Planning of the SCT construction

Task	Starting date	Duration (days)	End date
Site improving	01/10/2019	61	01/12/2019
Heliostat civil work	01/11/2019	120	01/03/2020
Tower civil work	01/10/2019	365	01/10/2020
Heliostat mechanical structure	01/12/2019	121	01/04/2019
Heliostat mirror	01/10/2020	90	01/01/2021
Installation receiver	01/10/2020	30	01/11/2020
Connecting equipment	01/01/2021	30	01/02/2021
Electric and control system	01/02/2021	90	01/05/2021
Testing and commissioning	01/05/2021	60	01/07/2021
Total time for the project	639 days or around 21 months		

As shown in *Table IX. 1* the total time for the project would be around 21 months, hence if it's started in October 2019 it would be finished by July 2021.

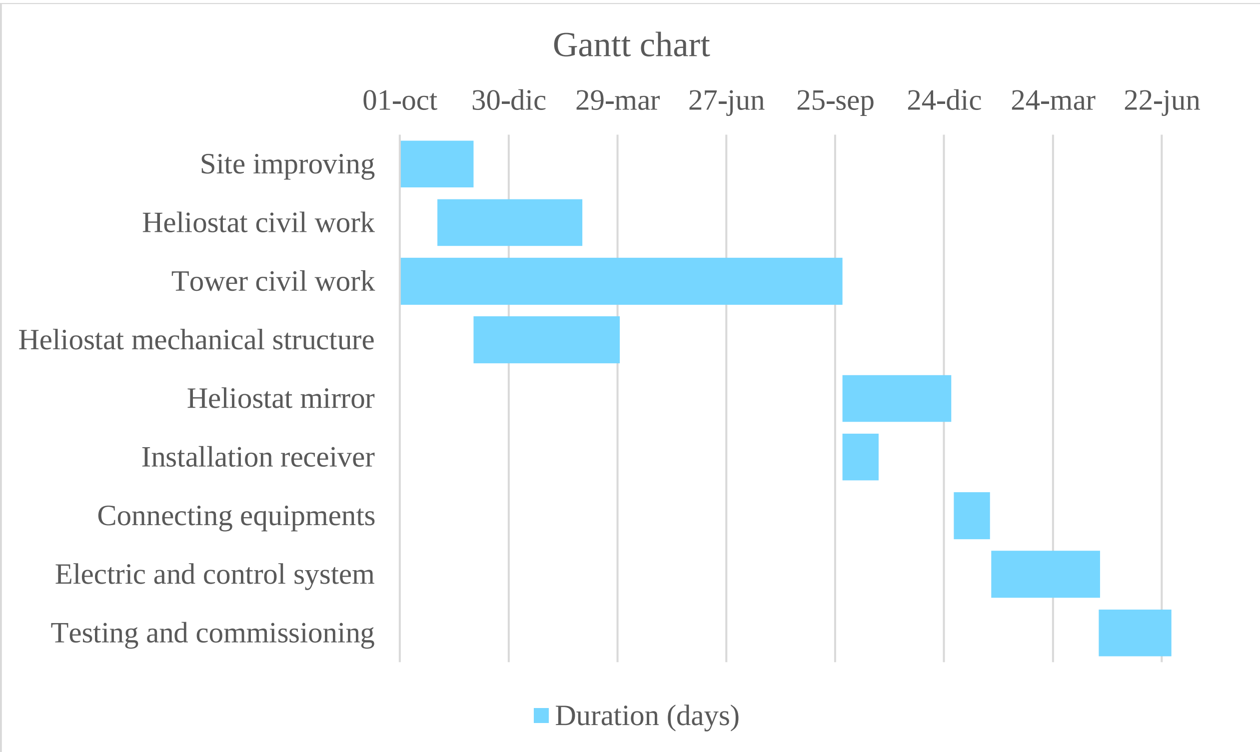


Figure IX. 1: Gantt chart

Chapter X. Priority order within the documents

According to the norm UNE 157001-2014, “Criterios generales para la elaboración de los documentos que constituyen un proyecto técnico”, the priority order within the documents is:

1. General Index
2. Main Text
3. Appendix
4. Technical drawings
5. Conditions statement
6. Measurements
7. Budget

Chapter XI. Economic profitability

In this chapter the conventional and improved smelting process are analyzed, collecting the corresponding economic information and determining if the project is economically acceptable or not. This decision is made by means of several economic indicators that give an idea of the rentability of the project. The economic indicators considered in this work are:

- Present Value of the Annuity (PVA): it's an indicator of the profitability of the process. For the project to be profitable the PVA must be over 0.
- Internal Rate of Return (IRR): the idea of this indicator is calculating the interest of the process if the PVA was equal to 0.
- Return Term (RT): it estimates the time necessary for recovering the initial investment.

In order to be able to estimate the mentioned indicators first the following economic factors should be determined:

- Exploitation Budget: it reflects the cost of the activity, how much it costs running the copper production.
- Profit: it estimates the economic benefice produced by the overall process.
- Cash flow: it represents the liquidity of the company.

Regarding the variation on the currency's value the following equation must be considered:

$$\boldsymbol{value = value_{year\,0} \cdot (1 + CPI)^{year-1}}$$ **(Equation XI 1)**

CPI = Consumer Price Index = 2.5%

i_n = nominal interest = 4%

i_r = real interest = i_n/IPC = 1.6%

Now that the *Equation XI I* stablish the fluctuation on the currency's value, the first step in the economic assessment is calculating the total budget for the overall copper production, either in the conventional mode or with the implementation of the SCT system. Details in the *Budget* section:

Table XI. 1: Comparison overall BEI

	SCT system ($)	Conventional copper production ($)	Improved copper production ($)
Equipment	$2,053,316.00	$5,490,000,000.00	$5,487,416,588.67
Conductions	$18,827.20		
Aggregates	$1200		
Civil engineering	$2,093,736.96		
Overall BEI	**$4,167,080.16**	**$5,490,000,000.00**	**$5,487,416,588.67**

Table XI. 2: Comparison Contractor's Cost

	Cost SCT ($)	Cost conventional copper mining ($)	Cost improved copper mining ($)
Budget execution and implementation (BEI)	$4,167,080.16	$5,490,000,000.00	$5,487,416,588.67
General cost	$541,720.42	$713,700,000.00	$713,364,156.53
Industrial benefit	$250,024.81	$329,400,000.00	$329,244,995.32
Contractor's cost (CC)	$4,958,825.39	$6,533,100,000.00	$6,530,025,740.51

Table XI. 3: Comparison Total Budget

	Cost SCT ($)	Cost conventional copper mining ($)	Cost improved copper mining ($)
Contractor's cost (CC)	$4,958,825.39	$6,533,100,000.00	$6,530,025,740.51
IVA (21%)	$250,024.81	$1,371,951,000.00	$1,371,305,405.51
TOTAL BUDGET	$6,000,178.72	$7,905,051,000.00	$7,901,331,146.02

Table XI. 4: Summarizing of budget factors for the maximum production scenario

	Cost copper mining with maximum production ($)
BEI	$8,041,680,000.00
General Cost	$1,045,418,400.00
Industrial benefit	$482,500,800.00
Contractor's cost (CC)	$9,569,599,200.00

IVA (21%)	$2,009,615,832.00
TOTAL BUDGET	$11,579,215,032.00

Comments on the *Budget* section.

XI 1. Exploitation Budget

It represents the total annual expenses of the activity. It's composed by:

- Direct expenses: dependent on production.
- Indirect expenses: independent of the production, fixed expenses.

In this section, a comparative study between the conventional copper mining and the improved system is developed, under the hypothesis of a constant feed rate of 75 ton of concentrate per hour in both cases. Nevertheless, an economic study of the maximum production scenario is also developed independently of the previous comparison, providing the main economic factors for the process with a feed rate of 100 ton/h, but without going in detail with the economic assessment.

XI 1.1. Direct expenses

The direct expenses stand for the expenses depending directly from the production. This means that increasing the production would increase the direct expenses, and contrariwise.

The direct expenses are divided in:

- Cost of the production.
- Cost of the materials.

1.1.1. Cost of the production

The operation of the copper production for one year has the following production expenses:

Table XI. 5: Comparison cost of the production

Element	Quantity	Price	Cost conventional ($/year)	Cost SCT included ($/year)
Open-mining	183000	500 $/ton Cu	$305,000,000.00	$305,000,000.00

Concentrator	183000	1000 $/ton Cu	$610,000,000.00	$610,000,000.00
Concentrate reception and storage	610000	5 $/ton concentrate	$3,050,000.00	$3,050,000.00
Flash smelting operation*	610000	20 $/ton concentrate	$12,200,000.00	$12,200,000.00
Flash converting	610000	20 $/ton concentrate	$12,200,000.00	$12,200,000.00
Production of industrial oxygen**	610000	14 $/ton concentrate	$8,540,000.00	$8,093,484.46
Production of sulfuric acid	610000	10 $/ton concentrate	$6,100,000.00	$6,100,000.00
Cu recovery from smelting slag	610000	15 $/ton concentrate	$9,150,000.00	$9,150,000.00
Copper refining (anode-making)	610000	5 $/ton concentrate	$3,050,000.00	$3,050,000.00
Producing electro-refined cathode plates	183000	120 $/ton Cu	$21,960,000.00	$21,960,000.00
TOTAL production cost			**$991,250,000.00**	**$990,803,484.46**

*Concentrate drying, gas handling, and delivery of matte to flash converting.

**The industrial oxygen is directly produced in the plant, that's why the cost of the product is included as production cost.

The energetic expenses, residual treatment and waste management for every operation are included in the costs value.

The difference in the total production cost between the conventional and the improved smelting process comes from the oxygen plant, because the production of oxygen is reduced.

1.1.2. Materials

This section evaluates the cost of the materials needed in the smelting process:

Table XI. 6: Materials cost conventional smelting

Element	Quantity	Price	Cost conventional ($/year)
Industrial* oxygen	143751.6	59.41 $/ton O2 ind	$8,540,000.00
Hydrocarbon fuel	6570	1485.54 $/ton fuel	$9,760,000.00
Flux and refractories	76433.41	63.85 $/ton flux	$4,880,000.00
Maintenance supplies	610000	12 $/ton concentrate	$7,320,000.00
TOTAL products cost			**$30,500,000.00**

Table XI. 7: materials cost smelting with SCT system

Element	Quantity	Price	Cost SCT included ($/year)
Industrial* oxygen	118698	59.41 $/ton O2 ind	$8,093,484.46
Hydrocarbon fuel	4599	1485.54 $/ton fuel	$6,832,000.00
Flux and refractories	76433.41	63.85 $/ton flux	$4,880,000.00
Maintenance supplies	610000	12 $/ton concentrate	$7,320,000.00
TOTAL products cost			**$27,125,484.46**

*The cost of the oxygen is already included in the production cost, hence the TOTAL product cost effective for the study is $21,960,000.00 for the conventional system and $19,032,000.00 for the smelting with solar thermal energy scenario.

In this section it can be noticed the economic importance of saving the cost of the fuel, as $3,374,515.54 are saved from one process to the other.

Table XI. 8: Comparison total direct cost

	Cost conventional ($/year)	Cost SCT included ($/year)
Production cost	$991,250,000.00	$990,803,484.46
Materials	$21,960,000.00	$19,032,000.00
TOTAL DIRECT	$1,013,210,000.00	$1,009,835,484.46

The Table XI. 8 summarizes the total direct cost for the copper production. The expenses involved in the copper business are exceptionally high, but as it's shown later in the *Profit* section all the losses are matched, making the copper production a quite profitable business.

XI 1.2. Indirect expenses

They represent the costs not dependent of the production. The indirect expenses are divided in:

- Manpower and overhead expenses.
- Amortization.

1.2.1. Manpower and overhead expenses

Table XI. 9: Manpower and overhead expenses

Element	Quantity	Price ($/year)	Cost ($/year)
Operating and maintenance*	990 workers	$19,980.00	$19,780,200.00
Local services and overhead**	610000 tons	100 $/ton Cu	$18,300,000.00

TOTAL		**$38,080,200.00**

*Manpower including surveillance

**Accounting, clerical, environmental, laboratory, management, property taxes, safety, illumination and other expenses, cleaning.

1.2.2. Amortization

The amortization is an element of the economic balance associated with the losses of value of the equipment and the facilities. They are considered indirect expenses. The formula for the calculation of the amortizations consists in dividing the initial investment by the useful years of the facilities:

$$A = \frac{I_o}{useful\ life} \qquad \textbf{(Equation XI 2)}$$

Table XI. 10: Amortization

	Conventional copper mining ($/year)	SCT ($/year)	Improved copper mining ($/year)
Initial Investment (I_o)	$7,905,051,000.00	$6,000,178.72	$7,901,331,146.02
Useful life	30 years	25 years	30 years
PARTIAL amortization	$263,501,700.00	$240,007.15	$263,377,704.87
TOTAL amortization	$263,501,700.00	$263,617,712.02	

The improved copper mining system is composed by the conventional mining equipment plus the SCT components, hence the amortization value has to consider both elements.

1.2.3. Total indirect expenses

Table XI. 11: Total indirect expenses

	Cost conventional ($/year)	Cost SCT included ($/year)
Manpower and overhead	$38,080,200.00	$38,080,200.00
Amortization	$263,501,700.00	$263,617,712.02
TOTAL INDIRECT	$301,581,900.00	$301,697,912.02

The indirect expenses have a similar value in both scenarios.

XI 1.3. Total expenses

Representing the total operation costs of the facilities, the total expenses are the addition of the direct plus the indirect expenses.

Table XI. 12: Comparison total expenses

	Cost conventional ($/year)	Cost SCT included ($/year)
Direct expenses	$1,013,210,000.00	$1,009,835,484.46
Indirect expenses	$301,581,900.00	$301,697,912.02
TOTAL EXPENSES	$1,314,791,900.00	$1,311,533,396.48

In the comparison between the two systems, is remarkable the savings achieved by the SCT system, with a reduction of $3,258,503.52 per year in the costs of the process.

Table XI. 13: Total expenses maximum copper production

	Cost conventional max production ($/year)
Direct expenses	$1,484,136,720.00
Indirect expenses	$432,559,634.40
TOTAL EXPENSES	$1,916,696,354.40

The total expenses for the maximum copper production are significantly higher than for a production of 75 ton per year, mainly because of the direct expenses. The indirect expenses are also higher because of the amortizations and the local overhead, but the costs directly related with the production increase 33% compared to the previous scenario.

XI 2. Profit

The economic benefice of a company can be divided in two types:

- Gross profit: incomes of the company minus the total expenses, without including taxes.
- Net profit: profit of the company once the corporation tax (25%) is discounted.

The incomes from copper mining industry come from the sales of refined copper and sulfuric acid.

Table XI. 14: Incomes

Element	Price*	Quantity	In-flow ($)
sulfuric acid	250 $/ton H_2SO_4	264114	$66,028,500.00
refined copper	7000 $/ ton Cu	183000	$1,281,000,000.00
TOTAL incomes			**$1,347,028,500.00**

*The price of the sulfuric acid in this work is the standard price for the USA in the current market, the price of the refined copper goes from 5.5 $/kg Cu to 9 $/kg Cu in the actual industry, so 7 $/kg Cu has been the chosen as reference.

Table XI. 15: Incomes máximum production

Element	Price*	Quantity	In-flow ($)
sulfuric acid	250 $/ton H_2SO_4	352187.04	$88,046,760.00
refined copper	7000 $/ ton Cu	268056	$1,876,392,000.00
TOTAL incomes			**$1,964,438,760.00**

The difference between the incomes of the maximum and the standard production is the main weakness of the solar preheating, as the plus $617,410,260 earned in the maximum production scenario versus the $3,258,503 saved with the SCT system makes the solar preheating non-profitable.

XI 2.1. Gross profit

In the estimation of the gross profit, it should be considered the increase of the currency's value using the *Equation XI 1*. The gross profit in the first 15 years of production would be calculated as:

Table XI. 16: Gross profit over 15 years

year	Cost conventional process ($/year)	Cost SCT ($/year)	Incomes ($/year)	Gross profit conv ($/year)	Gross profit SCT ($/year)

1	$1,314,791,900	$1,311,533,396	$1,347,028,500	$32,236,600	$35,495,104
2	$1,347,661,698	$1,344,321,731	$1,380,704,213	$33,042,515	$36,382,481
3	$1,381,353,240	$1,377,929,775	$1,415,221,818	$33,868,578	$37,292,043
4	$1,415,887,071	$1,412,378,019	$1,450,602,363	$34,715,292	$38,224,344
5	$1,451,284,248	$1,447,687,470	$1,486,867,422	$35,583,175	$39,179,953
6	$1,487,566,354	$1,483,879,656	$1,524,039,108	$36,472,754	$40,159,452
7	$1,524,755,513	$1,520,976,648	$1,562,140,086	$37,384,573	$41,163,438
8	$1,562,874,401	$1,559,001,064	$1,601,193,588	$38,319,187	$42,192,524
9	$1,601,946,261	$1,597,976,090	$1,641,223,427	$39,277,167	$43,247,337
10	$1,641,994,917	$1,637,925,493	$1,682,254,013	$40,259,096	$44,328,520
11	$1,683,044,790	$1,678,873,630	$1,724,310,363	$41,265,573	$45,436,733
12	$1,725,120,910	$1,720,845,471	$1,767,418,123	$42,297,213	$46,572,652
13	$1,768,248,933	$1,763,866,608	$1,811,603,576	$43,354,643	$47,736,968
14	$1,812,455,156	$1,807,963,273	$1,856,893,665	$44,438,509	$48,930,392
15	$1,857,766,535	$1,853,162,355	$1,903,316,007	$45,549,472	$50,153,652

XI 2.2. Net profit

Stands for the profit of the company once the 25% of the corporation tax is subtracted.

Table XI. 17: Net profit over 15 years

year	Net profit conventional process ($/year)	Net profit SCT ($/year)	Improved profit ($/year)
1	$24,177,450	$26,621,328	$2,443,878
2	$24,781,886	$27,286,861	$2,504,975
3	$25,401,433	$27,969,032	$2,567,599
4	$26,036,469	$28,668,258	$2,631,789
5	$26,687,381	$29,384,965	$2,697,584
6	$27,354,565	$30,119,589	$2,765,023
7	$28,038,430	$30,872,578	$2,834,149
8	$28,739,390	$31,644,393	$2,905,003

9	$29,457,875	$32,435,503	$2,977,628
10	$30,194,322	$33,246,390	$3,052,068
11	$30,949,180	$34,077,550	$3,128,370
12	$31,722,910	$34,929,489	$3,206,579
13	$32,515,982	$35,802,726	$3,286,744
14	$33,328,882	$36,697,794	$3,368,912
15	$34,162,104	$37,615,239	$3,453,135

The net profit constitutes the real value earned by the company, and with a profit over $24,000,000 the copper mining is an activity highly profitable. With the standard production, the solar energy produces an improved profit of more than $2,000,000 since the first year.

XI 3. Cash flow

The cash flow represents the liquidity of a company, the incomes and outputs of money. It's the result of adding the amortizations to the net profit:

Table XI. 18: Cash flow over 15 years

year	Amortization conventional ($/year)	Amortization SCT ($/year)	Cash flow conventional process ($/year)	Cash flow SCT ($/year)
1	$263,501,700	$263,617,712	$287,679,150	$290,239,040
2	$270,089,243	$270,208,155	$294,871,129	$297,495,016
3	$276,841,474	$276,963,359	$302,242,907	$304,932,391
4	$283,762,510	$283,887,443	$309,798,980	$312,555,701
5	$290,856,573	$290,984,629	$317,543,954	$320,369,593
6	$298,127,987	$298,259,244	$325,482,553	$328,378,833
7	$305,581,187	$305,715,726	$333,619,617	$336,588,304
8	$313,220,717	$313,358,619	$341,960,107	$345,003,012
9	$321,051,235	$321,192,584	$350,509,110	$353,628,087
10	$329,077,516	$329,222,399	$359,271,838	$362,468,789
11	$337,304,454	$337,452,959	$368,253,634	$371,530,509

12	$345,737,065	$345,889,283	$377,459,974	$380,818,772
13	$354,380,491	$354,536,515	$386,896,474	$390,339,241
14	$363,240,004	$363,399,928	$396,568,886	$400,097,722
15	$372,321,004	$372,484,926	$406,483,108	$410,100,165

The Anglo American company, owner of the Chagres Smelter would dispose of enough liquidity to afford the implementation of the project if the productivity issue was solved, as the initial investment corresponds to the total budget for the Solar Central Tower system ($6,000,178.72).

Completing the economic study for the maximum production scenario, the *Table XI. 19* provide the main economic factors considered in this work:

Table XI. 19: summarizing of economic factors for the maximum production scenario

Cost conventional process ($/year)	Incomes ($/year)	Gross profit conv ($/year)	Net profit conventional process ($/year)	Cash flow conventional process ($/year)
$1,916,696,354.40	**$1,964,438,760.00**	$47,742,406	$35,806,804	$421,780,639

XI 4. Present Value of Annuity (PVA)

It's an indicator of the profitability of the project. Depending on the result it's possible to estimate if the project is economically worth, being the three possible scenarios:

i. PVA < 0: project no profitable during the period considered.
ii. PVA = 0: the project doesn't generate neither profits or losses.
iii. PVA > 0: project profitable during the period considered.

The formula used to calculate the PVA involves the initial investment, the annual cash flow and the real interest during *n* years:

$$\boldsymbol{PVA = -I_o + \sum_{n=1}^{n=10} \frac{CF}{(1+i_r)^n}}$$ **(Equation XI 3)**

Because the goal of this study is the solar energy integration, for this section only the investment corresponding to the integration of the SCT into the copper mining process is assessed. Therefore, the initial investment corresponds to the total budget for the Solar Central Tower system ($6,000,178.72). Regarding the flash flow, as long as the benefice of solar energy integration is reflected as a saving in the cost of the project, *Equation XI 3* should be adapted to the following:

$$\boldsymbol{PVA = -I_o + \sum_{n=1}^{n=10} \frac{CF_{SCT} - CF_{conventional}}{(1+i_r)^n}} \qquad \textbf{(Equation XI 4)}$$

For a period of ten years, the resulting PVA is $20,224,041.08, showing the huge profitability of the project. However, it should be considered that the preheating on the blast would suppose a reduction of the production because of the increase on the blast volume.

XI 5. Internal rate of return (IRR)

It shows the profitability of the investment using the same principle than the PVA, but turning the Equation XI 3 the other way around. For the IRR the addition of the cash flow divided per $(1 + IRR)^n$ must be equal or superior to the initial investment, being *n* the number of years given to the project for the profitability assessment.

$$\boldsymbol{0 = -I_o + \sum_{n=1}^{n=10} \frac{CF_{SCT} - CF_{conventional}}{(1+IRR)^n}} \qquad \textbf{(Equation XI 5)}$$

For ten years the value of the IRR goes up to 43.7 %, which is even bigger than the nominal interest (4%). This result encourages the profitability of the project, confirming the potential of the SCT system for saving resources and costs.

XI 6. Return term (RT)

The return term estimates the time it would take before recovering the initial investment on the project. It can be calculated using the Equation XI 6:

$$RT = -\frac{I_o}{Average\ anual\ net\ profi} = \frac{\$6{,}000{,}178.72}{\$3{,}258{,}503.52} = \mathbf{1.84}\ years$$ **(Equation XI 6)**

In the case of the implementation and adaptation of the SCT system to the smelting process it would take only two years before recovering the initial investment, making the project very profitable with a very little risk.

Chapter XII. Environmental study

In this Chapter, a Life Cycle Assessment (LCA) is provided in order to remark the environmental advantages of including the solar thermal energy in the smelting process.

Instead of an extended analysis involving all the process, from the mining to the refining and production of the cathode copper, a more specific approach has been chosen in this work. Only the smelting process is assessed, from the reception and treatment of the concentrate to the production of the matte, therefore the environmental impacts of the process, as well as the carbon footprint and other indicators, are limited to the smelting.

