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INSTALACIÓN Y PUESTA A PUNTO DEL SISTEMA DE ASPIRACIÓN Y DEPURACIÓN DE VAPORES EN CUBAS DE DECAPADO DE LA INDUSTRIA SIDERÚRGICA

(Installation and commissioning of vapour extraction and scrubbing system for pickling tanks in the steel industry)

Para acceder al Título de

Graduada en Ingeniería Química

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TÍTULO	Instalación y puesta a punto del sistema de aspiración y depuración de vapores en cubas de decapado de la industria siderúrgica		
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PALABRAS CLAVE

Instalación y puesta a punto, depuradora, decapado, ácido clorhídrico, gases ácidos

PLANTEAMIENTO DEL PROBLEMA

El proceso utilizado por TYCSA PSC para eliminar el óxido de hierro (Fe_2O_3) y la calamina de la superficie del metal es el decapado químico con ácido clorhídrico (HCl). Este método también prepara el alambrón para su trefilado posterior mediante la adición de fosfato y una sal portadora. Durante el proceso de decapado, se generan gases ácidos en las cubas de la línea de tratamiento, los cuales deben ser tratados antes de su liberación a la atmósfera para cumplir con las normativas medioambientales de España. Las regulaciones establecidas en el Boletín Oficial del Estado (BOC) Ley 17/2006, de 11 de diciembre, de control ambiental integrado [1], establecen un límite máximo permitido de concentración de 30 mg HCl/Nm^3 para la emisión de gases ácidos a la atmósfera.

En este contexto, el objetivo de este Trabajo Fin de Grado ha sido implementar y poner en marcha un sistema diseñado para reducir la concentración de ácido clorhídrico en los gases ácidos emitidos por las cubas de decapado, cumpliendo así con el objetivo de TYCSA PSC de ser una empresa con impacto neto positivo (Net positive) [2].

RESULTADOS

El lavador de gases húmedos de columna empaquetada fue seleccionado debido a su eficacia en el tratamiento de vapor de gas contaminado. Después de ensamblar todos los componentes, se llevan a cabo comprobaciones y pruebas previas a la puesta en marcha para verificar el correcto funcionamiento de las máquinas y el sellado adecuado de los equipos y tuberías.
Para evaluar el tratamiento de un caudal máximo de entrada de 21,000 m^3/h a 20ºC con una purga de 0.2 m^3/h, se realizó un estudio de la acidez total de la purga mediante volumetría con NaOH. A partir de los valores obtenidos en este estudio, se determinó la concentración de HCl para cada muestra tomada en la purga. El promedio de estas concentraciones de HCl es $5.41 \cdot 10^{-3}$ mg HCl/Nm^3, lo cual es cercano a $5.33 \cdot 10^{-3}$ mg HCl/Nm^3, obtenido en el blanco realizado con agua de red. Por lo tanto, el vertido al sistema de alcantarillado no causaría condiciones tóxicas para la población de

organismos acuáticos. No obstante, el agua proveniente de la purga se trata en la depuradora de la empresa.

En 2018, la concentración de ácido clorhídrico en las emisiones atmosféricas fue de 17.16 mg HCl/Nm^3. Con el objetivo de ser una empresa Net positive y reducir la concentración obtenida en 2018, se instaló y se puso en marcha un lavador de gases para reducir las emisiones ácidas. Con este equipo se logró una concentración de 0.07 mg HCl/Nm^3, lo cual es muy bajo y se considera una eliminación total del ácido del gas antes de su emisión a la atmósfera. Por lo tanto, la eficacia de la instalación del equipo utilizado para reducir las emisiones ácidas en el caudal gaseoso de entrada es del 99.99%. Este valor se calcula utilizando la concentración inicial de HCl, que es de 1000 mg HCl/Nm^3 y el valor obtenido en la medición de mayo de 2023, que es de 0.07 mg HCl/Nm^3.

Se ha llevado a cabo una evaluación económica que incluye el cálculo del costo de inversión inicial para adquirir los principales equipos del sistema. Esta inversión ascendió a 71,000 €. Además, se ha determinado el costo de operar el sistema durante un año, el cual se estima en 35,406 €/año, con el objetivo de reducir las emisiones de HCl a la atmósfera y lograr que la empresa sea Net positive.