The reasons why the crave-to-gate assessment hasn't been utterly respected are:

i. The exclusive analysis of the smelting process facilitates the task of remarking the differences between the scenarios considered in the study: conventional smelting without SO_2 treatment, conventional smelting, and smelting with SCT system associate.

ii. The lack of economic support and the unavailability of LCA software limits the accuracy of the study, as the data inventory and the full operational LCA software require paid licenses. In the case of the smelting process, the data compiled in this work allow a precise LCA assessment, but as for the rest of the copper production, the uncertainty would diminish the value of the LCA study.

In all the scenarios considered in this section, the LCA is done for one full year of copper smelting.

The damages to the three safeguard subjects are weighted and added to one single score representing the overall environmental damage. The Eco-indicator 99 points are used as a comparative reference with other processes. Being so, the recurrent examples used in this work are the household (estimated between 5000 and 30000 kWh per year) using the French electricity supply, or the production of paper (*Section III 9*).

XII 1. Conventional Smelting without SO_2 treatment

In a first approach, it's considered a scenario where the off-gas isn't treated, releasing all the SO_2 content into the atmosphere. The combustion of fuel produces CO_2 that is also directly released to the environment.

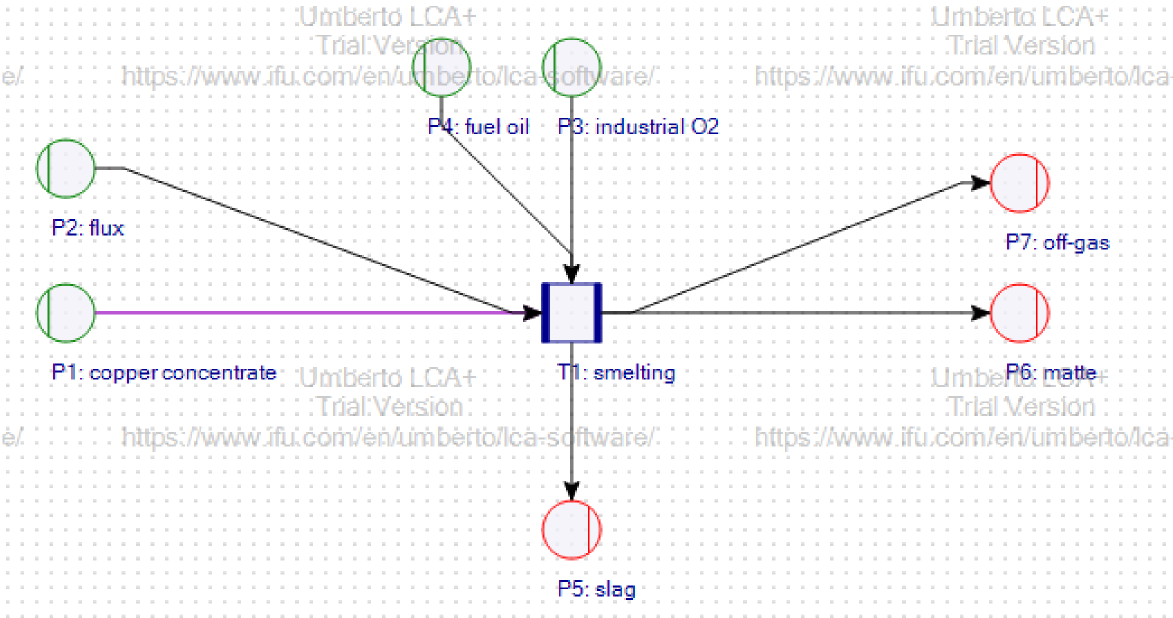


Figure XII 1: Umberto screenshot

Using Umberto (*Figure XII 2*) the following results are found:

Table XII 1: Results of the LCA assessment

	Unit	Value
Carbon footprint	kg CO_2-Eq	2416.67
Eco-indicator 99, (E,E): resources	Points	00.00
Eco-indicator 99, (E,E): human health	Points	33552.65
Eco-indicator 99, (E,E): ecosystem quality	Points	3220.34
Eco-indicator 99, (E,E): Total	Points	36772.99

Regarding the CO_2 emissions, the value of the carbon footprint is not negligible. Considering that a flight from Santiago of Chile to Valencia emits 775 kg of CO_2 per person, the smelting process would have the same effect during a year than if one person was making an intercontinental flight three times. Another illustrative comparison would be saying that the CO_2 emissions are equivalent to burn 72 liters of gasoline (*reference in Section III 9*). In conclusion, even if the process is a source of CO_2 emissions, taking into account that they are distributed during all the year, they stay inside the reasonable limits.

On the other side, the environmental impact of the process due to the SO_2 released without treatment would be extremely harmful. With a total of 36773 Eco-indicator 99 points, it would have the same impact than producing 383 tons of paper, providing electricity in France for 207 houses, or producing 34823 MJ of thermal energy in an industrial furnace. It has special significance the fact that of 36773 points 33552.65 correspond to human health, meaning that the worst effects of the environmental impact are related to diseases and loss of life years.

The main consequence of the SO_2 emissions is the acid rain, created by the combination of the water steam and the SO_2. Besides the danger to human health, this phenomenon can cause losses of millions of dollars in the maintenance of facades and infrastructures.

The Umberto's demo doesn't consider any impact on the resources because of the concentrate being externally handed to smelting system, but in a more extended model, it should be considered the surplus energy needed in future to extract lower quality mineral and fossil resources.

XII 2. Conventional Smelting

In the present section the conventional smelting process is assessed. This analysis would stand for the production of copper matte for one year.

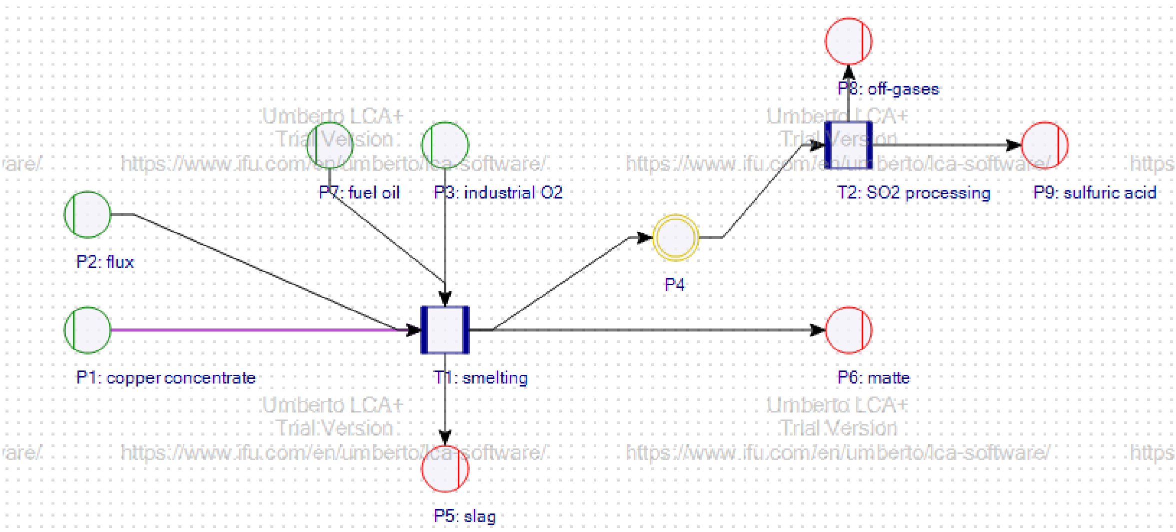


Figure XII 2: Umberto screenshot

Table XII 2: Results of the LCA assessment

	Unit	Value
Carbon footprint	kg CO_2-Eq	2416.67
Eco-indicator 99, (E,E): resources	Points	00.00
Eco-indicator 99, (E,E): human health	Points	1686.96
Eco-indicator 99, (E,E): ecosystem quality	Points	161.02
Eco-indicator 99, (E,E): Total	Points	1847.98

The comments on the CO_2 emissions are the same than in *Section XII 1*, as the treatment of the off-gases reduces the emissions of SO_2 but doesn't improve the carbon footprint.

In comparison with *Section XII 1* the environmental impact is greatly reduced, having a total indicator weight 95% lower (which stands for the 95% SO_2 removal). The conventional smelting has an environmental impact equivalent to the production of 19.25 tons of paper, or the household of 38.2 houses in France. The numbers improve considerably, but the issue remains of having human health as the main impact.

The sources of energy in the conventional process are the additional oxygen supply and the fuel consummation, both assessed by the Umberto software.

XII 3. Smelting with SCT System associate

Finally the improved system is assessed, the main differences in relation with the conventional smelting is the removal of the fuel supply (hence the CO_2 emissions) and the reduction in the oxygen consummation, which is reflected in the Eco-indicator points, because the electricity used for the industrial oxygen production has its impact, superior to the value associated with the solar thermal energy production.

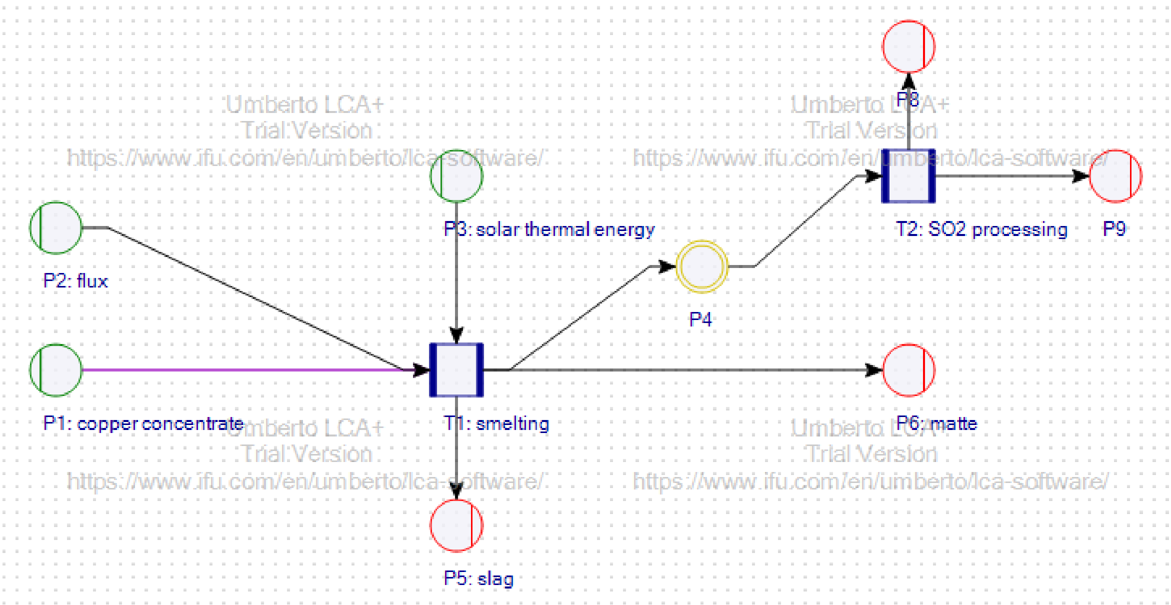


Figure XII 3: Umberto screenshot

Table XII 3: Results of the LCA assessment

	Unit	Value
Carbon footprint	kg CO_2-Eq	0
Eco-indicator 99, (E,E): resources	Points	00.00

Eco-indicator 99, (E,E): human health	Points	1677.14
Eco-indicator 99, (E,E): ecosystem quality	Points	161.02
Eco-indicator 99, (E,E): Total	Points	1838.16

As expected, the smelting process complemented with the SCT system doesn't produces any carbon footprint, which doesn't mean that the overall copper production doesn't have a strong impact related to the carbon emissions, the assessment in this work is exclusively focused in the smelter.

However, there still exists a strong environmental impact, related mainly to the human health, but unfortunately the solar preheating wouldn't eliminate this impact. There should be developed further research regarding the SO_2 emissions, the slag and scrap handling and the production of the copper concentrate in order reduce the impact, in spite that at some point it's almost impossible to find a process without any kind of environmental impact.

Appendix

Table of contents

Appendix I. Thermodynamic and design data

Source thermodynamic data:

[34]

T. Allison, ‘JANAF Thermochemical Tables, NIST Standard Reference Database 13’. National Institute of Standards and Technology, 1996.

Source SCT design data:

[16]

SERC Chile, ‘Solar research data’.

Pressure one atmosphere and temperature of 288 K

H_{CuFeS_2} = -1.04 MJ/kg

$H_{SiO_2 in}$ = -15.16 MJ/kg

H_{oil} = -1.2 MJ/kg

Pressure one atmosphere and temperature of 1500 K

H_{Cu_2S} = 0.25 MJ/kg

H_{FeS} = 0.11 MJ/kg

H_{FeO} = -2.49 MJ/kg

$H_{SiO_2 out}$ = -13.7 MJ/kg

H_{SO_2} = -3.66 MJ/kg

$H_{N_2 out}$ = 1.37 MJ/kg

H_{CO_2} = -7.54 MJ/kg

H_{HO_2} = -10.75 MJ/kg

Estimation of the heat loss for the Chagres Outokumpu Flash Furnace

Q_{loss} = 650 MJ/ton of concentrate

Evolution of the specific enthalpy and specific heat of oxygen and nitrogen depending on the temperature

T (K)	H_{O_2} (KJ/mol)	H_{N_2} (KJ/mol)	Cp_{O_2} (kJ/K.mol)	Cp_{N_2} (kJ/K.mol)
0	-8.683	-8.67		
100	-5.779	,-5.768	29.1	29.1
200	-2.868	-2.857	29.1	29.1
250	-1.410	-1.402	29.2	29.1
298.15	0	0	29.37	29.124
300	0.054	0.054	29.38	29.125
350	1.531	1.511	29.7	29.165
400	3.025	2.971	30.1	29.249
450	4.543	4.437	30.5	29.4
500	6.084	5.911	31	29.6
600	9.244	8.894	32	30.1
700	12.499	11.937	33	30.75
800	15.835	15.046	33.8	31.4
900	19.241	18.223	34.35	32
1000	22.703	21.463	34.87	32.7
1100	26.212	24.76	35.3	33.24
1200	29.761	28.109	35.66	33.72
1300	33.344	31.503	35.98	34.15
1400	36.957	34.936	36.3	34.52
1500	40.599	38.405	36.5	34.84

SCT system design constants

C_g = 300

σ = $5.67 \cdot 10^{-8}$ W/m^2·K

Abs = 0.91

$R_{opt\ ref}$ = 0.579

R_{int} = 0.673

R_{opt} = 0.86

$\varepsilon_{receiver}$ = 0.86

Appendix II. Matlab modeling

Launching script

```
clear all
%oil
moil=0; %kg oil / ton of concentrate

feed=75000 %kg conc / h

restrict=35000 %NM3/h

% creating the maximum feed rate diagram
every=cases(moil,restrict)

%[P_O_blast,EVER]=solveur(moil)
[P_O_blast,ever,performance,mass_blast,T_out]= trial(moil,feed);

m_air=12; %kg/s
m_blast=[11.975,15.04]

T_air_outlet=600; %K
T_air_outlet2=[600,800];
%setting the design results, just one area
[solar_receiver_design_results,area_field]=design_tower(m_air,T_air_outle
t);

area_mirror=3*3;
number_mirrors=area_field/area_mirror;
%setting the diagrams and performance data, it should be able to adapt
the
%temperature of the trial fonction. The results, even if they are for
different
%temperatures and mass flow, adapt the design in order to get the best
%result, in other words, even if area_field is calculated for 600 K, in
the
%performance fonction the area will be adapted for 900 K in order to
%display the results.

[solar_receiver_performance_results1,plot1]=performance_SCT(m_blast(1),T_
air_outlet2(1));
[solar_receiver_performance_results2,plot2]=performance_SCT(m_blast(2),T_
air_outlet2(2));

%double plot
%dibu=[hour,irra,heat,effi1,effi2];

figure(6)
     plot(plot1(:,1),plot1(:,2),'k',plot2(:,1),plot2(:,2),'r');
     title ('solar direct normal irradiance')
     legend('600 K','800 K')
    % axis([0 1500 0 10000]) %[xmin xmax ymin ymax]
     xlabel('hour of the day')
```

```
     ylabel('W/m2')



 figure(7)
     plot(plot1(:,1),plot1(:,3),'k',plot2(:,1),plot2(:,3),'r');
     title ('heat exchanged in the receiver')
    legend('600 K','800 K')
    % axis([0 1500 0 10000]) %[xmin xmax ymin ymax]
     xlabel('hour of the day')
     ylabel('MW')

     figure(8)
    plot(plot1(:,1),plot1(:,4),'k',plot1(:,1),plot1(:,5),'k-
.',plot2(:,1),plot2(:,4),'r',plot2(:,1),plot2(:,5),'r-.');
    title ('Evaluation of the performance')
    legend('Efficiency of the receiver 600 K','Efficiency of the system
600 K','Efficiency of the receiver 800 K','Efficiency of the system 800
K')
    %axis([0 1500 0 10000]) %[xmin xmax ymin ymax]
     xlabel('hour of the day')
    %ylabel('MW')

 figure (9)
     plot(plot1(:,1),plot1(:,6),'k',plot2(:,1),plot2(:,6),'r');
     title ('temperature of the blast')
     legend('600 K','800 K')
    % axis([0 1500 0 10000]) %[xmin xmax ymin ymax]
     xlabel('hour of the day')
     ylabel('K')
```

Trial function

```
function [P_O_blast,ever_ton,performance,mass_blast,T_out] =
trial(moil,feed)


%unkonwn values as 0
%m = masse(kg)
%T = temperature(K)
Tin=288; %15°C
%Tinblast=500; %now we suppose a preheating of the blast
Tout=1500;

P=101320; %for the moment we'll suppose Pamb, even when we know that the
O2 comes at 2 atm

%concentrate (known)
mCuFeS2=1000; TCuFeS2=Tin; Cu_CuFeS2=0.346; Fe_CuFeS2=0.304;
S_CuFeS2=0.35;

%blast (now with N2)
mO2in=0; TO2in=Tin; O_O2in=1; %(1)
mN2in=0; % (2)
O_air=0.23; N_air=0.77;
```

```
%O_blast=0.4; N_blast=0.6; (we suppose it's unfixed)

%oil (input argument)
C_oil=0.87; Hidro_oil=0.13; %(known)

%flux
mSiO2in=0; TSiO2in=Tin; %SiO2 considered as a pure element // (3)

%matte
mCu2Sout=0; TCu2Sout=Tout; Cu_Cu2Sout=0.8; S_Cu2Sout=0.2; %(balance)
mFeSout=0; TFeSout=Tout; Fe_FeSout=0.64; S_FeSout=0.36; %(balance)
mmatte=0; Cu_matte=0.6; % (balance)

%slag
mFeOout=0; TFeOout=Tout; Fe_FeOout=0.78; O_FeOout=0.22; % (4)
mSiO2out=0; TSiO2out=Tout; % (5)

%off-gas
mSO2out=0; TSO2out=Tout; S_SO2out=0.5; O_SO2out=0.5; % (6)
mN2out=0; % (7)
mCO2=0; C_CO2=0.27; O_CO2=0.73; % (8)
mH2O=0; Hidro_H2O=0.11; O_H2O=0.89; %(9)

%Equations
Aeq=zeros(9);
%Mass balance
%Cu
mCu2Sout = mCuFeS2*Cu_CuFeS2/Cu_Cu2Sout;

mmatte= mCu2Sout*Cu_Cu2Sout/Cu_matte;

mFeSout= mmatte-mCu2Sout;


%Fe
%mCuFeS2*Fe_CuFeS2 == mFeSout*Fe_FeSout+mFeOout*Fe_FeOout;
Aeq(1,[4])=[Fe_FeOout];
beq(1,1)=mCuFeS2*Fe_CuFeS2-mFeSout*Fe_FeSout;

%S
%mCuFeS2*S_CuFeS2 ==
mCu2Sout*S_Cu2Sout+mFeSout*S_FeSout+mSO2out*O_SO2out;
Aeq(2,[6])=[S_SO2out];
beq(2,1)=mCuFeS2*S_CuFeS2-mCu2Sout*S_Cu2Sout-mFeSout*S_FeSout;

%O
%0=-mO2in+mFeOout*O_FeOout+mSO2out*O_SO2out+mCO2*O_CO2+mH2O*O_H2O;
Aeq(3,[1,4,6,8,9])=[-1,O_FeOout,O_SO2out,O_CO2,O_H2O];
beq(3,1)=0;

%SiO2
%0==-mSiO2in+ mSiO2out;
Aeq(4,[3,5])=[-1,1];
beq(4,1)=0;

%0 ==-mSiO2out + mFeOout*(0.3/0.7); %if the ratio of SiO2 in the slag is
supposed to be 0.3/0.7
Aeq(6,[5,4])=[-1,0.3/0.7];
```

```
beq(6,1)=0;

%N
%m_N2in=m_N2out
Aeq(5,[2,7])=[-1,1];
beq(5,1)=0;

%m_N2in == m_O2in* N_blast/O_blast
%Aeq(6,[2,1])=[1,- N_blast/O_blast];
%beq(6,1)=0;

%C
%moil*C_oil == mCO2*C_CO2
Aeq(7,[8])=[C_CO2];
beq(7,1)=moil*C_oil;

%H
%moil*Hidro_oil == mH2O*Hidro_H2O
Aeq(8,[9])=[Hidro_H2O];
beq(8,1)=moil*Hidro_oil;

%time to create the enthalpies of O2 and N2 depending of T
T=[0:100:200,250,298.15,300:50:500,600:100:1500];

%H of reference at 298.15k, standard state pressure= 1 bar (enthalpy
%depends on the pressure, so we'll consider it constant in order to
%simplify the procedure

Hmol_N2=[-8.67,-5.768,-2.857,-
1.402,0,0.054,1.511,2.971,4.437,5.911,8.894,11.937,15.046,18.223,21.463,2
4.76,28.109,31.503,34.936,38.405];
%kJ/mol

MN2=28; %mol/g

H_N2=Hmol_N2/MN2; %MJ/kg

Hmol_O2=[-8.683,-5.779,-2.868,-
1.410,0,0.054,1.531,3.025,4.543,6.084,9.244,12.499,15.835,19.241,22.703,2
6.212,29.761,33.344,36.957,40.599];

MO2=32;

H_O2=Hmol_O2/MO2;

% figure(1)
     plot(T,H_O2,'k',T,H_N2,'r-.');
     title ('Enthalpies of O2 and N2')
     legend('H_O2','H_N2')
     xlabel('Temp (K)')
     ylabel('MJ/kg')



for i = 1:length(T)

%Enthalpy Balance (MJ)
```

```
HCuFeS2=-1.04; %MJ/kg=Hmolar/MWeight
HO2in=H_O2(i); %at 500k
HSiO2in=-15.16;
HN2in=H_N2(i); %at 500k
Hoil=-1.2;
%Hreac=moil*Hoil+mCuFeS2*HCuFeS2+mO2in*HO2in+mSiO2in*HSiO2in+mN2in*HN2in;

HCu2Sout=0.25;
HFeSout=0.11;
HFeOout=-2.49;
HSiO2out=-13.7;
HSO2out=-3.66;
HN2out=1.37;
HCO2=-7.54;
HH2O=-10.75;
%Hprod=mCO2*HCO2+mH2O*HH2O+mCu2Sout*HCu2Sout+mFeSout*HFeSout+mFeOout*HFeO
out+mSiO2out*HSiO2out+mSO2out*HSO2out+mN2out*HN2out;

Hloss=650; %estimation MJ/1000kg of concentrate
%Hreac=Hprod+Hloss;
%mCuFeS2*HCuFeS2==-
(mO2in*HO2in+mSiO2in*HSiO2in+mN2in*HN2in)+mCu2Sout*HCu2Sout+mFeSout*HFeSo
ut+mFeOout*HFeOout+mSiO2out*HSiO2out+mSO2out*HSO2out+mN2out*HN2out+Hloss;
Aeq(9,[1,3,4,5,6,2,7,8,9])=[-HO2in,-HSiO2in,HFeOout,HSiO2out,HSO2out,-
HN2in,HN2out,HCO2,HH2O];
beq(9,1)=moil*Hoil+mCuFeS2*HCuFeS2-Hloss-mCu2Sout*HCu2Sout-
mFeSout*HFeSout;

%creation of the solver fonction

x=zeros(9,1);

%creating inequities

Air=zeros(9);
b=zeros (9,1);

f=zeros (9,1);


%calling solver fonction
[x fval]=linprog(f,Air,b,Aeq,beq);
c=(feed)/mCuFeS2;

%asigning values
mO2in(i)=x(1,1);
mN2in(i)=x(2,1);
mSiO2in(i)=x(3,1);
mFeOout(i)=x(4,1);
mSiO2out(i)=x(5,1);
mSO2out(i)=x(6,1);
mN2out(i)=x(7,1);
mCO2(i)=x(8,1);
mH2O(i)=x(9,1);

if i==1

ever=[mO2in(i),mN2in(i),moil,mSiO2in(i),mCu2Sout,mFeSout,mmatte,mFeOout(i
),mSiO2out(i),mSO2out(i),mN2out(i),mCO2(i),mH2O(i)];
```

```
else
ever=[ever;mO2in(i),mN2in(i),moil,mSiO2in(i),mCu2Sout,mFeSout,mmatte,mFeO
out(i),mSiO2out(i),mSO2out(i),mN2out(i),mCO2(i),mH2O(i)];

end

ever_ton=ever*c/1000 %ever for the feed rate, ton/h

%O2 industry needed

mAir(i)=mN2in(i)/N_air;
mO2indus(i)=mO2in(i)-mAir(i)*O_air;
mblast(i)=mAir(i)+mO2indus(i);
P_O_blast(i)=mO2in(i)/(mO2in(i)+mN2in(i));
P_SO2_out_mass(i)=mSO2out(i)/(mSO2out(i)+mN2in(i)+mH2O(i)+mCO2(i));
P_SO2_out_vol(i)=(mSO2out(i)/64)/(mSO2out(i)/64+mN2in(i)/28+mH2O(i)/18+mC
O2(i)/44);

%volumes in Nm3 (273K and 1atm)
Vblast(i)=8.31*273*1000*(mO2in(i)/32+mN2in(i)/28)/101320; %volume in Nm3
Voff_gas(i)=8.31*273*1000*(mSO2out(i)/64+mN2in(i)/28+mH2O(i)/18+mCO2(i)/4
4)/101320;

%energy needed for the preheat
CpO2avmol=0.033; %kJ/k.mol , avarage value
CpO2mol=[0,29.1,29.1,29.2,29.37,29.38,29.7,30.1,30.5,31,32,33,33.8,34.35,
34.87,35.3,35.66,35.98,36.3,36.5]; %J/k.mol
CpO2=CpO2mol/(1000*MO2); %MJ/K.kg

CpN2avmol=0.031;
CpN2mol=[0,29.1,29.1,29.1,29.124,29.125,29.165,29.249,29.4,29.6,30.1,30.7
5,31.4,32,32.7,3.24,33.72,34.15,34.52,34.84];
CpN2=CpN2mol/(MN2*1000);

Cp_air(i)=((1.03409*(T(i)^0))+(-0.2848870e-3*(T(i)^1))+(0.7816818e-
6*(T(i)^2))+(-0.4970786e-9*(T(i)^3))+(0.1077024e-12*(T(i)^4)))*1000;

Energy (i)=mO2in(i)*CpO2(i)*(T(i)-Tin)+mN2in(i)*CpN2(i)*(T(i)-Tin);
Energy2 (i)=(mO2in(i)+mN2in(i))*Cp_air(i)*(T(i)-Tin)/(10^6);

Energy_oil(i)=moil*Hoil;

Energy_ind(i)=H_O2(i)*mO2indus(i)
end

%limitating the third plot to only positive values of mO2 ind and for the
%flow rate
     Air=0;
     Oxi=0;
     temp=0;
     bla=0;
     off=0;
     en=0;
     per=0;

     feed_rate=feed %kg/h, 75 ton par hour feed rate
     conc_flow=(feed_rate)/mCuFeS2; %(kg/h)
```

```
    for j = 1:(length(mO2indus)-1)
       if  mO2indus(j)> 0

           Air(j)= mAir (j)*conc_flow;
           Oxi(j)= mO2indus(j)*conc_flow;
           temp(j)= T(j);
           bla(j)=Vblast(j)*conc_flow;
           off(j)=Voff_gas(j)*conc_flow;
           en(j)=Energy(j)*conc_flow/3600; %MW
           per(j)=100*P_O_blast(j);
           mbla(j)=mblast(j)*conc_flow;
           en2(j)=Energy2 (j)*conc_flow/3600; %MW
           en_oil(j)=Energy_oil(j)*conc_flow/3600;
           en_ind(j)=Energy_ind(j)*conc_flow/3600;
           Sodosm(j)=100*P_SO2_out_mass(j);
           Sodosv(j)=100*P_SO2_out_vol(j)
       end
    end

mass_blast= mbla/3600; %for the design of the CTS

T_out=temp;

performance=[transpose(temp),transpose(mbla),transpose(Oxi),transpose(bla
),transpose(off),transpose(per),transpose(en)];

ever_ton=[transpose(T),ever_ton];

figure(2)
     plot(temp,per);
     title ('Percentage of oxygen in the blast')
     legend('mass % of O in the blast')
     xlabel('T (K)')
     ylabel('%')

figure(3)
     plot(temp,Air,'g-.',temp,Oxi,'r-.',temp,mbla,'k');
     title ('Mass flow of air needed')
     legend('air mass flow','industrial O2 mass flow','blast mass flow')
    % axis([0 1500 0 10000]) %[xmin xmax ymin ymax]
     xlabel('T (K)')
     ylabel('kg/h')


figure(4)
     plot(temp,bla,'k',temp,off,'r-.');
     title ('flow of gas in the furnace')
     legend('blast flow','off-gas flow')
    % axis([0 1500 0 10000]) %[xmin xmax ymin ymax]
     xlabel('T (K)')
     ylabel('Nm3/h')

figure(5)
     plot(temp,en,temp,en2);
     title ('Energy needed for the preheating of the blast')
    legend('method 1','method 2')
     xlim([Tin inf])
     ylim([0 inf])
     xlabel('T (K)')
```

```
     ylabel('MW')

     figure(10)
     plot(temp,Sodosm,temp,Sodosv);
     title ('SO2 in the off-gas')
    legend('mass %','volume %')
     xlim([Tin inf])
     ylim([0 inf])
     xlabel('T (K)')
     ylabel('%')

     %figure(9)
    % plot(temp,en,'r',temp,en_oil,'k',temp,en_ind,'b');
    % title ('Energy supply')
    %legend('preheating','oil','industrial O2')
    % xlim([Tin inf])
    % ylim([0 inf])
    % xlabel('T (K)')
    % ylabel('MW')
end
```