CONCLUSIONES

La instalación y puesta en marcha del lavador húmedo de torre empacada ha sido exitosa, logrando un rendimiento del 99.99% al reducir la concentración de HCl de 1,000 mg HCl/Nm^3 a un valor de 0.07 mg HCl/Nm^3. Este resultado cumple con el objetivo de la empresa de ser Net positive, ya que el valor es muy bajo y demuestra la eliminación de HCl en las emisiones a la atmósfera [2].

Además, el valor promedio de la concentración de HCl obtenido en las muestras, $5.41 \cdot 10^{-3}$ mg HCl/Nm^3, se acerca al valor de $5.33 \cdot 10^{-3}$ mg HCl/Nm^3 obtenido en el blanco utilizando agua de red. Por lo tanto, no se considera realizar un vaciado total y lavado adicional del lavador de gases húmedo de torre empacada, ya que no se observa un incremento en la concentración de HCl en las mediciones. Sin embargo, como medida preventiva, se llevará a cabo una limpieza a fondo una vez al año durante la parada anual de mantenimiento para evitar el fallo del impulsor de la bomba en caso de acumulación de lodos en el fondo de la torre empaquetada.

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[2] CELSA GROUP. 2022. [Accessed on: 06/05/2023]. Available at: https://www.celsagroup.com/wp-content/uploads/2022/11/crcular_cast_web_22baja.pdf

TITLE	Installation and commissioning of vapour extraction and scrubbing system for pickling tanks in the steel industry		
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DEGREE	Chemical engineering degree	**DATE**	07-07-2023

KEYWORDS

Installation and commissioning, scrubber, pickling, acid gases, hydrochloric acid

SCOPE

At TYCSA PSC, the current method employed for removing ferrous oxide (Fe_2O_3) and calamine from the metal surface metal involves chemical pickling using hydrochloric acid (HCl). This pickling process not only facilitates the subsequent wire rod drawing but also requires the addition of phosphate and a carrier salt. However, as a part of the process, acid gases are generated in the treatment line tanks, necessitating their treatment before being released into the atmosphere to meet Spanish environmental regulations. The relevant regulations, specified in the Boletín Oficial del Estado (BOC) Ley 17/2006, de 11 de diciembre, de control ambiental integrado [1], establish a maximum permissible concentration limit of 30 mg HCl/Nm^3 for the emission of acid gases into the atmosphere.

In this context, the objective of this Final Degree Project has been to install and commission a system designed to reduce the concentration of HCl in the acid gases emitted by the pickling tanks. By achieving this goal, TYCSA PSC aims to fulfill its commitment to becoming a company with a Net positive impact [2].

RESULTS

The packed column wet gas scrubber was selected due to its high efficiency in treating gas vapor containing gaseous contaminants. After assembling all the components, pre-commissioning checks and tests are carried out to ensure proper machine operation and equipment and piping sealing. To evaluate the treatment for a maximum inlet flow of 21,000 m^3/h at 20ºC with a purge rate of 0.2 m^3/h, a study on the total acidity of the purge is carried out using volumetry with NaOH. The results of this study are used to determine the concentration of HCl in the gas emissions for each collected sample. The average HCl concentration is found to be $5.41 \cdot 10^{-3}$ mg HCl/Nm^3, which closely matches the value of $5.33 \cdot 10^{-3}$ mg HCl/Nm^3 obtained from the black test using tap water. Consequently, discharging the purge into the sewage system would not pose toxic conditions for the aquatic organism population. However, the discharging water undergoes treatment in the company's wastewater treatment plant.

In 2018, atmospheric emissions contained 17.16 mg HCl/Nm^3 of hydrochloric acid. To become a Net positive company, a scrubber is installed and commissioned to reduce acidic emissions. With this equipment, a concentration of 0.07 mg HCl/Nm^3 was achieved, which is extremely low and can be considered as the complete removal of acid from the treated gas prior to its release into the atmosphere. As a result, the installed equipment is proven to be 99.99% effective in reducing acid emissions in the input gas flow compared to the 2018 value.

Furthermore, an economic evaluation has been conducted to calculate the initial investment cost for purchasing the main equipment of the system, which amounts to 71,000 €. The annual operational cost of maintaining the system to reduce HCl emissions and achieve net positivity is estimated at 35,406 €/year.