Cases function

```
function [ever] = cases(moil,restrict)


%unkonwn values as 0
%m = masse(kg)
%T = temperature(K)
Tin=288; %15°C
%Tinblast=500; %now we suppose a preheating of the blast
Tout=1500;

P=101320; %for the moment we'll suppose Pamb, even when we know that the
O2 comes at 2 atm

%concentrate (known)
mCuFeS2=1000; TCuFeS2=Tin; Cu_CuFeS2=0.346; Fe_CuFeS2=0.304;
S_CuFeS2=0.35;

%blast (now with N2)
mO2in=0; TO2in=Tin; O_O2in=1; %(1)
mN2in=0; % (2)
O_air=0.23; N_air=0.77;
%O_blast=0.4; N_blast=0.6; (we suppose it's unfixed)

%oil (input argument)
C_oil=0.87; Hidro_oil=0.13; %(known)

%flux
mSiO2in=0; TSiO2in=Tin; %SiO2 considered as a pure element // (3)

%matte
mCu2Sout=0; TCu2Sout=Tout; Cu_Cu2Sout=0.8; S_Cu2Sout=0.2; %(balance)
mFeSout=0; TFeSout=Tout; Fe_FeSout=0.64; S_FeSout=0.36; %(balance)
mmatte=0; Cu_matte=0.6; % (balance)
```

```
%slag
mFeOout=0; TFeOout=Tout; Fe_FeOout=0.78; O_FeOout=0.22; % (4)
mSiO2out=0; TSiO2out=Tout; % (5)

%off-gas
mSO2out=0; TSO2out=Tout; S_SO2out=0.5; O_SO2out=0.5; % (6)
mN2out=0; % (7)
mCO2=0; C_CO2=0.27; O_CO2=0.73; % (8)
mH2O=0; Hidro_H2O=0.11; O_H2O=0.89; %(9)

%Equations
Aeq=zeros(9);
%Mass balance
%Cu
mCu2Sout = mCuFeS2*Cu_CuFeS2/Cu_Cu2Sout;

mmatte= mCu2Sout*Cu_Cu2Sout/Cu_matte;

mFeSout= mmatte-mCu2Sout;


%Fe
%mCuFeS2*Fe_CuFeS2 == mFeSout*Fe_FeSout+mFeOout*Fe_FeOout;
Aeq(1,[4])=[Fe_FeOout];
beq(1,1)=mCuFeS2*Fe_CuFeS2-mFeSout*Fe_FeSout;

%S
%mCuFeS2*S_CuFeS2 ==
mCu2Sout*S_Cu2Sout+mFeSout*S_FeSout+mSO2out*O_SO2out;
Aeq(2,[6])=[S_SO2out];
beq(2,1)=mCuFeS2*S_CuFeS2-mCu2Sout*S_Cu2Sout-mFeSout*S_FeSout;

%O
%0=-mO2in+mFeOout*O_FeOout+mSO2out*O_SO2out+mCO2*O_CO2+mH2O*O_H2O;
Aeq(3,[1,4,6,8,9])=[-1,O_FeOout,O_SO2out,O_CO2,O_H2O];
beq(3,1)=0;

%SiO2
%0==-mSiO2in+ mSiO2out;
Aeq(4,[3,5])=[-1,1];
beq(4,1)=0;

%0 ==-mSiO2out + mFeOout*(0.3/0.7); %if the ratio of SiO2 in the slag is
supposed to be 0.3/0.7
Aeq(6,[5,4])=[-1,0.3/0.7];
beq(6,1)=0;

%N
%m_N2in=m_N2out
Aeq(5,[2,7])=[-1,1];
beq(5,1)=0;

%m_N2in == m_O2in* N_blast/O_blast
%Aeq(6,[2,1])=[1,- N_blast/O_blast];
%beq(6,1)=0;

%C
```

```
%moil*C_oil == mCO2*C_CO2
Aeq(7,[8])=[C_CO2];
beq(7,1)=moil*C_oil;

%H
%moil*Hidro_oil == mH2O*Hidro_H2O
Aeq(8,[9])=[Hidro_H2O];
beq(8,1)=moil*Hidro_oil;

%time to create the enthalpies of O2 and N2 depending of T
T=[0:100:200,250,298.15,300:50:500,600:100:1500];

%H of reference at 298.15k, standard state pressure= 1 bar (enthalpy
%depends on the pressure, so we'll consider it constant in order to
%simplify the procedure

Hmol_N2=[-8.67,-5.768,-2.857,-
1.402,0,0.054,1.511,2.971,4.437,5.911,8.894,11.937,15.046,18.223,21.463,2
4.76,28.109,31.503,34.936,38.405];
%kJ/mol

MN2=28; %mol/g

H_N2=Hmol_N2/MN2; %MJ/kg

Hmol_O2=[-8.683,-5.779,-2.868,-
1.410,0,0.054,1.531,3.025,4.543,6.084,9.244,12.499,15.835,19.241,22.703,2
6.212,29.761,33.344,36.957,40.599];

MO2=32;

H_O2=Hmol_O2/MO2;

% figure(1)
     plot(T,H_O2,'k',T,H_N2,'r-.');
     title ('Enthalpies of O2 and N2')
     legend('H_O2','H_N2')
     xlabel('Temp (K)')
     ylabel('MJ/kg')



for i = 1:length(T)

%Enthalpy Balance (MJ)
HCuFeS2=-1.04; %MJ/kg=Hmolar/MWeight
HO2in=H_O2(i); %at 500k
HSiO2in=-15.16;
HN2in=H_N2(i); %at 500k
Hoil=-1.2;
%Hreac=moil*Hoil+mCuFeS2*HCuFeS2+mO2in*HO2in+mSiO2in*HSiO2in+mN2in*HN2in;

HCu2Sout=0.25;
HFeSout=0.11;
HFeOout=-2.49;
HSiO2out=-13.7;
HSO2out=-3.66;
HN2out=1.37;
```

```
HCO2=-7.54;
HH2O=-10.75;
%Hprod=mCO2*HCO2+mH2O*HH2O+mCu2Sout*HCu2Sout+mFeSout*HFeSout+mFeOout*HFeO
out+mSiO2out*HSiO2out+mSO2out*HSO2out+mN2out*HN2out;

Hloss=650; %estimation MJ/1000kg of concentrate
%Hreac=Hprod+Hloss;
%mCuFeS2*HCuFeS2==-
(mO2in*HO2in+mSiO2in*HSiO2in+mN2in*HN2in)+mCu2Sout*HCu2Sout+mFeSout*HFeSo
ut+mFeOout*HFeOout+mSiO2out*HSiO2out+mSO2out*HSO2out+mN2out*HN2out+Hloss;
Aeq(9,[1,3,4,5,6,2,7,8,9])=[-HO2in,-HSiO2in,HFeOout,HSiO2out,HSO2out,-
HN2in,HN2out,HCO2,HH2O];
beq(9,1)=moil*Hoil+mCuFeS2*HCuFeS2-Hloss-mCu2Sout*HCu2Sout-
mFeSout*HFeSout;

%creation of the solver fonction

x=zeros(9,1);

%creating inequities

Air=zeros(9);
b=zeros (9,1);

f=zeros (9,1);


%calling solver fonction
[x fval]=linprog(f,Air,b,Aeq,beq);

%asigning values
mO2in(i)=x(1,1);
mN2in(i)=x(2,1);
mSiO2in(i)=x(3,1);
mFeOout(i)=x(4,1);
mSiO2out(i)=x(5,1);
mSO2out(i)=x(6,1);
mN2out(i)=x(7,1);
mCO2(i)=x(8,1);
mH2O(i)=x(9,1);

if i==1

ever=[mO2in(i),mN2in(i),moil,mSiO2in(i),mCu2Sout,mFeSout,mmatte,mFeOout(i
),mSiO2out(i),mSO2out(i),mN2out(i),mCO2(i),mH2O(i)];
else
ever=[ever;mO2in(i),mN2in(i),moil,mSiO2in(i),mCu2Sout,mFeSout,mmatte,mFeO
out(i),mSiO2out(i),mSO2out(i),mN2out(i),mCO2(i),mH2O(i)];

end

%O2 industry needed

mAir(i)=mN2in(i)/N_air;
mO2indus(i)=mO2in(i)-mAir(i)*O_air;
mblast(i)=mAir(i)+mO2indus(i);
P_O_blast(i)=mO2in(i)/(mO2in(i)+mN2in(i));
P_SO2_out_mass(i)=mSO2out(i)/(mSO2out(i)+mN2in(i)+mH2O(i)+mCO2(i));
```

```
P_SO2_out_vol(i)=(mSO2out(i)/64)/(mSO2out(i)/64+mN2in(i)/28+mH2O(i)/18+mC
O2(i)/44);

%volumes in Nm3 (273K and 1atm)
Vblast(i)=8.31*273*1000*(mO2in(i)/32+mN2in(i)/28)/101320; %volume in Nm3
Voff_gas(i)=8.31*273*1000*(mSO2out(i)/64+mN2in(i)/28+mH2O(i)/18+mCO2(i)/4
4)/101320;

%energy needed for the preheat
CpO2avmol=0.033; %kJ/k.mol , avarage value
CpO2mol=[0,29.1,29.1,29.2,29.37,29.38,29.7,30.1,30.5,31,32,33,33.8,34.35,
34.87,35.3,35.66,35.98,36.3,36.5]; %J/k.mol
CpO2=CpO2mol/(1000*MO2); %MJ/K.kg

CpN2avmol=0.031;
CpN2mol=[0,29.1,29.1,29.1,29.124,29.125,29.165,29.249,29.4,29.6,30.1,30.7
5,31.4,32,32.7,3.24,33.72,34.15,34.52,34.84];
CpN2=CpN2mol/(MN2*1000);

Cp_air(i)=((1.03409*(T(i)^0))+(-0.2848870e-3*(T(i)^1))+(0.7816818e-
6*(T(i)^2))+(-0.4970786e-9*(T(i)^3))+(0.1077024e-12*(T(i)^4)))*1000;

Energy (i)=mO2in(i)*CpO2(i)*(T(i)-Tin)+mN2in(i)*CpN2(i)*(T(i)-Tin);
Energy2 (i)=(mO2in(i)+mN2in(i))*Cp_air(i)*(T(i)-Tin)/(10^6);

Energy_oil(i)=moil*Hoil;

Energy_ind(i)=H_O2(i)*mO2indus(i)
end

%limitating the third plot to only positive values of mO2 ind and for the
%flow rate
     Air=0;
     Oxi=0;
     temp=0;
     bla=0;
     off=0;
     en=0;
     per=0;

     feed_rate=[40:1:130] %kg/h, 75 ton par hour feed rate
     conc_flow=(feed_rate)*1000/mCuFeS2; %(kg/h)

   for w = 1:(length(feed_rate)-1)

   for j = 1:(length(mO2indus)-1)
      if  mO2indus(j)> 0

          temp(j)= T(j);
          bla(j)=Vblast(j)*conc_flow(w);

      if bla(j)< restrict

          lowmass(w)=feed_rate(w); %guarda el último valor de feed rate
antes del boiler capacity
          lowvol(w)=bla(j); %guarda el último valor de bla antes del
boiler capacity
```

```
            lowtemp(w)=temp(j); %guarda el último valor de T antes del
boiler capacity
        end
        end
    end
    end


figure(2)
    plot(lowmass,lowtemp);
    title ('Maximum preheating depending on the feed rate')

    xlabel('ton/h')
    ylabel('T (K)')


    % axis([0 1500 0 10000]) %[xmin xmax ymin ymax]




end
```

Design_tower function

```
function [solar_receiver_design_results,area_field] =
design_tower(m_air,T_air_outlet)
T0=273.15
stef_bolt=5.67*10^-8 %W/m2.K


%% Ambient conditions
% ambient temperature K
T_amb=15+T0
% Solar Direct Normal Irradiance at the design point W/m2
%it's not the average but the normal value in sun hours
DNI=750
% Day of the year staring from 1 in 1 january to 365 in 31 december
j=1;
% hour of the day 1 to 24h
si=12;
% the number of line in the matrix results
n_si=1;

%% air data
% mass flow rate at design point (kg/s)
%% **********************
%m_air=7
%% ********************
% inlet temperature of the air K
T_air_inlet=T_amb
% oulet temperature of the air
%T_air_outlet=T_air_outlet;
% Heat transfer coefficient to the ambient W/K.m2
%U_amb=10
% heat transfer coefficient from the solar receiver to the air
```

```
%U_fluid=300

%% Receiver wall temperature
T_receiver=T_air_outlet

%% Resonable concentration ratio for air solar receiver (C_geometric: 200
to 350)
C_geometric=300

%% Design data
% Heliostat field optical efficiency
R_opt_sf=0.673
% Intercept factor
R_intercept=0.86

%% optical efficiency, quality of the mirrors, reflectivity
R_opt_reflectors=R_opt_sf*R_intercept
% Absorbtance of the reciver
Abs_receiver=0.91
% Thermal emittance of the receiver
e_receiver=0.86

%% Calculate the heat required for heating the air (Q_air)
% calculate the heat capacity of the air at average temperature
(Tin+Tout/2)
T=(T_air_inlet+T_air_outlet)/2
% Heat capacity of the air in (J/kg.K)
Cp_air=((1.03409*(T^0))+(-0.2848870e-3*(T^1))+(0.7816818e-6*(T^2))+(-
0.4970786e-9*(T^3))+(0.1077024e-12*(T^4)))*1000;
Q_air=m_air*Cp_air*(T_air_outlet-T_air_inlet)

%% Design data fo the system
%% Receiver (Reactor): cylinder of D*L
% wide of the receiver aperture (square)
D_receiver=1; % initial value of the diameter receiver
%% Setting the diameter of receiver aperture
epsilon_D_ap_receiver=100; % initial difference heat of air and exchanger
value for the iteration
e_D_ap_receiver=epsilon_D_ap_receiver; %empezar ittts
d_D_ap_receiver=0.1; % step in the iteration
while abs(epsilon_D_ap_receiver)>10e-1

% Absorber area of the receiver square
A_abs_receiver=D_receiver^2

%% Heliostat total reflective area
A_heliostat_field=A_abs_receiver*C_geometric

%% Energy balance on the receiver
%% Total input energy into the receiver
Q_in_receiver=R_opt_reflectors*DNI*A_heliostat_field

%% Absorbered energy by the receiver absorbtance surface
Q_abs_receiver=Abs_receiver*Q_in_receiver

%% Heat losses from the receiver to the ambient (convection and
conduction neglected, cavity)
Q_loss_receiver=A_abs_receiver*e_receiver*stef_bolt*((T_receiver^4)-
(T_amb^4))
```

```
%% The useful thermal energy transfered to the air
Q_useful_receiver=Q_abs_receiver-Q_loss_receiver

%% Receiver thermal efficiency
eff_receiver=Q_useful_receiver/Q_in_receiver

%% Global solar to useful heat efficiency
eff_system=Q_useful_receiver/(A_heliostat_field*DNI)

%% Flux density on the reciver apearture (MW/m2)
solar_flux_ap_receiver=DNI*C_geometric/1e6

%% find the appropriate size of the receiver
epsilon_D_ap_receiver=Q_air-Q_useful_receiver %difference between target
and available heat

%% convergence (imposible having negative epsilon)
 if epsilon_D_ap_receiver<0 %if Qair-Quseful negative, loop for the
receiver diameter
      D_receiver=D_receiver-d_D_ap_receiver; % -0.1 empequeñecer el
diametro del receiver
 else %if Qair-Quseful positive
       D_receiver=D_receiver+d_D_ap_receiver; % +0.1 agrandar el
diametro//area del receiver
  end
    if (e_D_ap_receiver*epsilon_D_ap_receiver)<0 %cuando pasa de
diferencia positiva a negativa
        d_D_ap_receiver=d_D_ap_receiver/2; %disminuir el step
    end
       e_D_ap_receiver=epsilon_D_ap_receiver; %e_D = diff heat
end

solar_receiver_design_results(n_si,:)=
[j,si,n_si,T_amb,DNI,m_air,Q_air,C_geometric,R_opt_sf,R_intercept,D_recei
ver,A_abs_receiver,Q_in_receiver,Q_abs_receiver,Q_loss_receiver,Q_useful_
receiver,eff_receiver,eff_system,A_heliostat_field,solar_flux_ap_receiver
]

area_field=A_heliostat_field;
end
```