CONCLUSIONS

The installation and commissioning of the packed column wet gas scrubber has been highly successful, achieving an impressive efficiency of 99.99%. This remarkable achievement is the result of reducing the HCl concentration in the gases emitted from the pickling line tanks from 1,000 mg HCl/Nm^3 to an average value of 0.07 mg HCl/Nm^3. By attaining such a low concentration, the company has successfully fulfilled its objective of being Net positive, as it can be considered the complete elimination of HCl in the emissions to the atmosphere [2].

Furthermore, the mean value of the total acidity obtained in the samples, which is $5.41 \cdot 10^{-3}$ mg HCl/Nm^3, closely aligns with the total acidity of $5.33 \cdot 10^{-3}$ mg HCl/Nm^3 obtained in the blank test using mains water. This similarly indicates that there is no significant increase in HCl concentration during the measurements, eliminating the need for setting a period for a total emptying and subsequent washing of the packed tower wet scrubber. However, as a preventive measure, a thorough cleaning will still be conducted once a year during the annual maintenance shutdown in order to avoid pump impeller failure in the event of sludge build-up at the bottom of the packed tower.

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1. Introduction

1.1. Collaborating company

The Final Degree Project focuses on “TYCSA PSC” (Company logo in Figure 1).

***Figure 1**. TYCSA PSC company logo.*

TYCSA PSC is a company dedicated to the manufacture of wires and high yield strength steel strands for various industrial applications since its origin in the 50's in Barberá del Vallés (Barcelona). The company expensed its operations with the inauguration of the new factory in Santander (Cantabria) in 1988 at the same time it was annexed to CELSA GROUP™ through Global Steel Wire (GSW). In 2015, TYCSA PSC merged with other Spanish wire drawing companies to form GLOBAL SPECIAL STEEL PRODUCTS, S.A.U (GSSP). Today, TYCSA PSC is globally recognized as a leading producer of high-strength steel wire, renowned for its innovation and competitiveness in major markets worldwide [1].

CELSA GROUP™, founded in 1967 in Castellbisbal (Barcelona) and owned by the Rubiralta family, is a Spanish multinational with presence in France, United Kingdom, Denmark, Finland, Norway, Poland, Sweden and Ireland. It holds the distinction of being the first Spanish private steel group and the third-largest steel products manufacturer in Europe, specializing in the production of low-emission circular steel. The group comprises six business divisions and operates more than 120 locations.

As the largest circular supply chain in Europe, CELSA GROUP™ is committed to addressing two major systemic risks facing our planet: climate change and the depletion of natural resources. The company operates as an integrated company entity, boasting a fully circular industrial process in which all its products are 100% recyclable and can be recycled numerous times. Additionally, 93.5% of the steel it produces is derived from recycled steel (scrap). CELSA GROUP™ valorizes 90% of the waste generated in its processes and contributes to the recovery and recycling of 9.5 million metric tons of waste each year [2]. These efforts align with its ambitious goals of reducing CO_2 emissions by 50% and achieving 98% circularity by 2030, ultimately striving to become a Net Positive and zero waste company by 2050.

1.2. TYCSA PSC final products

TYCSA PSC offers a diverse range of wires and strands, classified into various categories. These products cater to different industrial needs.

The different wire diameters are available in plain, graphited and galvanized surfaces. The galvanized surfaces, in particular, are notable for their exceptional strength, exceeding 1800 N/mm^2. Additionally, TYCSA PSC manufactures cords with two, three and seven wires.

The seven-wire cords can be protected with up to three different barriers against corrosion. For instance, galvanized cords are coated with wax or grease and can also feature a high-density polyethylene sheath of different colours. The manufacturing process of TYCSA PSC final products is depicted in Figure 2.