Performance_SCT function

```
unction [solar_receiver_performance_results,dibu] =
performance_SCT(m_air,T_air_outlet)
T0=273.15
stef_bolt=5.67*10^-8 %W/m2.K
%% we need to retake all the design calculations inside the fonction
before we can see the performance
DNI=750
% Day of the year staring from 1 in 1 january to 365 in 31 december
j=1;
% hour of the day 1 to 24h
si=12;
% the number of line in the matrix results
```

```
n_si=1;

% ambient temperature K
T_amb=15+T0
% inlet temperature of the air K
T_air_inlet=T_amb

% Heat transfer coefficient to the ambient W/K.m2
U_amb=10
% heat transfer coefficient from the solar receiver to the air
U_fluid=300

%% Receiver wall temperature
T_receiver=T_air_outlet

%% Resonable concentration ratio for air solar receiver (C_geometric: 200
to 350)
C_geometric=300

%% Design data
% Heliostat field optical efficiency
R_opt_sf=0.673
% Intercept factor
R_intercept=0.86

%% optical efficiency
R_opt_reflectors=R_opt_sf*R_intercept
% Absorbtance of the reciver
Abs_receiver=0.91
% Thermal emittance of the receiver
e_receiver=0.86


%% Calculate the heat required for heating the air (Q_air)
% calculate the heat capacity of the air at average temperature
(Tin+Tout/2)
T=(T_air_inlet+T_air_outlet)/2
% Heat capacity of the air in (J/kg.K)
Cp_air=((1.03409*(T^0))+(-0.2848870e-3*(T^1))+(0.7816818e-6*(T^2))+(-
0.4970786e-9*(T^3))+(0.1077024e-12*(T^4)))*1000;
Q_air=m_air*Cp_air*(T_air_outlet-T_air_inlet)

%% Design data fo the system
%% Receiver (Reactor): cylinder of D*L
% wide of the receiver aperture (square)
D_receiver=1; % initial value
%% Setting the diameter of receiver aperture
epsilon_D_ap_receiver=100; % initial difference value for the iteration
e_D_ap_receiver=epsilon_D_ap_receiver;
d_D_ap_receiver=0.1; % step in the iteration
while abs(epsilon_D_ap_receiver)>10e-1

% Absorber area of the receiver
A_abs_receiver=D_receiver^2

%% Heliostat total reflective area
A_heliostat_field=A_abs_receiver*C_geometric
```

```
%% Energy balance on the receiver
%% Total input energy into the receiver
Q_in_receiver=R_opt_reflectors*DNI*A_heliostat_field

%% Absorbered energy by the receiver absorbtance surface
Q_abs_receiver=Abs_receiver*Q_in_receiver

%% Heat losses from the receiver to the ambient (convection and
conduction neglicted, cavity)
Q_loss_receiver=A_abs_receiver*e_receiver*stef_bolt*((T_receiver^4)-
(T_amb^4))

%% The useful thermal energy transfered to the air
Q_useful_receiver=Q_abs_receiver-Q_loss_receiver

%% Receiver thermal efficiency
eff_receiver=Q_useful_receiver/Q_in_receiver

%% Global solar to useful heat efficiency
eff_system=Q_useful_receiver/(A_heliostat_field*DNI)

%% Flux density on the reciver apearture (MW/m2)
solar_flux_ap_receiver=DNI*C_geometric/1e6

%% find the appropriate size of the receiver
epsilon_D_ap_receiver=Q_air-Q_useful_receiver

%% convergence (imposible having negative epsilon)
 if epsilon_D_ap_receiver<0
      D_receiver=D_receiver-d_D_ap_receiver;
  else
       D_receiver=D_receiver+d_D_ap_receiver;
  end
    if (e_D_ap_receiver*epsilon_D_ap_receiver)<0
        d_D_ap_receiver=d_D_ap_receiver/2;
    end
       e_D_ap_receiver=epsilon_D_ap_receiver;
end

%now we know the area of the solar field

%% Peformance model:
% ============ October Chagres Smelting Factory
%DNI_matrix=[0 0 0 0 0 0 0 400 700 900 925 950 950 925 900 700 400 0 0 0
0 0 0 0]
DNI_matrix=[0    0    0    0    0    0    423.73279    514.27023    610.71978
727.27519    767.15622    787.88443    804.87019    798.37334    793.6045
730.38164    629.23799    530.15749    0    0    0    0    0]
T_amb_matrix=[287.890455    284.72974    283.92211    283.09276    282.4371
281.81439    281.22699    280.04899    281.99774    284.32865    287.01681
289.71127    292.29397    293.46088    294.65144    295.56729    295.30204
294.61793    293.6784    292.23889    290.2319    288.52431    287.06587
286.01988    285.39157]
n_si=0;
for si=1:1:24
    % Read DNI
   DNI=DNI_matrix(si)
   % Read T_amb
   T_amb=T_amb_matrix(si)
```

```
   n_si=n_si+1
    %% check the value of DNI
    if DNI>0
% ==============
% air inlet temperature
T_air_inlet=T_amb;
%% Energy balance on the receiver
%% Total input energy into the receiver
Q_in_receiver=R_opt_reflectors*DNI*A_heliostat_field

%% Absorbered energy by the receiver absorbtance surface
Q_abs_receiver=Abs_receiver*Q_in_receiver

%% Heat losses from the receiver to the ambient
Q_loss_receiver=A_abs_receiver*e_receiver*stef_bolt*((T_receiver^4)-
(T_amb^4))

%% The useful thermal energy transfered to the air
if Q_abs_receiver>Q_loss_receiver

Q_useful_receiver=Q_abs_receiver-Q_loss_receiver;

else
    Q_useful_receiver=0;
end

%% Receiver thermal efficiency
eff_receiver=Q_useful_receiver/Q_in_receiver

%% Global solar to useful heat efficiency
eff_system=Q_useful_receiver/(A_heliostat_field*DNI)

%% Flux density on the reciver apearture (MW)
solar_flux_ap_receiver=DNI*C_geometric/1e6

%% calculate the outlet temperature of the air
% let initial value for the air outlet temperatue
%T_air_outlet=700; % initial value
T_air_outlet=T_air_outlet;
%% Setting the diameter of receiver aperture
epsilon_T_air_outlet=100;
e_T_air_outlet=epsilon_T_air_outlet;
d_T_air_outlet=30;
while abs(epsilon_T_air_outlet)>10e-1

% calculate the heat capacity of the air at average temperature
(Tin+Tout/2)
T=(T_air_inlet+T_air_outlet)/2
% Heat capacity of the air in (J/kg.K)
Cp_air=((1.03409*(T^0))+(-0.2848870e-3*(T^1))+(0.7816818e-6*(T^2))+(-
0.4970786e-9*(T^3))+(0.1077024e-12*(T^4)))*1000;
Q_air=m_air*Cp_air*(T_air_outlet-T_air_inlet)


%% set the outlet temperature of the air
% it is the temperature at equates  Q_air and Q_useful_receiver
epsilon_T_air_outlet=Q_useful_receiver-Q_air;
```

```
%% convergence
 if epsilon_T_air_outlet<0
      T_air_outlet=T_air_outlet-d_T_air_outlet;
  else
       T_air_outlet=T_air_outlet+d_T_air_outlet;
  end
    if (e_T_air_outlet*epsilon_T_air_outlet)<0
        d_T_air_outlet=d_T_air_outlet/2;
    end
       e_T_air_outlet=epsilon_T_air_outlet;
end
solar_receiver_performance_results(n_si,:)=
[j,si,n_si,T_amb,DNI,m_air,Q_air,C_geometric,R_opt_sf,R_intercept,T_air_o
utlet,A_abs_receiver,Q_in_receiver,Q_abs_receiver,Q_loss_receiver,Q_usefu
l_receiver,eff_receiver,eff_system,A_heliostat_field,solar_flux_ap_receiv
er]
    else
        T_air_outlet=T_air_inlet;
solar_receiver_performance_results(n_si,:)=
[j,si,n_si,T_amb,DNI,m_air,0,0,0,0,T_air_outlet,A_abs_receiver,0,0,0,0,0,
0,A_heliostat_field,0]
    end
end

hour=solar_receiver_performance_results(:,2);
irra=solar_receiver_performance_results(:,5);
heat=solar_receiver_performance_results(:,16)/10^6;
effi1=solar_receiver_performance_results(:,17);
effi2=solar_receiver_performance_results(:,18);
tempp=solar_receiver_performance_results(:,11);
dibu=[hour,irra,heat,effi1,effi2,tempp];

figure(6)

plot(solar_receiver_performance_results(:,2),solar_receiver_performance_r
esults(:,5),'k');
     title ('solar direct normal irradiance')
     %legend('air mass flow','industrial O2 mass flow','blast mass flow')
    % axis([0 1500 0 10000]) %[xmin xmax ymin ymax]
     xlabel('hour of the day')
     ylabel('W/m2')



 figure(7)
     plot(solar_receiver_performance_results(:,2),heat,'k');
     title ('heat exchanged in the receiver')
     %legend('air mass flow','industrial O2 mass flow','blast mass flow')
    % axis([0 1500 0 10000]) %[xmin xmax ymin ymax]
     xlabel('hour of the day')
     ylabel('MW')

     figure(8)

plot(solar_receiver_performance_results(:,2),solar_receiver_performance_r
esults(:,17),'k',solar_receiver_performance_results(:,2),solar_receiver_p
erformance_results(:,18),'r');
     title ('Evaluation of the performance')
    legend('Efficiency of the receiver','Efficiency of the system')
    %axis([0 1500 0 10000]) %[xmin xmax ymin ymax]
```

```
    % xlabel('hour of the day')
    xlabel('hour of the day')

    figure (9)

plot(solar_receiver_performance_results(:,2),solar_receiver_performance_r
esults(:,11),'k');
     title ('temperature of the blast')
     %legend('air mass flow','industrial O2 mass flow','blast mass flow')
    % axis([0 1500 0 10000]) %[xmin xmax ymin ymax]
     xlabel('hour of the day')
     ylabel('K')
end
```

Appendix III. Own entity studies

Health and security study

The content of this chapter has been developed considering the regulations specified in the Spanish law "Ley de prevención de Riesgos Laborales" [ref. 36]. The health and security study is limited to the flash furnace smelting and the SCT system, without considering the full copper production process.

The safety of the process is the responsibility of the corporative entity and the staff working in the risk areas of the smelting facilities. As long as the employees of the company are protected by the safety laws and dispose of ensured rights in case of a work accident, they are enforced to respect the safety measures and develop their activity following a preventive policy.

The "Ley de prevención de Riesgos Laborales" has the essential function of stablishing the main responsibilities and conditions to create appropriate protection of the worker's health against the risks related to their job. It gives the definitions of the basic safety terms as the work accident, work's condition, professional illness, evaluation of risks, or industrial hygiene. In this section, it's assessed how all these regulations would apply to this project, and how the health and security of the operators of the solar system and the flash furnace could be guaranteed.

The operation of the SCT system the main risks come from the high temperatures on the conductions transporting the gases, and the possible leakage of gases. The risks related to the SCT system are:

RISKS

- Falls from the tower during the construction, taking into account the height (around 120 meters in some cases) it may be mortal.

- Falling objects during the construction of the tower, producing wounds, fractures or bruises.

- Electric contact with the automatisms and tracking system of the heliostats.

- Fires or thermic contact because of a short circuit or a problem with the conduction's temperature.

- Hits and cuts with the surface of the mirrors or other sharp edge objects.

- Projection of fragments or particles during the civil works.

Regarding the operation of the Outokumpu Flash Furnace, it's a piece of equipment working at high temperatures, involving the existence of several gases dangerous for the health and safety of the staff [ref. 35]. The main risks and safety measures considered in this study are:

RISKS

- Fall of heavy objects (mainly the concentrate going into the furnace)
- Projection of the fragments coming from the scrap
- Falls from the platform of furnace charge
- Intoxication because of the emissions or leakages of carbon monoxide from the furnace or the gas pipes inside the smelting facilities
- Explosion because of the contact between water and metal or the scrap waste
- Intoxication because of the smelting vapors
- Intoxication because of the SO_2 leakage.

For all the risks mentioned several safety measures are proposed:

SAFETY MEASURES

- In order to reduce the size of the scrap, so it becomes manageable, making it possible for the scrap to be recycled, charged in the furnace or stored, there may be used breaker mazes and electromagnetic cranes. The crane operating space must be protected, and the staff formed in the use of such equipment.

- The use of leather gloves is compulsory for the employees working directly with raw materials. Moreover, they should use safety shoes and a helmet.

- The operator working with materials at high temperatures should use special equipment and wear safety clothes, not fireproof and resistant to high temperatures.

- If the platform of furnace charge is over the floor it will be necessary, with the aim of avoiding the risk of fall, to dispose of an anti-slip surface and strong holdings around the platform.

- If necessary, there will be included cardiopulmonary resuscitation equipment, the use of which should be taught to the operators. It will be compulsory to work in pairs when an emergency task must be done.

- It will be avoided any contact between the scrap, the slag or the matte with the water, because of the explosion risk. Any person not involved in the operation of the furnace should stay away from the risk space, keeping a distance of four meters from the furnace. All the conductions and conveyors should be checked and dry before the transportation of any molten material.

- The cleaning, arrangement, and supervision of the raw materials should be endorsed as a safety measure.

- The carbon monoxide has no color and no odor, and it can reach toxic levels in the working environment easily. The use of sensors and continuous surveillance are essential for the safe operation of the furnace.

- The SO_2 is a source of respiratory illnesses and corrosive danger. The use of sensors and continuous surveillance are essential for the safe operation of the furnace.

- The installation of extinguishers according to the “Real Decreto 2267/2004” must be respected and enforced in the working space.

- Marking out the zones with a risk of falling objects, using railings and protection measures.

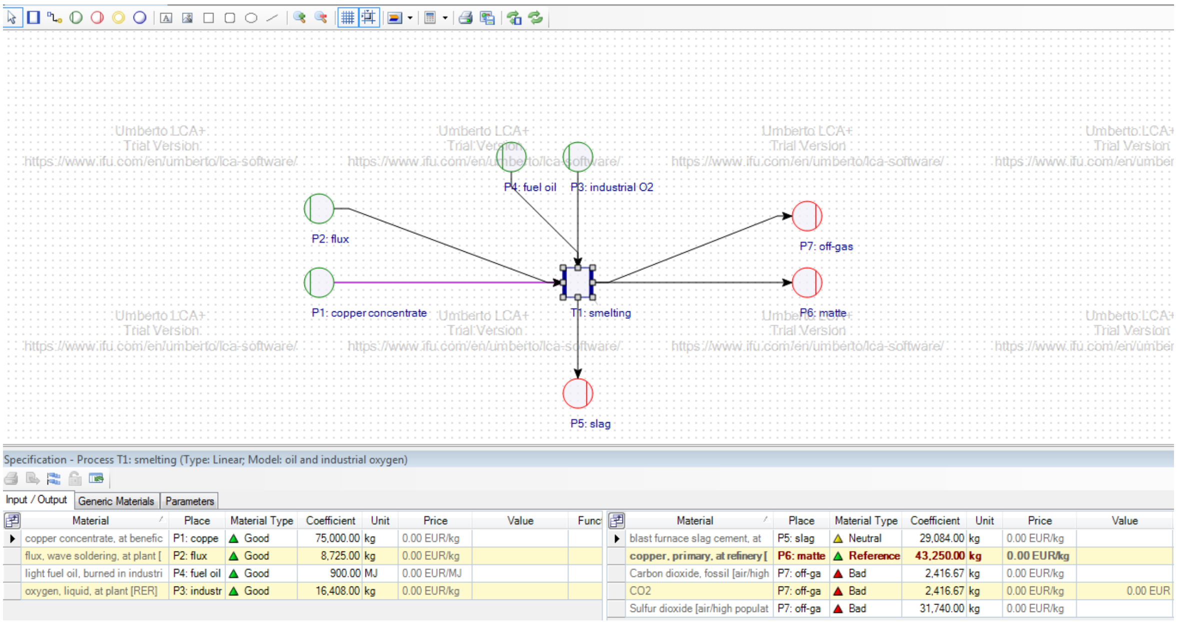
- Using the height protection equipment in order to avoid the danger of falling from 3.5 meters on. The workers should use anti-slip shoes and harness.

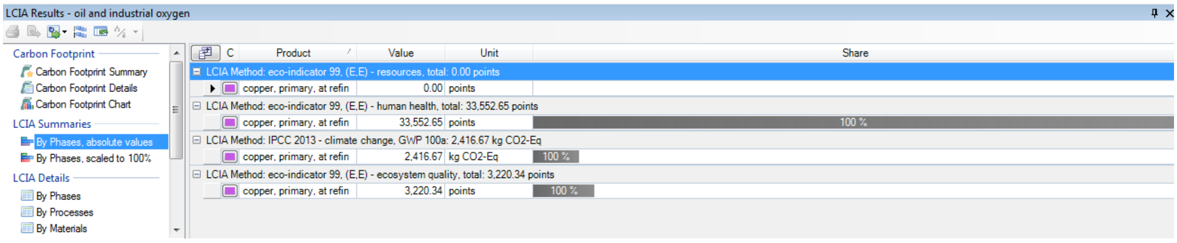
- All the tools for electric manipulation should be well isolated, and the operators must use isolating gloves.

- All the units must be disconnected and without electric current when being manipulated.

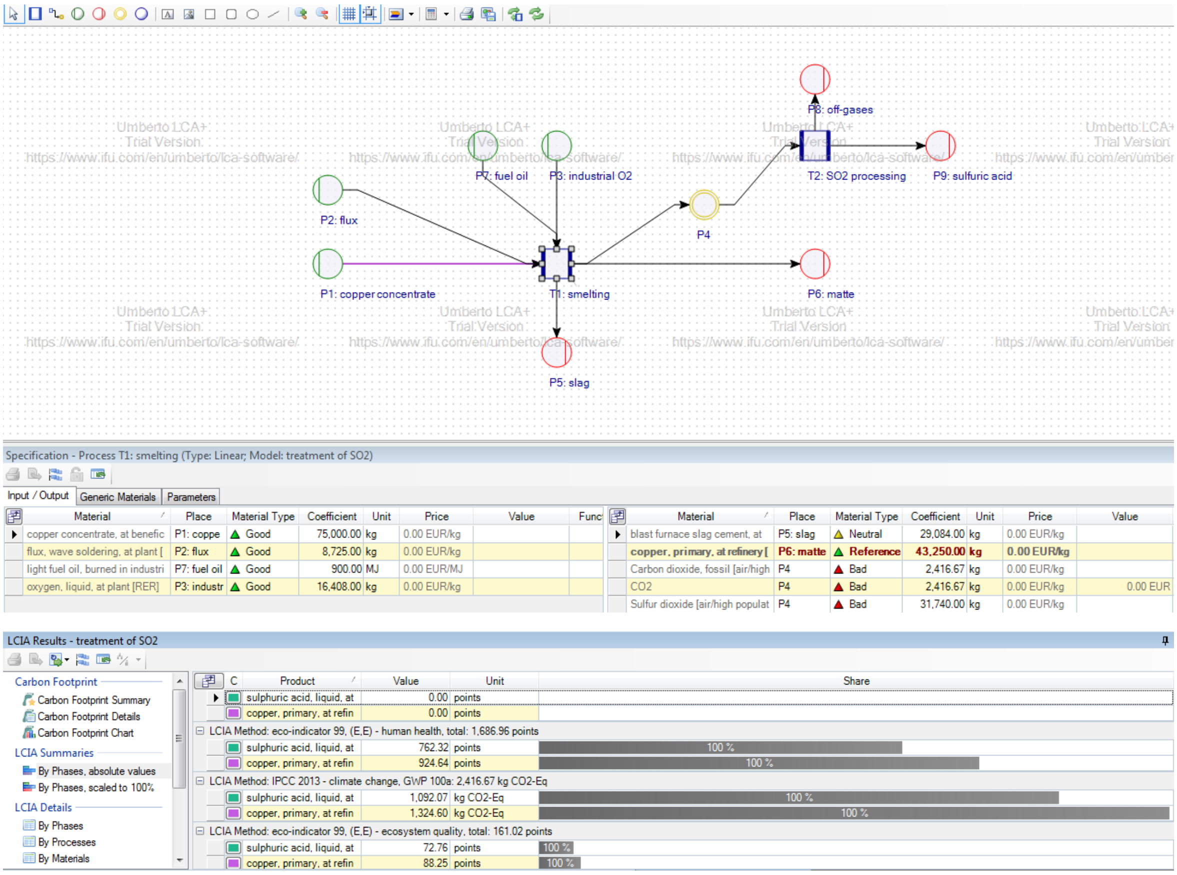
Appendix IV. Umberto

Conventional smelting without SO2 treatment

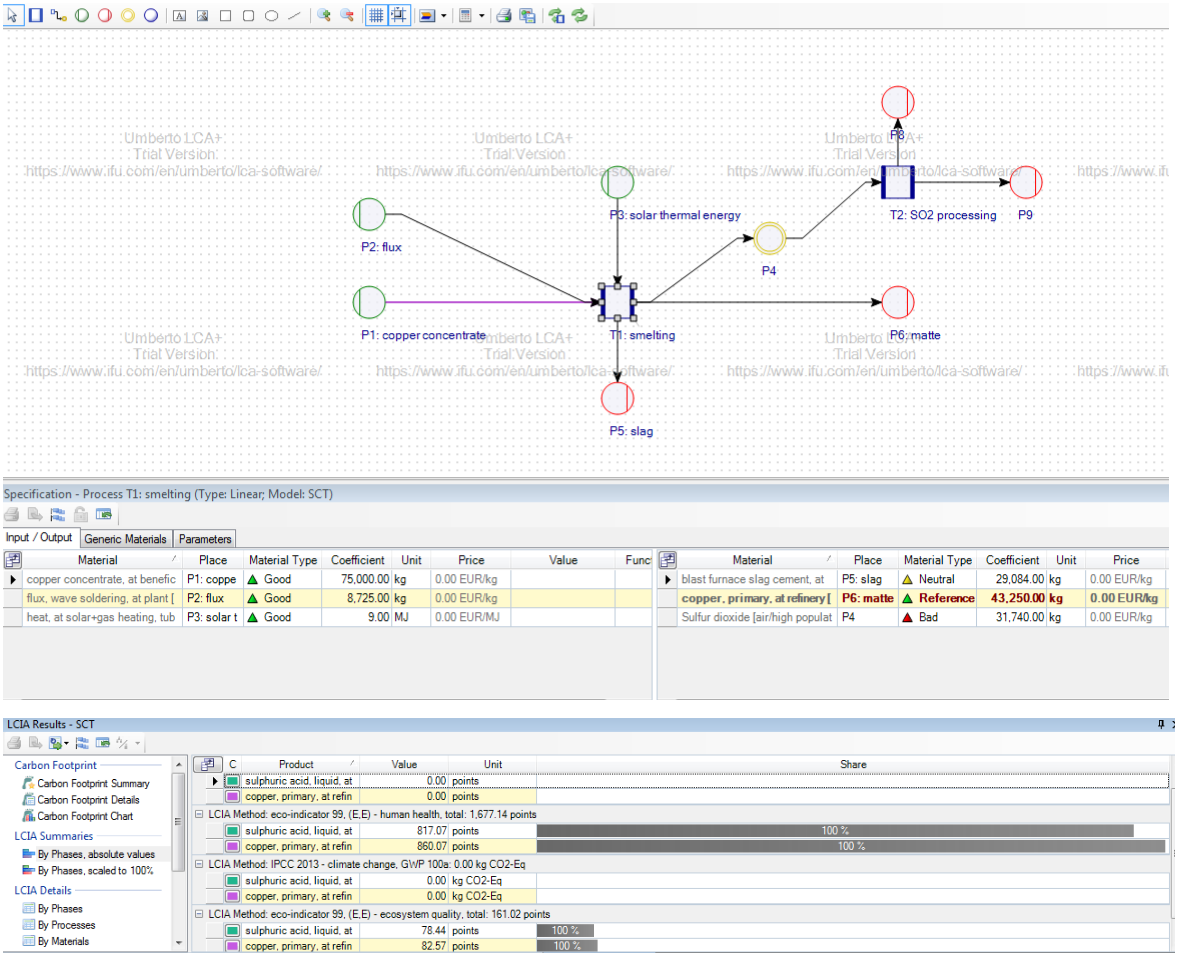




Treatment of SO2



Smelting with SCT system



Appendix IV. Catalogs

ArcelorMittal Tubular Products Ostrava

ArcelorMittal

Tubes and pipes

Production programme

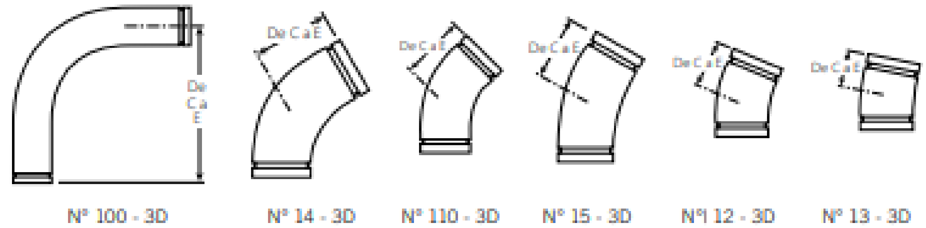
Dimensional range, weight according to API Spec 5L/ISO 3183 (44th edition, 2007)

Outside diameter		Wall thickness (in/mm)									
		5.6	6.3	7.1	8	8.8	10	11	12.5		
in	mm	Weight (lb.ft⁻¹ / kg.m⁻¹)									
12 3/4	323.9	29.34/43.96	33.41/50.11	37.46/55.47	41.48/61.56						
14	355.6	32.26/48.33	36.75/55.11	41.21/61.02	45.65/67.74						
16	406.4	36.95/55.35	42.09/63.13	47.22/69.91	52.32/77.63	57.57/85.32	62.64/92.98	67.68/100.61	72.86/108.20		
18	457	41.63/62.34	47.44/71.12	53.23/78.77	58.994/87.49	64.93/96.18	70.65/104.84	76.36/113.46	82.23/122.05	87.89/130.62	93.54/139.15
20	508	46.31/69.38	52.78/79.16	59.23/87.70	65.66/97.43	72.28/107.12	78.67/116.78	85.04/126.41	91.59/136.01	97.92/145.58	104.23/155.12
22	559		58.13/87.21	65.24/96.63	72.34/107.36	79.64/118.06	86.69/128.73	93.72/139.37	100.96/149.97	107.95/160.55	114.92/171.09
24	610		63.47/95.26	71.25/105.56	79.01/117.30	86.99/129.00	94.71/140.68	102.40/152.32	110.32/163.93	117.98/175.51	125.61/187.06
26	660			77.26/114.31	85.68/127.04	94.35/139.73	102.72/152.39	111.08/165.02	119.69/177.62	128.00/190.19	136.30/202.72
28	711			83.26/123.24	92.35/136.97	101.70/150.67	110.74/164.34	119.76/177.98	128.05/191.58	138.03/205.15	146.99/218.69
30	762[1]				99.02/146.91	109.06/162.61	118.76/176.29	128.44/190.42	138.42/205.54	148.06/220.12	157.68/234.67
32	813[1]					116.41/172.56	126.78/188.24	137.12/203.88	147.78/219.50	158.08/235.09	168.37/250.64

[1] Supplied by prior agreement.