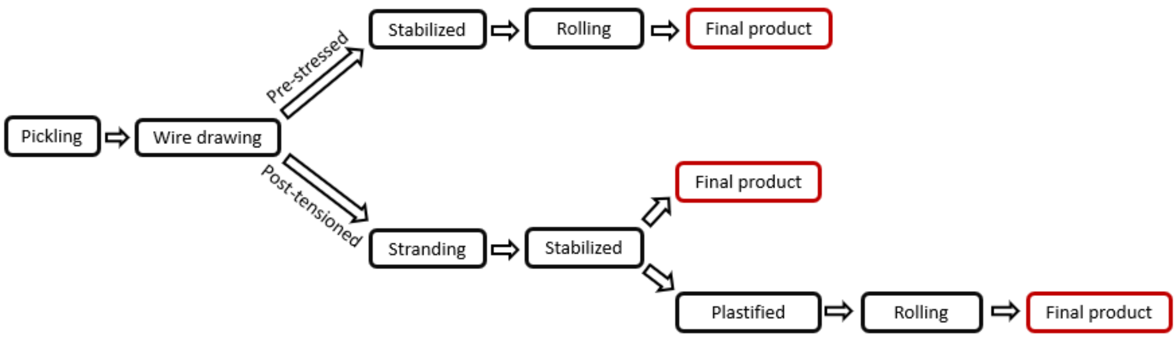

__Figure 2__. Manufacturing process of the different final products of TYCSA PSC.

TYCSA PSC wires and cables, each possessing distinct characteristics, find application in various areas [1]:

- Main cables.

- Pendulums.
- Protective wire of the main cable.
- Connectors for pendulums.
- Cables for temporary walkways.
- Temporary storm cable system.
- Special cables for spinning operation.
- Post-tensioning cord.
- Cable for fencing.

These products cater to a wide array of industrial and construction needs, showcasing the versality of TYCSA PSC's offerings.

1.3. Manufacturing processes

To achieve high yield strength strands and wires through cold deformation, the initial step involves utilizing high carbon wire rod as the raw material. This wire rod undergoes several transformation stages [3]:

- **Pickling:** This initial step involves removing rust, scale and impurities from the metal surfaces. The wire rod is treated in a pickling line, where a chemical reaction occurs between the metal and the acid. The objective is to clean the wire rod surface and prepare it for subsequent drawing. Additionally, a phosphate and a carrier salt coating are applied to the steel surface to minimize friction during drawing and enhance corrosion resistance. This coating also aids in the removal of iron oxide (Fe_2O_3) and calamine that accumulates on the surface during the hot rolling of the wire rod.

- **Cold drawing:** The high carbon wire rod's cross section is progressively reduced by passing it through consecutively smaller diameter rows. This process induces significant plastic deformation, resulting in high levels of residuals stresses.

- **Drawing**: The wire is passed through rollers that create corrugations or "grafilas" on its surface, improving its adherence to concrete.

- **Stabilizing:** This treatment aims to relieve the stresses generated during drawing and stabilize the mechanical properties of the wire. The wire is heated to around 400°C while being subjected to a tensile force for a short duration.
- **Winding**: The wires are wound into rolls for ease handling and transportation.
- **Stranding**: The wires are helically rolled to form different types of cords.
- **Extrusion**: The plasticized cords undergo extrusion, during which they are coated with a polyethylene sheath. Specific materials such as waxes and greases are injected between the sheath and the steel, providing additional protection and lubrication.

1.4. Pickling process

The pickling process is an initial stage in preparing the wire rod and removing impurities such as stains, inorganic contaminants and rust or scale, commonly referred to as calamine, from ferrous metals before cold drawing. The presence of calamine negatively impacts the effectiveness due to its poor thermal conductivity. This causes the electric arc produced during the welding process to remain short, and therefore, the welded material does not flow well, resulting in a less effective and less resistant weld. The high hardness of the calamine shortens the service life of rolling rolls and leads to a loss of component performance due to the creation of uneven areas when the calamine flakes off.

Calamine is a bluish-gray oxide layer that forms immediately on the surface of hot-rolled steel products due to the high temperature and pressures exerted by the rolling mill rolls. It consists of distinct and separate layers of wustite (FeO), magnetite (Fe_3O_4) and hematite (Fe_2O_3), without metallurgically bonding. Consequently, when the steel is manipulated and deformed, the scale easily breaks and detaches from the surface. The distribution of these oxide layers can be seen in Figure 3 [4].