Dimensiones

Codos de acero de radio largo - 3D



Tamaño de la conexión		Nº 100 - 3D 90º		Nº 14 - 3D 60º		Nº 110 - 3D 45º		Nº 15 - 3D 30º		Nº 12 - 3D 22 ½º		Nº 13 - 3D 11 ¼º	
Diámetro exterior nominal pulgadas mm	Diámetro exterior real pulgadas mm	De C a E pulgadas mm	Peso unitario aprox. lbs. kg	De C a E pulgadas mm	Peso unitario aprox. lbs. kg	De C a E pulgadas mm	Peso unitario aprox. lbs. kg	De C a E pulgadas mm	Peso unitario aprox. lbs. kg	De C a E pulgadas mm	Peso unitario aprox. lbs. kg	De C a E pulgadas mm	Peso unitario aprox. lbs. kg
2 50	2,375 60,3	10,00 254	5,3 2,4	7,50 191	4,3 2,0	6,50 165	3,9 1,8	5,75 146	3,4 1,5	5,25 133	3,2 1,5	4,50 114	2,8 1,3
2 ½ 65	2,875 73,0	11,50 292	9,5 4,3	8,25 210	7,7 3,5	7,25 184	6,7 3,0	6,00 152	5,8 2,6	5,50 140	5,3 2,4	4,75 121	4,6 2,1
3 80	3,500 88,9	13,00 330	14,0 6,4	9,25 235	11,0 5,0	7,75 197	9,5 4,3	6,50 165	8,0 3,6	5,75 146	7,3 3,3	5,00 127	6,2 2,8
3 ½ 90	4,000 101,6	14,50 368	18,6 8,4	10,00 254	14,4 6,5	8,50 216	12,3 5,6	6,75 172	10,2 4,6	6,00 152	9,2 4,2	5,00 127	7,6 3,4
4 100	4,500 114,3	16,00 407	24,1 10,9	11,00 279	18,5 8,4	9,00 229	15,7 7,1	7,25 184	12,8 5,8	6,50 165	11,4 5,2	5,25 133	9,3 4,2
4 ½ 120	5,000 127,0	18,00 457	31,6 14,3	12,25 311	24,2 11,0	10,00 254	20,5 9,3	8,25 210	16,8 7,6	7,25 184	14,9 6,8	5,75 146	12,2 5,5
5 125	5,563 141,3	20,00 508	40,9 18,6	13,75 349	31,3 14,2	11,25 286	26,5 12,0	9,00 229	21,8 9,9	8,00 203	19,4 8,8	6,50 165	15,8 7,2
6 150	6,625 168,3	24,00 610	63,7 28,9	16,50 419	48,8 22,1	13,50 343	41,3 18,7	10,75 273	33,9 15,4	9,50 241	30,1 13,7	7,75 197	24,6 11,2
8 200	8,625 219,1	32,00 813	127,8 58,0	22,00 559	97,9 44,4	18,00 457	82,9 37,6	14,50 368	68,0 30,8	12,75 324	60,5 27,4	10,50 267	49,3 22,4
10 250	10,750 273,0	40,00 1016	226,4 102,7	27,25 692	173,4 78,7	22,50 572	146,9 66,6	18,00 457	120,5 54,7	16,00 406	107,2 48,6	13,00 330	87,3 39,6
12 300	12,750 323,9	48,00 1219	332,7 150,9	32,75 832	254,8 115,6	27,00 686	215,9 97,9	21,75 553	177,0 80,3	19,25 489	157,5 71,4	15,50 394	128,3 58,2
14 350	14,000 355,6	56,00 1422	427,3 193,8	38,25 972	327,3 148,5	31,50 800	277,3 125,8	25,25 641	227,3 103,1	22,50 572	202,3 91,8	18,25 464	164,8 74,8
15 375	15,000 381,0	60,00 1524	480,8 218,1	41,00 1041	368,3 167,1	33,75 857	312,0 141,5	27,00 656	255,8 116,0	24,00 610	227,6 103,2	19,50 495	185,4 84,1
16 400	16,000 406,4	64,00 1626	560,1 254,1	43,75 1111	429,0 194,6	36,00 914	363,5 164,9	29,00 737	297,9 135,1	25,50 648	265,2 120,3	20,75 527	216,0 98,0
18 450	18,000 457,2	72,00 1829	710,7 322,4	49,25 1251	544,4 246,9	40,50 1029	461,3 209,2	32,50 826	378,1 171,5	28,75 730	336,5 152,6	23,25 591	274,1 124,3
20 500	20,000 508,0	80,00 2032	879,3 398,9	54,75 1391	673,5 305,5	45,00 1143	540,7 245,3	36,00 914	467,8 212,2	32,00 813	416,3 188,8	26,00 660	339,2 153,9
22 550	22,000 559,0	88,00 2235	1067,7 484,3	60,25 1530	817,9 371,0	49,25 1251	692,9 314,3	39,75 1010	568,0 257,6	35,25 895	505,2 229,2	28,50 724	411,8 186,8
24 600	24,000 609,6	96,00 2438	1270,3 576,2	65,50 1664	973,0 441,4	53,75 1365	824,4 373,9	43,25 1099	675,7 306,5	38,25 972	601,4 272,8	31,00 787	490,0 222,3

Notas generales

Los codos de radio largo (3D, 5D y 6D) de hasta 4" se suministran con una tangente integral de 4". Los tamaños restantes tienen tangentes integrales de igual longitud que el tamaño nominal de la tubería.

Disponibles con extremo ranurado y extremo plano. Especifique su preferencia en el pedido.

La flexión se adapta a los radios anteriores.

Tolerancias de C a E: 2 - 6" ± ⅛"; 8 - 15" ± ⅛"; 16 - 24" ± ⅛"

Todos los pesos son aproximados y se basan en el peso calculado de la tubería.

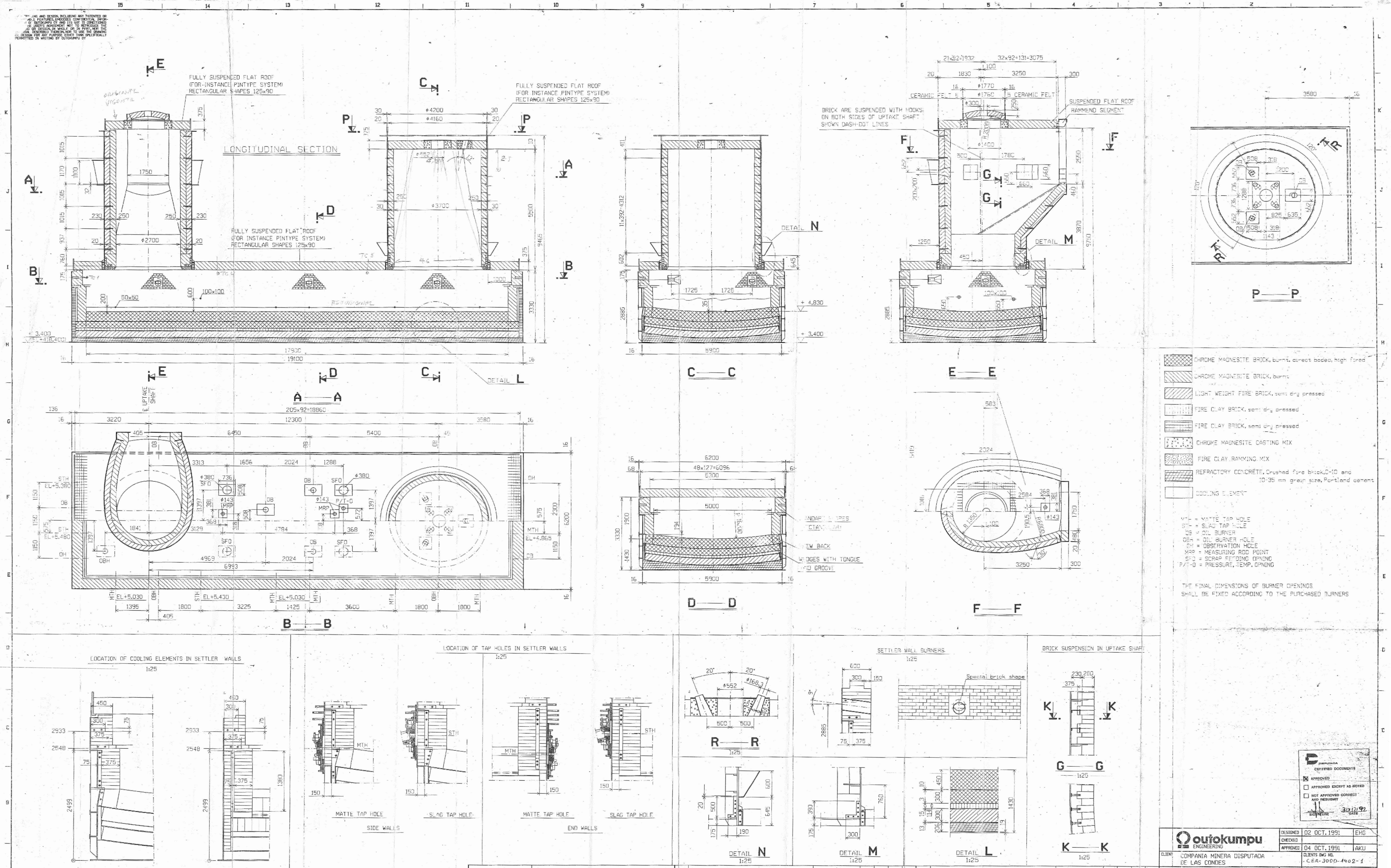
Material: tubería es acero de pared estándar conforme a la norma ASTM A-53, Clase B (hay otros materiales disponibles a pedido).

Appendix V. Plans

This Appendix provides the plans considered for the design of the technical drawings and the theorical developments of the *Chapters VI, VII and VIII* of the *Main Text*.

The plans included in this Appendix are:

- Technical plans for the Outokumpu Flash Furnace in the Chagres facilities.
- Heliostat design (credits to the Stellerborsch University)



REVISION NO.	REVISIONS	DATE	DRAWN	CHECKED	APPROVED
3	REVISED	31 DEC 1992	EHG	KPe	AKU
2	COMPLETED	26 MAR.1992	EHG		AKU
1	REVISED	17 DEC. 1991	EHG		AKU
0	FOR FSF DETAIL DESIGN	02 OCT. 1991	EHG		AKU

outokumpu ENGINEERING

DESIGNED	02 OCT. 1991	EHG
CHECKED		
APPROVED	04 OCT. 1991	AKU

CLIENT: COMPANIA MINERA DISPUTADA DE LAS CONDES

CLIENTS DWG NO.: CER-3000-1402-1

PROJECT: CHAGRES SMELTER EXPANSION

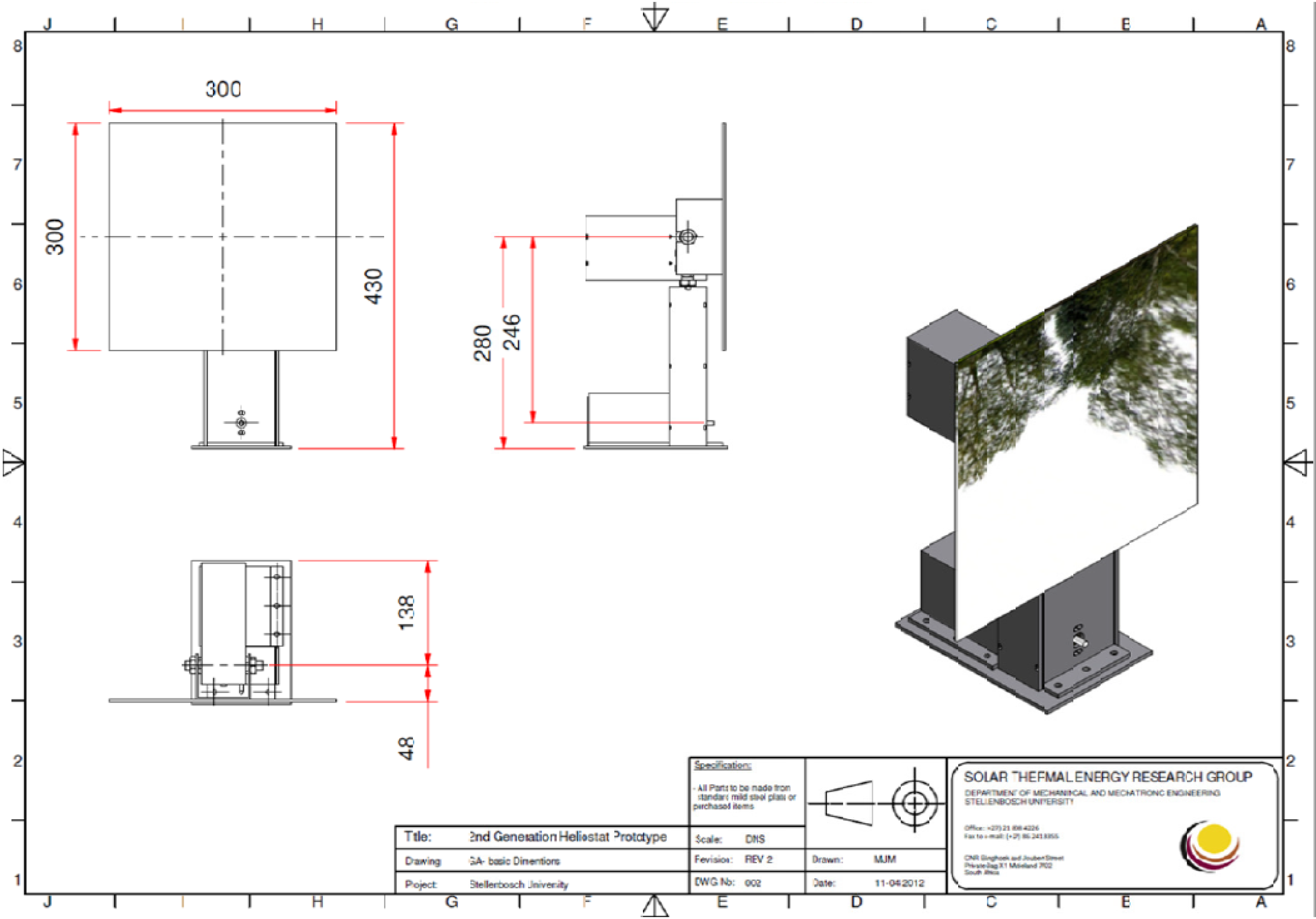
3200-ME-C382

DRAWING TITLE: TAG. 3000-1402-00 FLASH SMELTING FURNACE REFRACTORY LINING

SCALE: 1:50

REF. DWG

DWG NO.: 484 300 261 001-0



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Specification:
- All Parts to be made from standard mild steel plate or purchased items
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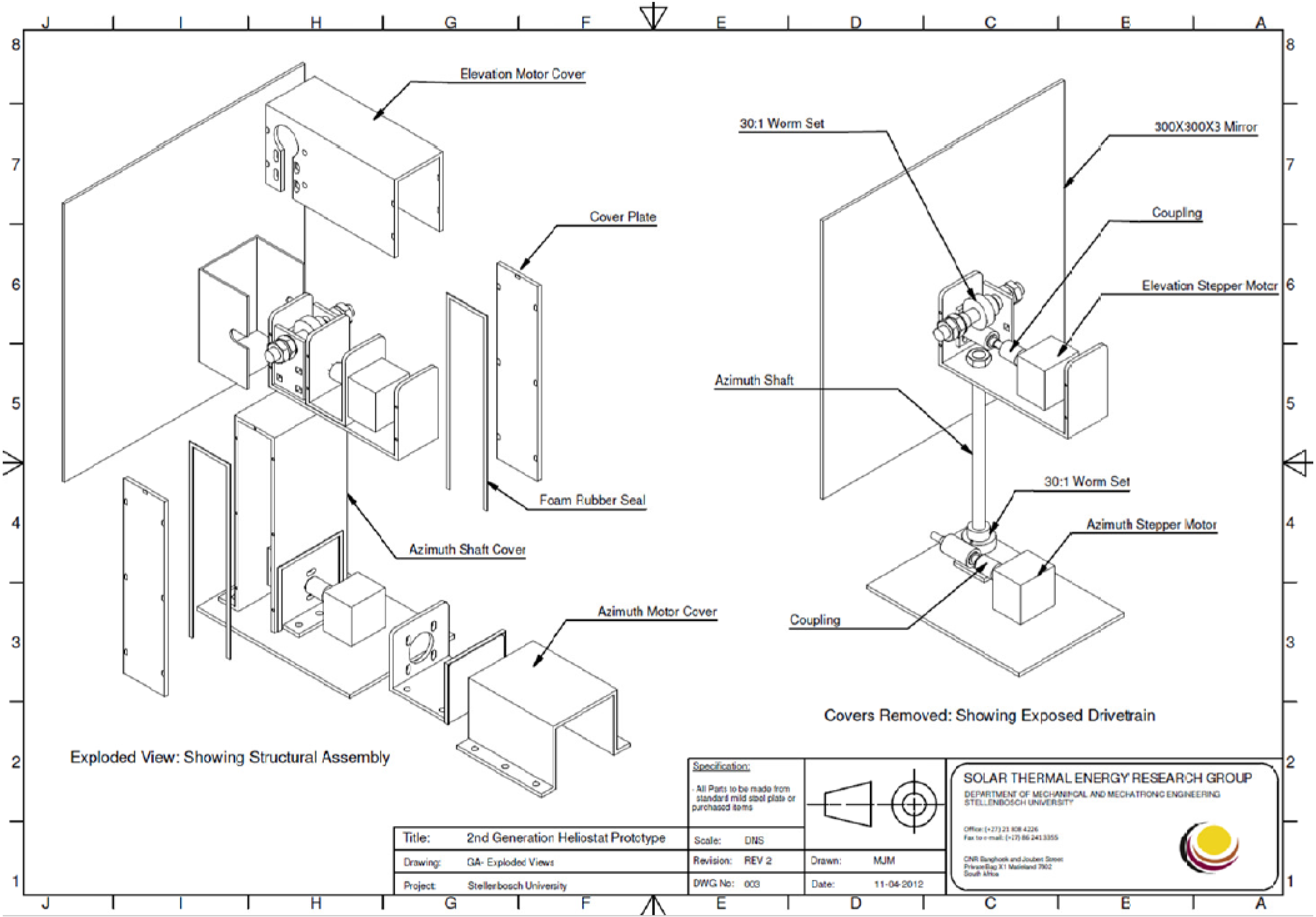
Drawing: GA- basic Dimentions
Project: Stellenbosch University
Scale: DNS
Revision: REV 2
DWG No: 002
Drawn: MJM
Date: 11-04-2012
SOLAR THERMAL ENERGY RESEARCH GROUP
DEPARTMENT OF MECHANICAL AND MECHATRONIC ENGINEERING
STELLENBOSCH UNIVERSITY


Elevation Motor Cover
Cover Plate
Foam Rubber Seal
Azimuth Shaft Cover
Azimuth Motor Cover
Exploded View: Showing Structural Assembly
30:1 Worm Set
300X300X3 Mirror
Coupling
Elevation Stepper Motor
Azimuth Shaft
30:1 Worm Set
Azimuth Stepper Motor
Coupling
Covers Removed: Showing Exposed Drivetrain
Specification:
- All Parts to be made from standard mild steel plate or purchased items
Title: 2nd Generation Heliostat Prototype
Drawing: GA- Exploded Views
Project: Stellenbosch University
Scale: DNS
Revision: REV 2
DWG No: 003
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Date: 11-04-2012
SOLAR THERMAL ENERGY RESEARCH GROUP
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STELLENBOSCH UNIVERSITY

Technical drawings

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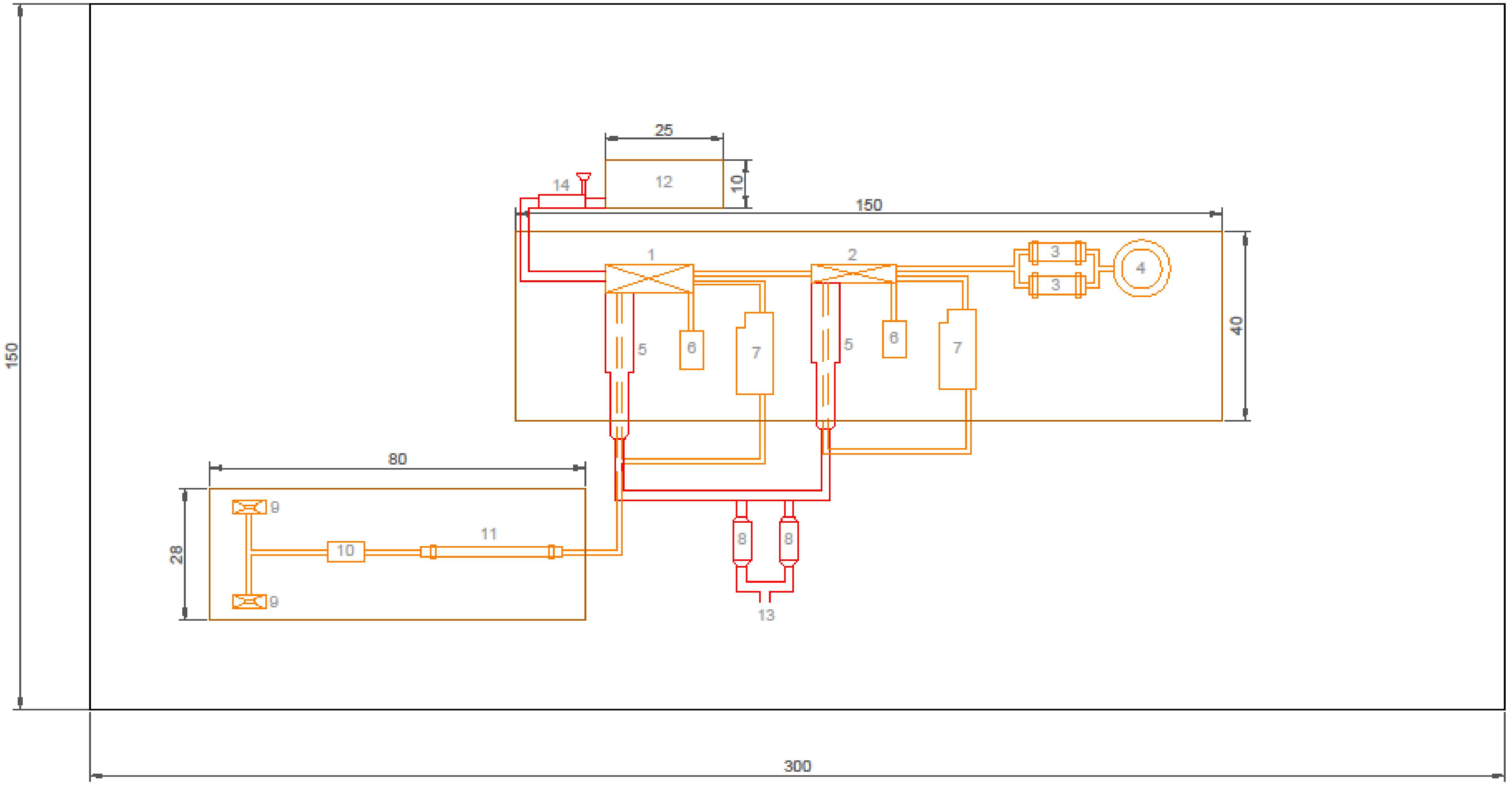
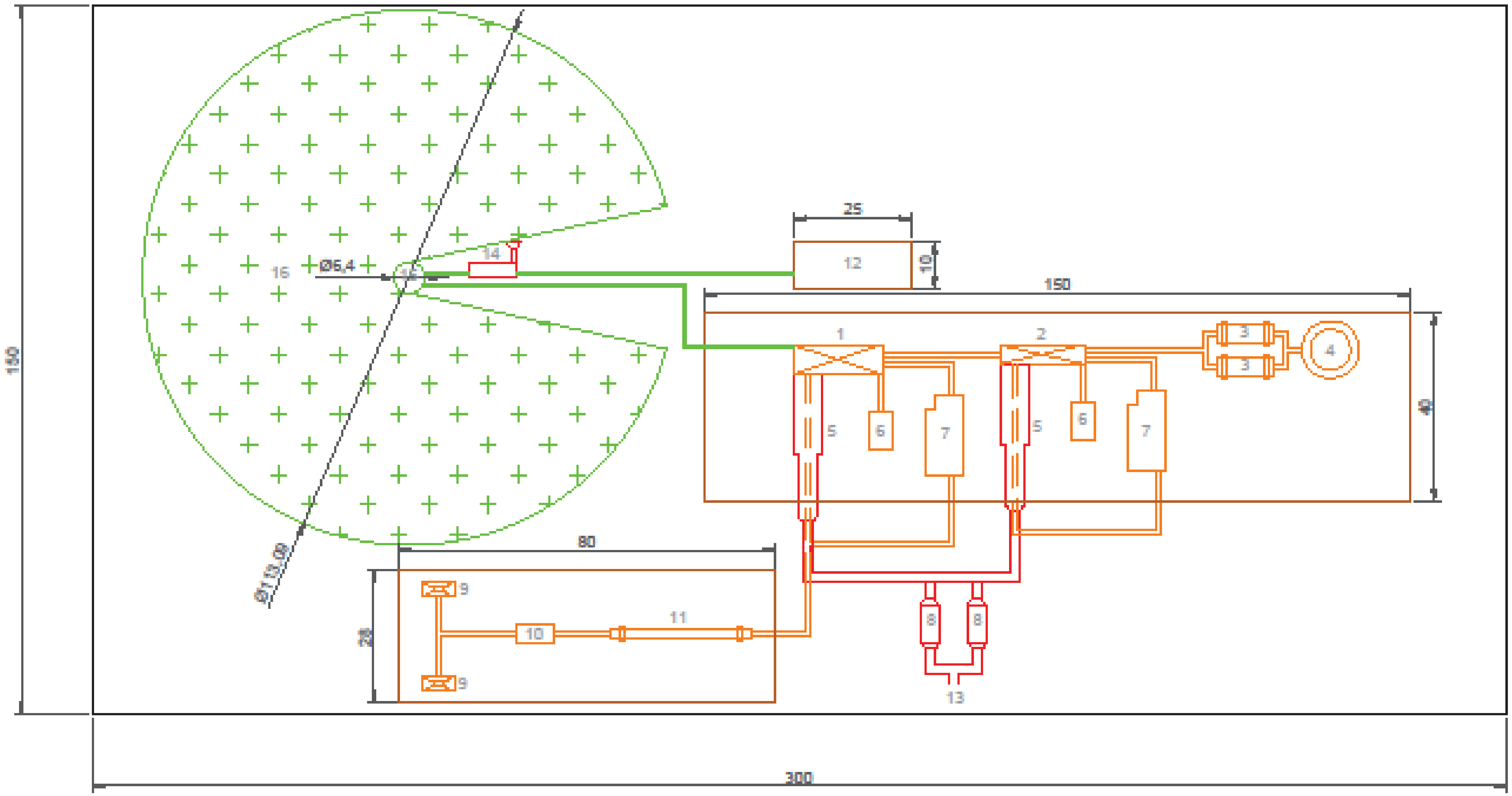


Nº	Description	Nº	Description
1	OUTOKUMPU FLASH FURNACE	8	ELECTROSTATIC PRECIPITATOR
2	CONVERTER	9	HOPPER (FLUX AND CONCENTRATE)
3	ANNODE FURNACE	10	MIXER
4	CASTING WHEEL	11	DRYER
5	BOILER	12	OXYGEN PLANT
6	SCRAP PIT	13	TO SULFURIC ACID PLANT
7	SLAG GRANULATION PIT	14	TURBINE AND BLAST REGULATION

Plant boundaries
Solid conveyors and processing
Gas conduction and processing

CHEMICAL ENGINEERING	TFG	Pau Parra Ramos
UNIVERSITAT JAUME·I	Scale: 1:1000	Document nature: Floor plan
	Format: A3	
	Title: Conventional smelting plant	Units: m
	Date: 06/09/2019	Number: 1/3

PRODUCED BY AN AUTODESK STUDENT VERSION



Nº	Description	Nº	Description	Nº	Description
1	OUTOKUMPU FLASH FURNACE	8	ELECTROSTATIC PRECIPITATOR	15	SOLAR CENTRAL TOWER
2	CONVERTER	9	HOPPER (FLUX AND CONCENTRATE)	16	HELIOSTAT FIELD
3	ANNODE FURNACE	10	MIXER		
4	CASTING WHEEL	11	DRYER		
5	BOILER	12	OXYGEN PLANT		
6	SCRAP PIT	13	TO SULFURIC ACID PLANT		
7	SLAG GRANULATION PIT	14	TURBINE AND BLAST REGULATION		

Plant boundaries
Solid conveyors and processing
Gas conduction and processing
New structures for the SCT system

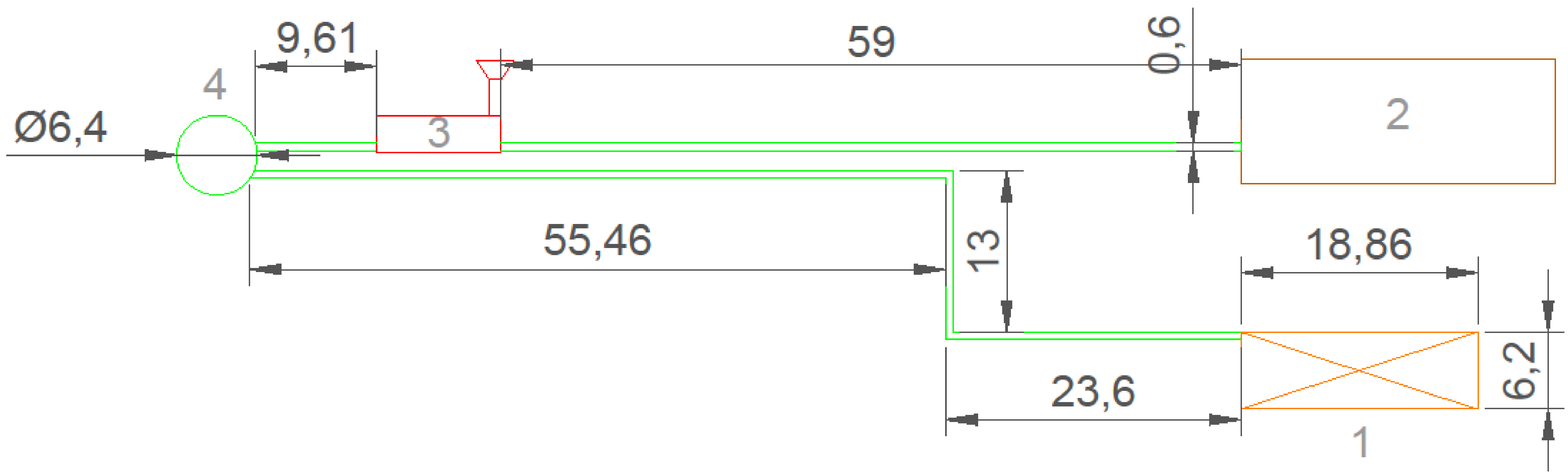
CHEMICAL ENGINEERING | TFG

UNIVERSITAT JAUME I

Pau Parra Ramos

Scale: 1:1000
Document nature: Floor plan
Format: A3

Title: Smelting plant improved by SCT technology
Units: m
Date: 06/09/2019
Number: 2/3



Nº	Description
1	OUTOKUMPU FLASH FURNACE
2	OXYGEN PLANT
3	TURBINE AND BLAST REGULATION
4	SOLAR CENTRAL TOWER

Plant boundaries
Solid conveyors and processing
Gas conduction and processing
New structures for the SCT system

CHEMICAL ENGINEERING | TFG

Pau Parra Ramos

Universitat Jaume·I

Scale: 1:300
Document nature: Floor plan
Format: A3
Title: SCT system
Units: m
Date: 06/09/2019
Number: 3/3

Conditions statement

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In this section, it’s discussed the conditions statement related to the construction of a SCT system for a smelting process inside the Spanish territory. In order to make the project as realistic as possible, through this section it’s considered that the project is developed for the Outokumpu flash furnace of Atlantic Copper, in Huelva.

Because the legal affectation of this section, the original language of the country where the project would be developed is used (Spanish).

1. DISPOSICIONES GENERALES

1.1. Objeto del Pliego de Condiciones

El objeto de este Pliego es fijar los criterios de la relación que se establece entre los agentes que intervienen en las obras definidas en el presente proyecto y servir de base para la realización del contrato de obra entre el promotor y el contratista. Se detallan las condiciones técnicas mínimas que deben cumplir las instalaciones solares térmicas, especificando los requisitos de durabilidad, fiabilidad y seguridad.

1.2. Generalidades

Las instalaciones recogidas bajo este Pliego le son de aplicación el Reglamento de Instalaciones Térmicas en Edificios (RITE), y sus Instrucciones Técnicas (IT), junto con la serie de normas UNE sobre la energía solar térmica, así como lo dispuesto en el Código Técnico de la Edificación (CTE) sobre la energía solar térmica.

En caso de discrepancias entre el presente Pliego y lo dispuesto en el RITE o CTE, siempre prevalecerán los puntos específicos de estos por sobre las condiciones técnicas expuestas en el Pliego.

1.3. Fluido de trabajo

Como fluido de trabajo en el circuito primario de Solar Central Tower se utilizará aire combinado con oxígeno industrial, cuya composición exacta dependerá de las características climatológicas del lugar.

El diseño de los circuitos evitará cualquier tipo de fuga o mezcla una vez la corriente de soplado haya sido tratada, manteniéndose constante la composición de dicho fluido.

1.4. Sobrecalentamientos

1.4.1. Protección contra sobrecalentamientos

El sistema deberá estar diseñado de tal forma que con altas radiaciones prolongadas sin circulación de aire enriquecido, no se produzcan situaciones en las cuales el usuario tenga que realizar alguna acción especial para llevar al sistema a su forma normal de operación.

Cuando el sistema disponga de la posibilidad de drenajes como protección ante sobrecalentamientos, la construcción deberá realizarse de tal forma que el aire caliente no suponga ningún peligro para los trabajadores y no se produzcan daños en el sistema.

1.4.2. Protección contra quemaduras

En los puntos donde el sistema pueda poner en riesgo la integridad de los trabajadores, deberá ser instalado in sistema de reducción de temperatura, aunque en la parte solar pueda alcanzar una temperatura superior para sufragar pérdidas. Este sistema deberá ser capaz de soportar la máxima temperatura posible de extracción del sistema solar.

1.4.3. Protección de materiales y componentes contra altas temperaturas

El sistema deberá ser diseñado de tal forma que nunca se exceda la máxima temperatura permitida por todos los materiales y componentes.

1.4.4. Resistencia a presión

Se deberán cumplir los requisitos de la norma UNE-EN 12976-1.

En caso de sistemas de consumo abiertos con conexión a la red, se tendrá en cuenta la máxima presión de la misma para verificar que todos los componentes del circuito de consumo soportan dicha presión.

1.4.5. Prevención de flujo inverso

La instalación del sistema deberá asegurar que no se produzcan pérdidas energéticas relevantes debidas a flujos inversos no intencionados en ningún circuito hidráulico del sistema.

La circulación natural que produce el flujo inverso se puede favorecer cuando el acumulador se encuentra por debajo del captador, por lo que habrá que tomar, en esos casos, las precauciones oportunas para evitarlo.

En sistemas con circulación forzada se aconseja utilizar una válvula anti-retorno para evitar flujos inversos.

1.1. Contrato de obra

Se recomienda la contratación de la ejecución de las obras por unidades de obra, con arreglo a los documentos del proyecto y en cifras fijas. A tal fin, el director de obra ofrece la documentación necesaria para la realización del contrato de obra.

1.2. Documentación del contrato de obra

Integran el contrato de obra los siguientes documentos, relacionados por orden de prelación atendiendo al valor de sus especificaciones, en el caso de posibles interpretaciones, omisiones o contradicciones:

- Las condiciones fijadas en el contrato de obra.
- El presente Pliego de Condiciones.
- La documentación gráfica y escrita del Proyecto: planos generales y de detalle, memorias, anexos, mediciones y presupuestos.

En el caso de interpretación, prevalecen las especificaciones literales sobre las gráficas y las cotas sobre las medidas a escala tomadas de los planos.

1.3. Proyecto Arquitectónico

El Proyecto Arquitectónico se define como el conjunto de documentos que definen y determinan las exigencias técnicas, funcionales y estéticas de las obras contempladas en la

"Ley 38/1999. Ley de Ordenación de la Edificación". En él se justificará técnicamente las soluciones propuestas de acuerdo con las especificaciones requeridas por la normativa técnica aplicable.

Los documentos complementarios al Proyecto serán:

- Los planos.
- El Libro de Órdenes y Asistencias.
- El Programa de Control de Calidad de Edificación y su Libro de Control.
- El Estudio de Seguridad y Salud o Estudio Básico de Seguridad y Salud en las obras.
- El Plan de Seguridad y Salud en el Trabajo, elaborado por cada contratista.
- Estudio de Gestión de Residuos de Construcción y Demolición.
- Licencias y otras autorizaciones administrativas.

1.4. Reglamentación urbanística

La obra a construir se ajustará a todas las limitaciones del proyecto aprobado por los organismos competentes, especialmente las que se refieren al volumen, alturas, emplazamiento y ocupación del solar, así como a todas las condiciones de reforma del proyecto que pueda exigir la Administración para ajustarlo a las Ordenanzas, a las Normas y al Planeamiento Vigente.

1.5. Formalización del Contrato de Obra

Los Contratos se formalizarán, en general, mediante documento privado, que podrá elevarse a escritura pública a petición de cualquiera de las partes.

El contratista, antes de la formalización del contrato de obra, dará también su conformidad con la firma al pie del Pliego de Condiciones, los Planos, Cuadro de Precios y Presupuesto General. Serán a cuenta del adjudicatario todos los gastos que ocasione la extensión del documento en que se consigne el contratista.

1.6. Jurisdicción competente

En el caso de no llegar a un acuerdo cuando surjan diferencias entre las partes, ambas quedan obligadas a someter la discusión de todas las cuestiones derivadas de su contrato a las Autoridades y Tribunales Administrativos con arreglo a la legislación vigente, renunciando al derecho común y al fuero de su domicilio, siendo competente la jurisdicción de Huelva, provincia de Huelva.

1.7. Ejecución de las obras y responsabilidad del contratista

Las obras se ejecutarán con estricta sujeción al proyecto que sirve de base al contrato y conforme a las instrucciones que la Dirección Facultativa de las obras diere al contratista.

El contratista es responsable de la ejecución de las obras y de todos los defectos que en la construcción puedan advertirse durante el desarrollo de las obras y hasta que se cumpla el plazo de garantía, en las condiciones establecidas en el contrato y en los documentos que componen el Proyecto.

En consecuencia, quedará obligado a la demolición y reconstrucción de todas las unidades de obra con deficiencias o mal ejecutadas, sin que pueda servir de excusa el hecho de que la Dirección Facultativa haya examinado y reconocido la construcción durante sus visitas de obra, ni que hayan sido abonadas en liquidaciones parciales.

1.8. Accidentes de trabajo

Es de obligado cumplimiento el "Real Decreto 1627/1997. Disposiciones mínimas de seguridad y de salud en las obras de construcción" y demás legislación vigente que, tanto directa como indirectamente, inciden sobre la planificación de la seguridad y salud en el trabajo de la construcción, conservación y mantenimiento de edificios.

1.9. Daños y perjuicios a terceros

El contratista será responsable de todos los accidentes que, por inexperiencia o descuido, sobrevinieran tanto en la edificación donde se efectúen las obras como en las colindantes o contiguas. Será por tanto de su cuenta el abono de las indemnizaciones a quien corresponda y cuando a ello hubiere lugar, y de todos los daños y perjuicios que puedan ocasionarse o causarse en las operaciones de la ejecución de las obras.

Asimismo, será responsable de los daños y perjuicios directos o indirectos que se puedan ocasionar frente a terceros como consecuencia de la obra, tanto en ella como en sus alrededores, incluso los que se produzcan por omisión o negligencia del personal a su cargo, así como los que se deriven de los subcontratistas e industriales que intervengan en la obra.

Es de su responsabilidad mantener vigente durante la ejecución de los trabajos una póliza de seguros frente a terceros, en la modalidad de "Todo riesgo al derribo y la construcción", suscrita por una compañía aseguradora con la suficiente solvencia para la cobertura de los trabajos contratados. Dicha póliza será aportada y ratificada por el promotor, no pudiendo ser cancelada mientras no se firme el Acta de Recepción Provisional de la obra.

1.10. Anuncios y carteles

Sin previa autorización del promotor, no se podrán colocar en las obras ni en sus vallas más inscripciones o anuncios que los convenientes al régimen de los trabajos y los exigidos por la policía local.

1.11. Copia de documentos

El contratista, a su costa, tiene derecho a sacar copias de los documentos integrantes del Proyecto.

1.12. Causas de rescisión del contrato de obra

Se considerarán causas suficientes de rescisión de contrato:

- La muerte o incapacitación del contratista.
- La quiebra del contratista.
- Las alteraciones del contrato por las causas siguientes:
    a. La modificación del proyecto en forma tal que represente alteraciones fundamentales del mismo a juicio del director de obra y, en cualquier caso,

siempre que la variación del Presupuesto de Ejecución Material, como consecuencia de estas modificaciones, represente una desviación mayor del 20%.

b. Las modificaciones de unidades de obra, siempre que representen variaciones en más o en menos del 40% del proyecto original, o más de un 50% de unidades de obra del proyecto reformado.
c. La suspensión de obra comenzada, siempre que el plazo de suspensión haya excedido de un año y, en todo caso, siempre que por causas ajenas al contratista no se dé comienzo a la obra adjudicada dentro del plazo de tres meses a partir de la adjudicación. En este caso, la devolución de la fianza será automática.

- La suspensión de la iniciación de las obras por plazo superior a cuatro meses.
- Que el contratista no comience los trabajos dentro del plazo señalado en el contrato.
- La demora injustificada en la comprobación del replanteo.
- La suspensión de las obras por plazo superior a ocho meses por parte del promotor.
- El incumplimiento de las condiciones del Contrato cuando implique descuido o mala fe, con perjuicio de los intereses de las obras.
- El vencimiento del plazo de ejecución de la obra.
- El desistimiento o el abandono de la obra sin causas justificadas.
- La mala fe en la ejecución de la obra.

1.13. Efectos de rescisión del contrato de obra

La resolución del contrato dará lugar a la comprobación, medición y liquidación de las obras realizadas con arreglo al proyecto, fijando los saldos pertinentes a favor o en contra del contratista.

Si se demorase injustificadamente la comprobación del replanteo, dando lugar a la resolución del contrato, el contratista sólo tendrá derecho por todos los conceptos a una indemnización equivalente al 2% del precio de la adjudicación, excluidos los impuestos.

En el supuesto de desistimiento antes de la iniciación de las obras, o de suspensión de la iniciación de las mismas por parte del promotor por plazo superior a cuatro meses, el contratista tendrá derecho a percibir por todos los conceptos una indemnización del 3% del precio de adjudicación, excluidos los impuestos.

En caso de desistimiento una vez iniciada la ejecución de las obras, o de suspensión de las obras iniciadas por plazo superior a ocho meses, el contratista tendrá derecho por todos los conceptos al 6% del precio de adjudicación del contrato de las obras dejadas de realizar en concepto de beneficio industrial, excluidos los impuestos.

2. CRITERIOS GENERALES DE DISEÑO

2.1. Dimensionado y cálculo

A los efectos de este Pliegue, el dimensionado básico de las instalaciones o sistemas a medida se refiere a la selección de la superficie de captadores solares y, en caso de que exista, al volumen de acumulación solar, para la aplicación a la que está destinada la instalación.

El dimensionado básico de una instalación, para cualquier aplicación, deberá realizarse de forma que en ningún mes del año la energía producida por la instalación solar supere el 110% de la demanda de consumo y no más de tres meses seguidos el 100%. A estos efectos, y para instalaciones de un marcado carácter estacional, no se tomarán en consideración aquellos períodos de tiempo en los cuales la demanda se sitúe un 50 % debajo de la media correspondiente al resto del año.

El rendimiento de la instalación se refiere sólo a la parte solar de la misma. A estos efectos, se definen los conceptos de fracción solar y rendimiento medio estacional o anual de la siguiente forma:

- Fracción solar mes “x” = (Energía solar aportada el mes “x”/ Demanda energética durante el mes “x”) ×100
- Fracción solar año “y” = (Energía solar aportada el año “y” / Demanda energética durante el año “y”) ×100
- Rendimiento medio año “y” = (Energía solar aportada el año “y” / Irradiación incidente año “y”) × 100
- Irradiación incidente año “y” = Suma de las irradiaciones incidentes de los meses del año “y”
- Irradiaciones incidentes en el mes “x” = Irradiación en el mes “x” × Superficie captadora

El concepto de energía solar aportada el año “y” se refiere a la energía demandada realmente satisfecha por la instalación de energía solar. Esto significa que para su cálculo nunca podrá considerarse más de un 100 % de aporte solar en un determinado mes.

Para el cálculo del dimensionado básico de instalaciones a medida podrá utilizarse cualquiera de los métodos de cálculo comerciales de uso aceptado por proyectistas, fabricantes e instaladores. El método de cálculo especificará, al menos sobre base mensual, los valores medios diarios de la demanda de energía y del aporte solar. Asimismo, el método de cálculo incluirá las prestaciones globales anuales definidas por:

- La demanda de energía térmica.
- La energía solar térmica aportada.
- Las fracciones solares medias mensuales y anual.
- El rendimiento medio anual.

La selección del sistema solar prefabricado se realizará a partir de los resultados de ensayo del sistema, teniendo en cuenta que tendrá también que cumplir lo especificado en el RITE.

2.2. *Diseño del sistema de captación*

2.2.1. Generalidades

El captador seleccionado deberá poseer la certificación emitida por un organismo competente en la materia, según la legislación vigente.

A efectos de este Pliegue, será necesaria la presentación de la certificación de los ensayos del captador realizados por laboratorio acreditado, así como las curvas de rendimiento obtenidas por el citado laboratorio.

2.2.2. Orientación, inclinación, sombras e integración arquitectónica

La orientación e inclinación del sistema de heliostats y las posibles sombras sobre el mismo serán tales que las pérdidas respecto al óptimo, sean inferiores a los límites de la *Tabla CS 1*. Se considerarán dos casos: general y superposición de heliostats. En todos los casos se han de cumplir tres condiciones: pérdidas por orientación e inclinación, pérdidas por sombreado y pérdidas totales inferiores a los límites estipulados respecto a los valores óptimos.

Table CS 1: Pérdidas respecto a la disposición óptima

	Orientación e inclinación (OI)	Sombras (S)	Total (OI+S)
General	10 %	10 %	15 %
Superposición	20 %	15 %	30 %

Se considera la dirección Sur como orientación óptima y la mejor inclinación, dependiendo del período de utilización, uno de los valores siguientes:

- Consumo constante anual: la latitud geográfica
- Consumo preferente en invierno: la latitud geográfica +10°
- Consumo preferente en verano: la latitud geográfica -10°

2.2.3. Estructura soporte

Si el sistema posee una estructura soporte que es montada normalmente en el exterior, el fabricante deberá especificar los valores máximos de s_k (carga de nieve) y v_m (velocidad media de viento) de acuerdo con ENV 1991-2-3 y ENV 1991-2-4.

Esto deberá verificarse durante el diseño calculando los esfuerzos de la estructura soporte de acuerdo con estas normas.

El sistema sólo podrá ser instalado en localizaciones donde los valores de s_k y v_m determinados de acuerdo con ENV 1991-2-3 y ENV 1991-2-4 sean menores que los valores máximos especificados por el fabricante.

El diseño y la construcción de la estructura y el sistema de fijación de captadores, permitirá las necesarias dilataciones térmicas, sin transmitir cargas que puedan afectar a la integridad de los captadores o al circuito hidráulico.

Los puntos de sujeción del captador serán suficientes en número, teniendo el área de apoyo y posición relativa adecuadas, de forma que no se produzcan flexiones en el captador superiores a las permitidas por el fabricante.

Los topes de sujeción de los captadores y la propia estructura no arrojarán sombra sobre estos últimos.

2.3. Diseño del sistema eléctrico y de control

El diseño del sistema de control asegurará el correcto funcionamiento de las instalaciones, procurando obtener un buen aprovechamiento de la energía solar captada y asegurando un uso adecuado de la energía auxiliar. El sistema de regulación y control comprende los siguientes sistemas:

- Control de funcionamiento del circuito primario y secundario (si existe).
- Sistemas de protección y seguridad de las instalaciones contra sobrecalentamientos, heladas, etc.

El sistema de control asegurará que en ningún caso se alcancen temperaturas superiores a las máximas soportadas por los materiales, componentes y tratamientos de los circuitos.

3. DISPOSICIONES FACULTATIVAS

3.1. Definición, atribuciones y obligaciones de los agentes de la edificación

Las atribuciones de los distintos agentes intervinientes en la edificación son las reguladas por la "Ley 38/1999. Ley de Ordenación de la Edificación".

Se definen agentes de la edificación todas las personas, físicas o jurídicas, que intervienen en el proceso de la edificación. Sus obligaciones quedan determinadas por lo dispuesto en la "Ley 38/1999. Ley de Ordenación de la Edificación" y demás disposiciones que sean de aplicación y por el contrato que origina su intervención.

Las definiciones y funciones de los agentes que intervienen en la edificación quedan recogidas a continuación:

3.1.1. El promotor

Es la persona física o jurídica, pública o privada, que individual o colectivamente decide, impulsa, programa y financia con recursos propios o ajenos, las obras de edificación para sí o para su posterior enajenación, entrega o cesión a terceros bajo cualquier título.

Asume la iniciativa de todo el proceso de la edificación, impulsando la gestión necesaria para llevar a cabo la obra proyectada, y se hace cargo de todos los costes necesarios.

Según la legislación vigente, a la figura del promotor se equiparán también las de gestor de sociedades cooperativas, comunidades de propietarios, u otras análogas que asumen la gestión económica de la edificación.

3.1.2. El proyectista

Es el agente que, por encargo del promotor y con sujeción a la normativa técnica y urbanística correspondiente, redacta el proyecto.

3.1.3. El constructor o contratista

Es el agente que asume, contractualmente ante el promotor, el compromiso de ejecutar con medios humanos y materiales, propios o ajenos, las obras o parte de las mismas con sujeción al Proyecto y al Contrato de obra.

Cabe efectuar especial mención de que la ley señala como responsable explícito de los vicios o defectos constructivos al contratista general de la obra, sin perjuicio del derecho de repetición de éste hacia los subcontratistas.

3.1.4. El director de obra

Es el agente que, formando parte de la dirección facultativa, dirige el desarrollo de la obra en los aspectos técnicos, estéticos, urbanísticos y medioambientales, de conformidad con el proyecto que la define, la licencia de edificación y demás autorizaciones preceptivas, y las condiciones del contrato, con el objeto de asegurar su adecuación al fin propuesto.

3.1.5. El director de la ejecución de la obra

Es el agente que, formando parte de la Dirección Facultativa, asume la función técnica de dirigir la Ejecución Material de la Obra y de controlar cualitativa y cuantitativamente la construcción y calidad de lo edificado. Para ello es requisito indispensable el estudio y análisis previo del proyecto de ejecución una vez redactado por el director de obra, procediendo a solicitarle, con antelación al inicio de las obras, todas aquellas aclaraciones, subsanaciones o documentos complementarios que, dentro de su competencia y atribuciones legales, estimare necesarios para poder dirigir de manera solvente la ejecución de las mismas.

3.1.6. Los suministradores de productos

Se consideran suministradores de productos los fabricantes, almacenistas, importadores o vendedores de productos de construcción.

Se entiende por producto de construcción aquel que se fabrica para su incorporación permanente en una obra, incluyendo materiales, elementos semielaborados, componentes y obras o parte de las mismas, tanto terminadas como en proceso de ejecución.

3.2. Obligaciones de los agentes intervinientes

3.2.1. El promotor

Ostentar sobre el solar la titularidad de un derecho que le faculte para construir en él, para el presente proyecto, Atlantic Copper.

Facilitar la documentación e información previa necesaria para la redacción del proyecto, así como autorizar al director de obra, al director de la ejecución de la obra y al contratista posteriores modificaciones del mismo que fueran imprescindibles para llevar a buen fin lo proyectado.

Elegir y contratar a los distintos agentes, con la titulación y capacitación profesional necesaria, que garanticen el cumplimiento de las condiciones legalmente exigibles para realizar en su globalidad y llevar a buen fin el objeto de lo promovido, en los plazos estipulados y en las condiciones de calidad exigibles mediante el cumplimiento de los requisitos básicos estipulados para los edificios.

Gestionar y hacerse cargo de las preceptivas licencias y demás autorizaciones administrativas procedentes que, de conformidad con la normativa aplicable, conlleva la construcción de edificios, la urbanización que procediera en su entorno inmediato, la realización de obras que en ellos se ejecuten y su ocupación.

Garantizar los daños materiales que el edificio pueda sufrir, para la adecuada protección de los intereses de los usuarios finales, en las condiciones legalmente establecidas, asumiendo la responsabilidad civil de forma personal e individualizada, tanto por actos propios como por actos de otros agentes por los que, con arreglo a la legislación vigente, se deba responder.

La suscripción obligatoria de un seguro, de acuerdo a las normas concretas fijadas al efecto, que cubra los daños materiales que ocasionen en el edificio el incumplimiento de las condiciones de habitabilidad en tres años o que afecten a la seguridad estructural en el plazo de diez años, con especial mención a las viviendas individuales en régimen de autopromoción, que se regirán por lo especialmente legislado al efecto.

Suscribir el acta de recepción final de las obras, una vez concluidas éstas, haciendo constar la aceptación de las obras, que podrá efectuarse con o sin reservas y que deberá abarcar la totalidad de las obras o fases completas. En el caso de hacer mención expresa a reservas para la recepción, deberán mencionarse de manera detallada las deficiencias y se deberá hacer constar el plazo en que deberán quedar subsanados los defectos observados.

Entregar al adquirente y usuario inicial, en su caso, el denominado Libro del Edificio que contiene el manual de uso y mantenimiento del mismo y demás documentación de obra ejecutada, o cualquier otro documento exigible por las Administraciones competentes.

3.2.2. El proyectista

Redactar el proyecto por encargo del promotor, con sujeción a la normativa urbanística y técnica en vigor y conteniendo la documentación necesaria para tramitar tanto la licencia de obras y demás permisos administrativos -proyecto básico- como para ser interpretada y poder ejecutar totalmente la obra, entregando al promotor las copias autorizadas correspondientes, debidamente visadas por su colegio profesional.

Ostentar la propiedad intelectual de su trabajo, tanto de la documentación escrita como de los cálculos de cualquier tipo, así como de los planos contenidos en la totalidad del proyecto y cualquiera de sus documentos complementarios.

3.2.3. El constructor o contratista

Tener la capacitación profesional o titulación que habilita para el cumplimiento de las condiciones legalmente exigibles para actuar como constructor.

Organizar los trabajos de construcción para cumplir con los plazos previstos, de acuerdo al correspondiente Plan de Obra, efectuando las instalaciones provisionales y disponiendo de los medios auxiliares necesarios.

Elaborar, y exigir de cada subcontratista, un plan de seguridad y salud en el trabajo en el que se analicen, estudien, desarrollen y complementen las previsiones contenidas en el estudio o estudio básico, en función de su propio sistema de ejecución de la obra. En dichos planes se incluirán, en su caso, las propuestas de medidas alternativas de prevención propuestas, con la correspondiente justificación técnica, que no podrán implicar disminución de los niveles de protección previstos en el estudio o estudio básico.

Comunicar a la autoridad laboral competente la apertura del centro de trabajo en la que incluirá el Plan de Seguridad y Salud al que se refiere el "Real Decreto 1627/1997. Disposiciones mínimas de seguridad y de salud en las obras de construcción".

Adoptar todas las medidas preventivas que cumplan los preceptos en materia de Prevención de Riesgos laborales y Seguridad y Salud que establece la legislación vigente, redactando el correspondiente Plan de Seguridad y ajustándose al cumplimiento estricto y permanente de lo establecido en el Estudio de Seguridad y Salud, disponiendo de todos los medios necesarios y dotando al personal del equipamiento de seguridad exigibles, así como cumplir las órdenes efectuadas por el Coordinador en materia de Seguridad y Salud en la fase de Ejecución de la obra.

Supervisar de manera continuada el cumplimiento de las normas de seguridad, tutelando las actividades de los trabajadores a su cargo y, en su caso, relevando de su puesto a todos aquellos que pudieran menoscabar las condiciones básicas de seguridad personales o generales, por no estar en las condiciones adecuadas.

Examinar la documentación aportada por los técnicos redactores correspondientes, tanto del Proyecto de Ejecución como de los proyectos complementarios, así como del Estudio de Seguridad y Salud, verificando que le resulta suficiente para la comprensión de la totalidad de la obra contratada o, en caso contrario, solicitando las aclaraciones pertinentes.

Facilitar la labor de la Dirección Facultativa, suscribiendo el Acta de Replanteo, ejecutando las obras con sujeción al Proyecto de Ejecución que deberá haber examinado previamente, a la legislación aplicable, a las Instrucciones del director de obra y del director de la ejecución material de la obra, a fin de alcanzar la calidad exigida en el proyecto.

Supervisar personalmente y de manera continuada y completa la marcha de las obras, que deberán transcurrir sin dilación y con adecuado orden y concierto, así como responder directamente de los trabajos efectuados por sus trabajadores subordinados, exigiéndoles el continuo autocontrol de los trabajos que efectúen, y ordenando la modificación de todas aquellas tareas que se presenten mal efectuadas.

Asegurar la idoneidad de todos y cada uno de los materiales utilizados y elementos constructivos, comprobando los preparados en obra y rechazando, por iniciativa propia o por prescripción facultativa del director de la ejecución de la obra, los suministros de material o prefabricados que no cuenten con las garantías, documentación mínima exigible o documentos de idoneidad requeridos por las normas de aplicación, debiendo recabar de la Dirección Facultativa la información que necesite para cumplir adecuadamente su cometido.

Poner a disposición del director de ejecución material de la obra los medios auxiliares y personal necesario para efectuar las pruebas pertinentes para el Control de Calidad, recabando de dicho técnico el plan a seguir en cuanto a las tomas de muestras, traslados, ensayos y demás actuaciones necesarias.

Facilitar a los directores de obra los datos necesarios para la elaboración de la documentación final de obra ejecutada.

Suscribir las garantías de obra que se señalan en la "Ley 38/1999. Ley de Ordenación de la Edificación" y que, en función de su naturaleza, alcanzan periodos de 1 año (daños por defectos de terminación o acabado de las obras), 3 años (daños por defectos o vicios de elementos constructivos o de instalaciones que afecten a la habitabilidad) o 10 años (daños en cimentación o estructura que comprometan directamente la resistencia mecánica y la estabilidad del edificio).

3.2.4. El director de obra

Dirigir la obra coordinándola con el Proyecto de Ejecución, facilitando su interpretación técnica, económica y estética a los agentes intervinientes en el proceso constructivo.

Detener la obra por causa grave y justificada, que se deberá hacer constar necesariamente en el Libro de Órdenes y Asistencias, dando cuenta inmediata al promotor.

Redactar las modificaciones, ajustes, rectificaciones o planos complementarios que se precisen para el adecuado desarrollo de las obras. Es facultad expresa y única la redacción de aquellas modificaciones o aclaraciones directamente relacionadas con la adecuación de la cimentación y de la estructura proyectadas a las características geotécnicas del terreno, el cálculo o recálculo del dimensionado y armado de todos y cada uno de los elementos principales y complementarios de la cimentación y de la estructura vertical y horizontal y los que afecten sustancialmente a la distribución de espacios.

Asistir a las obras a fin de resolver las contingencias que se produzcan para asegurar la correcta interpretación y ejecución del proyecto, así como impartir las soluciones aclaratorias que fueran necesarias, consignando en el Libro de Ordenes y Asistencias las instrucciones precisas que se estimara oportunas reseñar para la correcta interpretación de lo proyectado, sin perjuicio de efectuar todas las aclaraciones y órdenes verbales que estimare oportuno.

Firmar el Acta de replanteo o de comienzo de obra y el Certificado Final de Obra, así como firmar el visto bueno de las certificaciones parciales referidas al porcentaje de obra efectuada y, en su caso y a instancias del promotor, la supervisión de la documentación que se le presente relativa a las unidades de obra realmente ejecutadas previa a su liquidación final, todo ello con los visados que en su caso fueran preceptivos.

Informar puntualmente al promotor de aquellas modificaciones sustanciales que, por razones técnicas o normativas, conllevan una variación de lo construido con respecto al proyecto básico y de ejecución y que afecten o puedan afectar al contrato suscrito entre el promotor y los destinatarios finales de las viviendas.

Redactar la documentación final de obra, en lo que respecta a la documentación gráfica y escrita del proyecto ejecutado, incorporando las modificaciones efectuadas. Para ello, los técnicos redactores de proyectos y/o estudios complementarios deberán obligatoriamente entregarle la documentación final en la que se haga constar el estado final de las obras y/o instalaciones por ellos redactadas, supervisadas y realmente ejecutadas, siendo responsabilidad de los firmantes la veracidad y exactitud de los documentos presentados.

Al Proyecto Final de Obra se anexará el Acta de Recepción Final; la relación identificativa de los agentes que han intervenido en el proceso de edificación, incluidos todos los subcontratistas y oficios intervinientes; las instrucciones de Uso y Mantenimiento del Edificio y de sus instalaciones, de conformidad con la normativa que le sea de aplicación.

3.2.5. El director de la ejecución de la obra

Corresponde al director de ejecución material de la obra, según se establece en la "Ley 38/1999. Ley de Ordenación de la Edificación" y demás legislación vigente al efecto, las atribuciones competenciales y obligaciones que se señalan a continuación:

- La Dirección inmediata de la Obra.

- Verificar personalmente la recepción a pie de obra, previo a su acopio o colocación definitiva, de todos los productos y materiales suministrados necesarios para la ejecución de la obra, comprobando que se ajustan con precisión a las determinaciones del proyecto y a las normas exigibles de calidad, con la plena potestad de aceptación o rechazo de los mismos en caso de que lo considerase oportuno y por causa justificada, ordenando la realización de pruebas y ensayos que fueran necesarios.

- Dirigir la ejecución material de la obra de acuerdo con las especificaciones de la memoria y de los planos del Proyecto, así como, en su caso, con las instrucciones complementarias necesarias que recabara del director de obra.

- Anticiparse con la antelación suficiente a las distintas fases de la puesta en obra, requiriendo las aclaraciones al director de obra o directores de obra que fueran necesarias y planificando de manera anticipada y continuada con el contratista principal y los subcontratistas los trabajos a efectuar.

- Comprobar los replanteos, los materiales, hormigones y demás productos suministrados, exigiendo la presentación de los oportunos certificados de idoneidad de los mismos.

- Verificar la correcta ejecución y disposición de los elementos constructivos y de las instalaciones, extendiéndose dicho cometido a todos los elementos de cimentación y estructura horizontal y vertical, con comprobación de sus especificaciones concretas de dimensionado de elementos, tipos de viguetas y adecuación a ficha técnica homologada, diámetros nominales, longitudes de anclaje y adecuados solape y doblado de barras.

- Observancia de los tiempos de encofrado y desencofrado de vigas, pilares y forjados señalados por la Instrucción del Hormigón vigente y de aplicación.

- Asistir a la obra con la frecuencia, dedicación y diligencia necesarias para cumplir eficazmente la debida supervisión de la ejecución de la misma en todas sus fases, desde el replanteo inicial hasta la total finalización del edificio, dando las órdenes precisas de ejecución al contratista y, en su caso, a los subcontratistas.

- Consignar en el Libro de Ordenes y Asistencias las instrucciones precisas que considerara oportuno reseñar para la correcta ejecución material de las obras.

- Detener la Obra si, a su juicio, existiera causa grave y justificada, que se deberá hacer constar necesariamente en el Libro de Ordenes y Asistencias, dando cuenta inmediata a los directores de obra que deberán necesariamente corroborarla para su plena efectividad, y al promotor.

- Supervisar las pruebas pertinentes para el Control de Calidad, respecto a lo especificado por la normativa vigente, en cuyo cometido y obligaciones tiene legalmente competencia exclusiva, programando bajo su responsabilidad y debidamente coordinado y auxiliado por el contratista, las tomas de muestras, traslados, ensayos y demás actuaciones necesarias de elementos estructurales, así como las pruebas de estanqueidad de fachadas y de sus elementos, de cubiertas y sus impermeabilizaciones, comprobando la eficacia de las soluciones.

- Tras la oportuna comprobación, emitir las certificaciones parciales o totales relativas a las unidades de obra realmente ejecutadas, con los visados que en su caso fueran preceptivos.

- Elaborar y suscribir responsablemente la documentación final de obra relativa a los resultados del Control de Calidad y, en concreto, a aquellos ensayos y verificaciones de ejecución de obra realizados bajo su supervisión relativos a los elementos de la cimentación, muros y estructura, a las pruebas de estanqueidad y escorrentía de cubiertas y de fachadas, a las verificaciones del funcionamiento de las instalaciones de saneamiento y desagües de pluviales y demás aspectos señalados en la normativa de Control de Calidad.

- Suscribir conjuntamente el Certificado Final de Obra, acreditando con ello su conformidad a la correcta ejecución de las obras y a la comprobación y verificación positiva de los ensayos y pruebas realizadas.

3.2.6. Las entidades y los laboratorios de control de calidad de la edificación

Prestar asistencia técnica y entregar los resultados de su actividad al agente autor del encargo y, en todo caso, al director de la ejecución de la obra.

Justificar la capacidad suficiente de medios materiales y humanos necesarios para realizar adecuadamente los trabajos contratados, en su caso, a través de la correspondiente acreditación oficial otorgada por la comunidad autónoma de Andalucía.

4. DISPOSICIONES ECONÓMICAS

4.1. Definición

Las condiciones económicas fijan el marco de relaciones económicas para el abono y recepción de la obra. Tienen un carácter subsidiario respecto al contrato de obra, establecido entre las partes que intervienen, promotor y contratista, que es en definitiva el que tiene validez.

4.2. Contrato de obra

Se aconseja que se firme el contrato de obra, entre el promotor y el contratista, antes de iniciarse las obras, evitando en lo posible la realización de la obra por administración. A la Dirección Facultativa (director de obra y director de ejecución de la obra) se le facilitará una copia del contrato de obra, para poder certificar en los términos pactados.

El contrato de obra deberá prever las posibles interpretaciones y discrepancias que pudieran surgir entre las partes, así como garantizar que la Dirección Facultativa pueda, de hecho, coordinar, dirigir y controlar la obra, por lo que es conveniente que se especifiquen y determinen con claridad, como mínimo, los siguientes puntos:

- Documentos a aportar por el contratista.
- Condiciones de ocupación del solar e inicio de las obras.
- Determinación de los gastos de enganches y consumos.
- Responsabilidades y obligaciones del contratista: Legislación laboral.
- Responsabilidades y obligaciones del promotor.
- Presupuesto del contratista.
- Revisión de precios (en su caso).
- Forma de pago: Certificaciones.
- Plazos de ejecución: Planning.
- Retraso de la obra: Penalizaciones.
- Recepción de la obra: Provisional y definitiva.
- Litigio entre las partes.

4.3. Criterio general

Todos los agentes que intervienen en el proceso de la construcción, definidos en la "Ley 38/1999. Ley de Ordenación de la Edificación", tienen derecho a percibir puntualmente las cantidades devengadas por su correcta actuación con arreglo a las condiciones contractualmente establecidas, pudiendo exigirse recíprocamente las garantías suficientes para el cumplimiento diligente de sus obligaciones de pago.

4.4. Fianzas

El contratista presentará una fianza con arreglo al procedimiento que se estipule en el contrato de obra:

4.4.1. Ejecución de trabajos con cargo a la fianza

Si el contratista se negase a hacer por su cuenta los trabajos precisos para ultimar la obra en las condiciones contratadas, el director de obra, en nombre y representación del promotor, los ordenará ejecutar a un tercero, o podrá realizarlos directamente por administración, abonando su importe con la fianza depositada, sin perjuicio de las acciones a que tenga derecho el promotor, en el caso de que el importe de la fianza no bastase para cubrir el importe de los gastos efectuados en las unidades de obra que no fuesen de recibo.

4.4.2. Devolución de las fianzas

La fianza recibida será devuelta al contratista en un plazo establecido en el contrato de obra, una vez firmada el Acta de Recepción Definitiva de la obra. El promotor podrá exigir que el contratista le acredite la liquidación y finiquito de sus deudas causadas por la ejecución de la obra, tales como salarios, suministros y subcontratos.

4.4.3. Devolución de la fianza en el caso de efectuarse recepciones parciales

Si el promotor, con la conformidad del director de obra, accediera a hacer recepciones parciales, tendrá derecho el contratista a que se le devuelva la parte proporcional de la fianza.

4.5. De los precios

El objetivo principal de la elaboración del presupuesto es anticipar el coste del proceso de construir la obra. Se descompondrá el presupuesto en unidades de obra, componente menor que se contrata y certifica por separado, y basándonos en esos precios, calcularemos el presupuesto

.

4.5.1. Presupuesto de Ejecución Material (PEM)

Es el resultado de la suma de los precios unitarios de las diferentes unidades de obra que la componen.

Se denomina Presupuesto de Ejecución Material al resultado obtenido por la suma de los productos del número de cada unidad de obra por su precio unitario y de las partidas alzadas. Es decir, el coste de la obra sin incluir los gastos generales, el beneficio industrial y el impuesto sobre el valor añadido.

4.5.2. Reclamación de aumento de precios

Si el contratista, antes de la firma del contrato de obra, no hubiese hecho la reclamación u observación oportuna, no podrá bajo ningún pretexto de error u omisión reclamar aumento de los precios fijados en el cuadro correspondiente del presupuesto que sirva de base para la ejecución de las obras.

4.5.3. De la revisión de los precios contratados

El presupuesto presentado por el contratista se entiende que es cerrado, por lo que no se aplicará revisión de precios.

Sólo se procederá a efectuar revisión de precios cuando haya quedado explícitamente determinado en el contrato de obra entre el promotor y el contratista.

4.5.4. Acopio de materiales

El contratista queda obligado a ejecutar los acopios de materiales o aparatos de obra que el promotor ordene por escrito. Los materiales acopiados, una vez abonados por el propietario, son de la exclusiva propiedad de éste, siendo el contratista responsable de su guarda y conservación.

4.6. Valoración y abono de los trabajos

4.6.1. Forma y plazos de abono de las obras

Se realizará por certificaciones de obra y se recogerán las condiciones en el contrato de obra establecido entre las partes que intervienen (promotor y contratista) que, en definitiva, es el que tiene validez.

Los pagos se efectuarán por el promotor en los plazos previamente establecidos en el contrato de obra, y su importe corresponderá precisamente al de las certificaciones de la obra conformadas por el director de ejecución de la obra, en virtud de las cuáles se verifican aquéllos.

El director de ejecución de la obra realizará, en la forma y condiciones que establezca el criterio de medición en obra incorporado en las Prescripciones en cuanto a la Ejecución por Unidad de Obra, la medición de las unidades de obra ejecutadas durante el período de tiempo anterior, pudiendo el contratista presenciar la realización de tales mediciones.

Para las obras o partes de obra que, por sus dimensiones y características, hayan de quedar posterior y definitivamente ocultas, el contratista está obligado a avisar al director de ejecución de la obra con la suficiente antelación, a fin de que éste pueda realizar las correspondientes mediciones y toma de datos, levantando los planos que las definan, cuya conformidad suscribirá el contratista.

A falta de aviso anticipado, cuya existencia corresponde probar al contratista, queda este obligado a aceptar las decisiones del promotor sobre el particular.

4.6.2. Relaciones valoradas y certificaciones

En los plazos fijados en el contrato de obra entre el promotor y el contratista, éste último formulará una relación valorada de las obras ejecutadas durante las fechas previstas, según la medición practicada por el Director de Ejecución de la Obra.

Las certificaciones de obra serán el resultado de aplicar, a la cantidad de obra realmente ejecutada, los precios contratados de las unidades de obra. Sin embargo, los excesos de obra realizada en unidades, tales como excavaciones y hormigones, que sean imputables al contratista, no serán objeto de certificación alguna.

Los pagos se efectuarán por el promotor en los plazos previamente establecidos, y su importe corresponderá al de las certificaciones de obra, conformadas por la Dirección Facultativa. Tendrán el carácter de documento y entregas a buena cuenta, sujetas a las rectificaciones y variaciones que se deriven de la Liquidación Final, no suponiendo tampoco dichas certificaciones parciales la aceptación, la aprobación, ni la recepción de las obras que comprenden.

Las relaciones valoradas contendrán solamente la obra ejecutada en el plazo a que la valoración se refiere. Si la Dirección Facultativa lo exigiera, las certificaciones se extenderán a origen.

4.7. Indemnizaciones mutuas

4.7.1. Indemnización por retraso del plazo de terminación de las obras

Si, por causas imputables al contratista, las obras sufrieran un retraso en su finalización con relación al plazo de ejecución previsto, el promotor podrá imponer al contratista, con cargo a la última certificación, las penalizaciones establecidas en el contrato, que nunca serán inferiores al perjuicio que pudiera causar el retraso de la obra.

4.7.2. Demora de los pagos por parte del promotor

Se regulará en el contrato de obra las condiciones a cumplir por parte de ambos.

4.8. Plazos de ejecución: Planning de obra

En el contrato de obra deberán figurar los plazos de ejecución y entregas, tanto totales como parciales. Además, será conveniente adjuntar al respectivo contrato un Planning de la ejecución de la obra donde figuren de forma gráfica y detallada la duración de las distintas partidas de obra que deberán conformar las partes contratantes.

4.9. Liquidación económica de las obras

Simultáneamente al libramiento de la última certificación, se procederá al otorgamiento del Acta de Liquidación Económica de las obras, que deberán firmar el promotor y el contratista. En este acto se dará por terminada la obra y se entregarán, en su caso, las llaves, los correspondientes boletines debidamente cumplimentados de acuerdo a la Normativa Vigente, así como los proyectos Técnicos y permisos de las instalaciones contratadas.

Dicha Acta de Liquidación Económica servirá de Acta de Recepción Provisional de las obras, para lo cual será conformada por el promotor, el contratista, el director de obra y el director de ejecución de la obra, quedando desde dicho momento la conservación y custodia de las mismas a cargo del promotor.

La citada recepción de las obras, provisional y definitiva, queda regulada según se describe en las Disposiciones Generales del presente Pliego.

4.10. Liquidación final de la obra

Entre el promotor y contratista, la liquidación de la obra deberá hacerse de acuerdo con las certificaciones conformadas por la Dirección de Obra. Si la liquidación se realizara sin el visto bueno de la Dirección de Obra, ésta sólo mediará, en caso de desavenencia o desacuerdo, en el recurso ante los Tribunales.

5. DISPOSICIONES LEGALES

5.1. Reconocimiento de marcas registradas

El autor de este proyecto, así como su promotor, reconocen las marcas registradas que han aparecido a lo largo del desarrollo y ejecución, además de los derechos de autor recogidos en la bibliografía consultada y citada en el mismo.

5.2. Derechos de autor

Los derechos de autor de este proyecto serán los estipulados por la legislación y reglamentación vigente en el momento del comienzo del proyecto, a excepción de posibles correcciones legales resultantes de los recursos legales que se hayan interpuesto contra las mencionadas leyes y reglamentos.

6. CONDICIONES TÉCNICAS DE LOS EQUIPOS

6.1. Especificaciones de la instalación eléctrica

Las instalaciones eléctricas serán ejecutadas por la Empresa especializada, en posesión de todos los requisitos que establece la legislación vigente. Toda la documentación acreditativa será presentada por el Director de Obra para que pueda emitir la oportuna autorización de comienzo de los trabajos.

Todo el personal que intervenga en cualquier ejecución en cualquier parte de las instalaciones eléctricas, aunque sea accesoria, deberá estar en posesión de los oportunos certificados de calificación profesional.

Será condición necesaria para que la dirección autorice su intervención en los trabajos, la entrega de una copia, autentificada por la empresa especializada, de los certificados mencionados, así como la justificación de estar de alta en el Libro de Matrícula.

Antes de iniciar la obra, el Contratista presentará unos planos de detalle que indiquen preferentemente una situación real de los recorridos de canalizaciones y conductores. Al finalizar la obra, presentará los mismos planos corregidos en la forma como se hizo.

6.2. Instalación de la maquinaria

Todas las partes de la maquinaria que deben estar en contacto con los elementos a tratar, serán de material inalterable, con superficie lisa y fácil de limpiar. De la misma manera, el exterior de la maquinaria deberá estar esmaltado o cubierto de material inalterable y sin ángulos entrantes que impidan una limpieza perfecta.

Los elementos móviles deberán estar provistos de los debidos dispositivos de protección para el manejo del operador. Si en condiciones de trabajo normales una máquina, con fuerza de acondicionamiento suficiente y manejada de acuerdo con las instrucciones, no diera el rendimiento garantizado, se comunicará a la casa vendedora para que comunique las deficiencias y haga las modificaciones oportunas. Si en el plazo de un mes, estas deficiencias no fueran subsanadas, la casa se hará cargo de la maquinaria, puesta, embalada en la estación más próxima a la residencia del cliente, devolviendo el mismo importe que haya pagado, o suministrándole a elección de éste, en sustitución de la maquinaria retirada, otra de rendimiento correcto.

Serán de cuenta de la casa suministradora el transporte, embalaje, derechos de aduanas, riesgos, seguros e impuestos hasta que la maquinaria se encuentre en el lugar de su emplazamiento. El montaje será por cuenta de la casa vendedora, si bien el promotor proporcionará las escaleras, instalación eléctrica, herramienta gruesa y material de albañilería, carpintería y cerrajería necesaria para el montaje, así como personal auxiliar para ayudar al especializado que enviará la empresa suministradora.

El plazo que para la entrega de maquinaria pacte el promotor con el vendedor de la misma, no podrá ser ampliado más que por causa de fuerza mayor, como huelgas, lock-out, movilización del ejército, guerra o revolución. Si el retraso es imputable a la casa vendedora, el promotor tendrá derecho a un 1% de rebaja en el precio por cada semana de retraso como compensación por los perjuicios ocasionados.

Será por cuenta de la entidad vendedora suministrar los aparatos y útiles precisos para ejecutar las pruebas de las máquinas y verificar las comprobaciones necesarias, siendo de su cuenta los gastos que originen estas.

En cada máquina o grupo de máquinas, se establecerá una fecha de prueba con el objeto de poder efectuar la recepción provisional, para el plazo mínimo de garantía de un año, en el cual su funcionamiento ha de ser perfecto, comprometiéndose la empresa suministradora a reponer por su cuenta las piezas que aparezcan deterioradas a causa de una defectuosa construcción o instalación y a subsanar por su cuenta las anomalías o irregularidades de funcionamiento que impidan su uso normal.

7. REQUISITOS DEL SISTEMA SOLAR TÉRMICO Y COMPONENTES

Ensayos de calificación

Los colectores o sistemas solares térmicos tendrán que cumplir con las siguientes normas UNIT:

a. Colectores
   - UNIT 705:2009 Sistemas solares térmicos y componentes. Colectores solares, requisitos.
   - UNIT-ISO 9806-2:1995 Métodos de ensayos para colectores solares. PARTE 2: Procedimientos de ensayo de calificación.

b. Sistemas Prefabricados
   - UNIT 1185:2009 Sistemas solares térmicos y componentes. Sistemas prefabricados, requisitos.
   - UNIT 1184 – Sistemas solares térmicos y componentes. Sistemas prefabricados. Parte 2: Métodos de ensayo.

Measurements

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Measurements

The final goal of this work is to provide a prior study on the modification of an Outokumpu flash furnace in order to include a preheating system, using a Solar Central Tower (SCT) for the obtention of the solar thermal energy for the heat exchange. This document lists the elements needed to carry out this project, establishing the basic information for the following economic analysis.

For this project, it is understood the word items as the kind or type of different goods that compose the system. Each element considered in this section must be measurable and should have a specific price per unit of measure.

All the study is developed under the scenario of the "Chagres Smelter Anglo American", with a constant feed rate of 75 tons of concentrate per hour (610000 tons per year). The design of the solar field has been conceived for providing from seven to eight hours of reduced consummation of industrial oxygen and hydrocarbon fuel. Even if the process analyzed in detail through this work is the smelting, for the economic analysis the overall process must be considered in order to justify the price of the refined copper, which is the principal source of economical benefices for the copper mining industry.

The economical and design data for this study is based on the following works:

- M. E. Schlesinger, M. J. King, K. C. Sole, and W. G. Davenport, *Extractive metallurgy of copper*. 2011. [ref. 26]
- C. S. Turchi *et al.*, 'CSP Systems Analysis - Final Project Report', NREL/TP-5500-72856, 1513197, May 2019. [ref. 27]
- P. Rao and M. Muller, 'Industrial Oxygen: Its Generation and Use', p. 12, 2007. [ref. 28]
- 'Pipe 610mm-Pipe 610mm Manufacturers, Suppliers and Exporters on Alibaba.comSteel Pipes'. [Online]. Available: https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=pipe+610mm&isPremium=y. [Accessed: 13-Sep-2019]. [ref. 33]

The different items considered for this project are:

1. Equipment
2. Conductions
3. Aggregates
4. Civil engineering

All the assessment in this work is done for one year of copper production. It should be mentioned that the useful lifetime of the SCT is around 25 years, and for mining facilities around 30 years, after this period all the facilities should be renovated.

Item 1. Equipment

Table M. 1: Equipment

Element	Units	Quantity	Comments
Mine	Unit	1	These elements compose the conventional units for the copper production from the open mining to the production of the 99.99 % pure copper
Concentrating system	Unit	1	
Concentrate handling	Unit	1	
Oxygen plant	Unit	1	
Flash Furnace	Unit	1	
Flash Converter	Unit	1	
Cu-from-slag recovery equipment	Unit	1	
Anode furnaces and anode casting	Unit	1	
Electrorefinery with cathode	Unit	1	
Gas-handling system	Unit	1	
TOTAL copper production	**10**		
Heliostat Field	m^2 of mirror surface	10201	Data for design of 600 K blast preheating
Tower	kWt*	4113	
Receiver			
TOTAL Units	**2**		
TOTAL m^2	**10201**		

*The estimation of the investment for the tower and the receiver is done in function of the thermal energy that the SCT system is expected to provide.

The green part of the table stands for the measures corresponding to the investment required in this project, the rest of the data is only for making possible to calculate the costs of the overall facilities.

Item 2. Conductions

The conductions included in the *Measurements* section only represent the pipes needed for the blast conduction from the tower to the flash furnace, connecting with the oxygen plant.

Table M. 2: Conductions

Element	Length (m)	Density (ton/m)	Weight (ton)
Gas pipe 610 mm diameter	164	0.164	26.9

The diameter chosen for the pipes is selected in order to keep the safe conditions in the blast circulation system. The expected speed of the gases inside the pipes is 33.27 m/s.

The density is picked up from the catalogs (*Appendix V*).

Item 3. Aggregates

The *Aggregates* included in the Measurements section only represent the fittings needed for the blast conduction from the tower to the flash furnace, connecting with the oxygen plant.

Table M. 3: Aggregates

Element	Units	Quantity	Comments
Fitting 90º 610 mm diameter	Par unit	2	

The number of fittings is deduced from the design needs of the system, specified in the *Technical drawings*.

Item 4. Civil engineering

Table M. 4: Civil engineering

Element	Units	Quantity	Comments
Site improvement	m^2 of mirror surface	10201	The budget for the civil engineering of a SCT system is calculated in function of the % of the total investment
Engineers procurements, construction and owner cost	% of the SCT investment	13	
Maintenance loss	% of the SCT investment per year*	3	

*With an estimated useful life of 25 years the total cost of the maintenance for the SCT would be the 75% (25 times 3%) of the total investment.

Budget

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1. Budget Execution and Implementation (BEI)

The Budget of Execution and Implementation is the cost of the project, it's the measure of how much the project costs to the investors. It's the first step of the economical assessment, and it only takes into account the cost of the units previously listed in the *Measures* section, without considering taxes or additional expenses.

The economical and design data for this study is based on the following works:

- M. E. Schlesinger, M. J. King, K. C. Sole, and W. G. Davenport, *Extractive metallurgy of copper*. 2011. [ref. 26]
- C. S. Turchi *et al.*, 'CSP Systems Analysis - Final Project Report', NREL/TP-5500-72856, 1513197, May 2019. [ref. 27]
- P. Rao and M. Muller, 'Industrial Oxygen: Its Generation and Use', p. 12, 2007. [ref. 28]
- 'Pipe 610mm-Pipe 610mm Manufacturers, Suppliers and Exporters on Alibaba.comSteel Pipes'. [Online]. Available: https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=pipe+610mm&isPremium=y. [Accessed: 13-Sep-2019]. [ref. 33]

The BEI and all the economic factors estimated in this project are based on the data from the Chagres Anglo American Smelter, and so they are not accurate for all the copper mining facilities. The cost of the units is calculated using the economic study detailed in the work "*Extractive metallurgy of copper*" [ref. 26] and the economic models developed in collaboration with the SERC Chile, trying to give preference to the most updated economic trends.

Through all the economic study two different scenarios are assessed:

a. Conventional smelting
b. Smelting process improved by the SCT system

By this is pretended to facilitate the task of remarking the potential of the project as an alternative method for saving money and resources. The scenario of maximum copper production is also included in this work (without preheating and with the maximum enrichment of the blast), but it won't be detailed in the *Budget* section.

All the assessment in this work is done for one year of copper production. It should be mentioned that the useful life time of the SCT is around 25 years, and for mining facilities around 30 years, after this period all the facilities should be renovated.

1.1. Partial BEI

The different items considered for this project are:

1. Equipment
2. Conductions
3. Aggregates
4. Civil engineering

Item 1. Conductions

The *Table B. 2* details the cost of the conductions considered for connecting the SCT system with the smelting facilities:

Table B. 1: Conductions

Element	Price units	Price	Cost ($)
Gas pipe 610 mm diameter	$/ton	700	$18,827.20
TOTAL conductions			**$18,827.20**

Item 2. Equipment

The investment necessary for the copper production units depends directly on the expected annual production of copper. Considering that the Chagres Anglo American Smelter produces around 610000 tons of concentrate per year, with a content in copper of ~30 mass% the expected production is of 183000 tons of Cu per year. Therefore the cost of the equipment is detailed in the *Table B. 1*:

Table B. 2: Equipment

Element	Price units	Price	Cost conventional ($)	Cost SCT included ($)
Mine	$/ annual ton Cu	10000	$1,830,000,000.00	$1,830,000,000.00
Concentrating system	$/ annual ton Cu	10000	$1,830,000,000.00	$1,830,000,000.00
Concentrate handling system	$/ annual ton Cu	900	$164,700,000.00	$164,700,000.00
Oxygen plant	$/ annual ton Cu	900	$164,700,000.00	$162,116,588.67
Flash Furnace	$/ annual ton Cu	1350	$247,050,000.00	$247,050,000.00
Flash Converter	$/ annual ton Cu	1350	$247,050,000.00	$247,050,000.00
Cu-from-slag recovery equipment	$/ annual ton Cu	900	$164,700,000.00	$164,700,000.00
Anode furnaces and anode casting	$/ annual ton Cu	900	$164,700,000.00	$164,700,000.00
Electrorefinery with cathode	$/ annual ton Cu	1000	$183,000,000.00	$183,000,000.00
Gas-handling system	$/ annual ton Cu	2700	$494,100,000.00	$494,100,000.00
TOTAL copper production	**Useful life = 30 years**		**$5,490,000,000.00**	**$5,487,416,588.67**
Heliostat Field	$/m2	140		$1,428,140.00
Tower / Receiver	$/kWt *	152		$625,176.00

TOTAL SCT equipment	**Useful life = 25 years**	**$0**	**$2,053,316.00**

As in the *Measurements* section, the green squares represent the new investment. Depending on the working conditions of the smelting facilities the cost of the oxygen plant variates, as the production of the industrial oxygen is reduced when using the SCT system.

Item 3. Aggregates

The *Table B. 3* details the cost of the fittings needed for the construction of the blast conductions connecting the tower with the oxygen plant and the flash furnace:

Table B. 3: Aggregates

Element	Price units	Price	Cost ($)
Fitting 90º 610 mm diameter	$/piece	600	$1200
TOTAL aggregates			**$1200**

Item 4. Civil engineering

The *Table B. 4* details the cost of the civil engineering needed for the construction of the SCT system. It involves flattening the solar field, designing and building the tower, creating the mechanical structure of the heliostats, setting the mirrors, installing the receiver in the tower, connecting the equipment, setting the electric and control system, and testing and commissioning the new equipment. The cost of the maintenance during the useful life of the SCT system is also considered.

Table B. 4: Civil engineering

Element	Price units	Price	Cost ($)
Site improvement	$/m^2	16	$163,216.00

Engineers procurements, construction and owner cost	% of the SCT investment	13	$288,149.16
Maintenance loss	% of the SCT investment per year	3*	$1,642,371.80
TOTAL civil engineering			**$2,093,736.96**

*With an estimated useful life of 25 years the total cost of the maintenance for the SCT would be the 75% of the total investment.

It should be noticed that in the engineers procurements, construction and owner cost is included the manpower expenses of the project.

1.2. Overall BEI

Because the purpose of this work is the improvement of an already existing copper production facility, the only real investment belongs to the construction of the SCT system. Therefore, the overall BEI consists of:

Table B. 5: Overall BEI

	SCT system ($)	Conventional copper production ($)	Improved copper production ($)
Equipment	$2,053,316.00	$5,490,000,000.00	$5,487,416,588.67
Conductions	$18,827.20		
Aggregates	$1200		
Civil engineering	$2,093,736.96		
Overall BEI	**$4,167,080.16**	**$5,490,000,000.00**	**$5,487,416,588.67**

The BEI for the copper production with the SCT system it's lower than in the conventional scenario because of the savings on the oxygen facilities, but it must be added the BEI of the SCT system, making a total of $5,491,583,668.83.

2. Contractor's Cost (CC)

The contractor's cost is calculated in function of the BEI, being the CC the addition of the BEI, the General Costs (GC) and the Industrial Benefits (IB). The GC is defined as the 13% of the BEI and the IB as the 6% of the BEI.

Table B. 6:Contractor's Cost

	Cost SCT ($)	Cost conventional copper mining ($)	Cost improved copper mining ($)
Budget execution and implementation (BEI)	$4,167,080.16	$5,490,000,000.00	$5,487,416,588.67
General cost	$541,720.42	$713,700,000.00	$713,364,156.53
Industrial benefit	$250,024.81	$329,400,000.00	$329,244,995.32
Contractor's cost (CC)	$4,958,825.39	$6,533,100,000.00	$6,530,025,740.51

As in the previous section, the money saved in the oxygen plant is invested in the SCT system, making a total CC of $6,534,984,565.90, $1,884,565.90 over the conventional Contractor's Cost. However, the additional investment is worth when considering the operational savings of the process, as it's shown in the *Section XI*.

3. Total Budget

The total budget is equivalent to the Initial Investment (I_o). Once the CC is estimated the Total Budget can be determined by adding the 21% corresponding to the Added Value Tax (stands for IVA).

Table B. 7: Total Budget

	Cost SCT ($)	Cost conventional copper mining ($)	Cost improved copper mining ($)
Contractor's cost (CC)	$4,958,825.39	$6,533,100,000.00	$6,530,025,740.51
IVA (21%)	$250,024.81	$1,371,951,000.00	$1,371,305,405.51
TOTAL BUDGET	$6,000,178.72	$7,905,051,000.00	$7,901,331,146.02

The Total Budget, or Initial Investment, is one of the factors used in the *Chapter XI* to calculate the economic viability of the project. Specifically, the Total Budget is used for the estimation of the Amortizations, the annual value that represents the loss of value of the units composing the smelting system.

4. Maximum production scenario

In this section all the previous economic factors are estimated for the maximum productivity of the Chagres Flash Furnace. In the Chapter VII it was determined that the maximum productivity of the furnace is when working in the following conditions:

- Maximum oxygen enrichment: 22300 kg of industrial O_2 per hour
- Without fuel supply
- Without preheating

In these conditions it's possible to reach a feed rate of 102 tons of concentrate per hour respecting the boiler capacity, which would produce around 268056 tons of copper annually. The *table B. 8* illustrates the budget assessment in these conditions:

Table B. 8: Summarizing of budget factors for the maximum production scenario

	Cost copper mining with maximum production ($)
BEI	$8,041,680,000.00
General Cost	$1,045,418,400.00
Industrial benefit	$482,500,800.00
Contractor's cost (CC)	$9,569,599,200.00
IVA (21%)	$2,009,615,832.00
TOTAL BUDGET	$11,579,215,032.00

The total budget for copper production system is $3,674,164,032 bigger than in the normal conditions of the conventional smelting. This is logical, as the system is expected to work at its maximum capacity, increasing the cost of the maintenance.