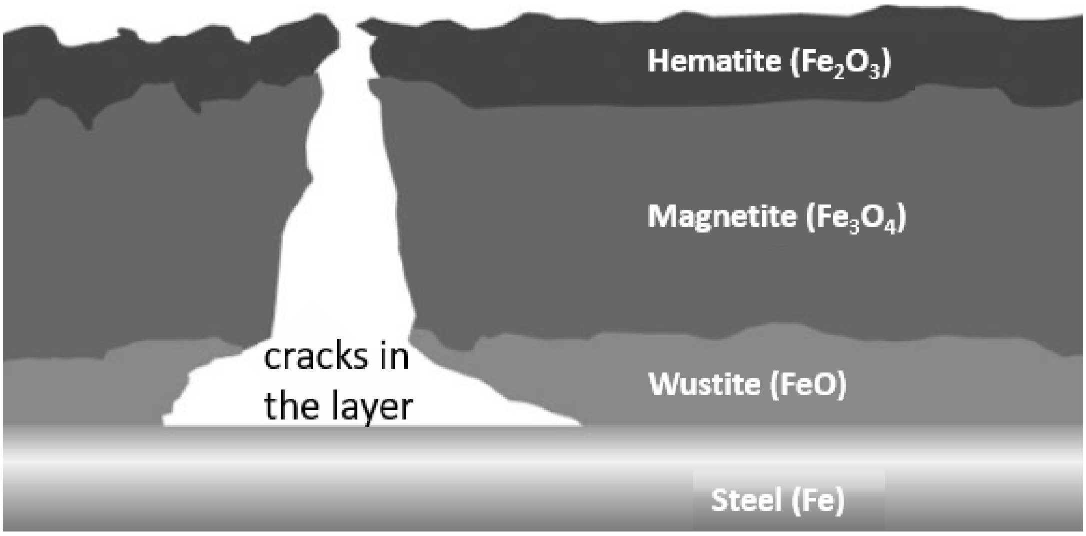

Figure 3. *Calamine layers present on the surface of the steel.*

There are two primary methods of pickling employed in the industry:

- **Chemical pickling**: This process involves immersing the metal surface in an acid bath, typically hydrochloric acid (HCl) or sulfuric acid (H_2SO_4), at specific concentrations and temperature for sufficient time to remove the oxide layer. HCl es the more commonly used acid for pickling. Chemical pickling facilitates the removal of oxides from the metal surface, preparing it for further processing.

- **Mechanical pickling:** This technique focuses on cleaning the metal surface through either shot blasting, sandblasting techniques, or bending shelling. Shot blasting involves directing a high-speed jet of small steel particles onto the wire rod’s surface under controlled conditions. Sandblasting, on the other hand, employs a jet of sand and air to erode the outermost layer of the wire rod. The bending shelling technique involves the deformation of the material by bending through multiple rollers. The bending action causes elongation in the base material, resulting in the breaking and detachment of the calamine layer from the surface. This mechanical deformation process does not require the use of chemicals and is particularly effective in treating smaller areas.

These two pickling methods have distinct characteristics in terms of coverage area and the resulting surface finish. Chemical pickling is suitable for treating larger surface areas and delivers a high-quality finish. On the other hand, mechanical pickling targets specific areas without the use of chemicals. Although mechanical pickling is considered a more sustainable process due to its chemical-free nature, it is generally effective in removing the high degree of oxidation of the wire rod coils, which can be more addressed by chemical pickling.

In the pickling process employed by TYCSA PSC, HCl is used. The HCl is sourced from DuPont Corporation and has an initial concentration of around 20% HCl. Prior to use, it is carefully diluted with water to achieve a desired HCl concentration of 18%. This controlled acid solution plays a crucial role in effective pickling the wire rod to ensuring that it meets the desired quality standards set by TYCSA PSC.

The automatic pickling line is organized based on numbered positions, indicating the locations where each of the three trolleys can positioned along the pickling line with the assistance of a forklift truck. The first three positions correspond to the entry positions of the wire rod into the pickling line depicted in Figure 4. Position 4 represent an outlet position for the wire rod, which is currently not use.

Figure 4. Pickling line inlet positions.

The pickling process starts with the introduction of the coil to be pickled into one of the three possible positions. A load transfer mechanism is the employed to pick up to the coil and transfer it to the first immersion tank, which corresponds to position 5 within the pickling line. Figure 5 provides a visual representation of one of the three load transfer mechanisms that are utilized in the pickling line.

Figure 5. *Load transfer in the automatic pickling line.*

The Figure 6 illustrates the sequence of tanks from position 5 to the final position in the automatic pickling line:

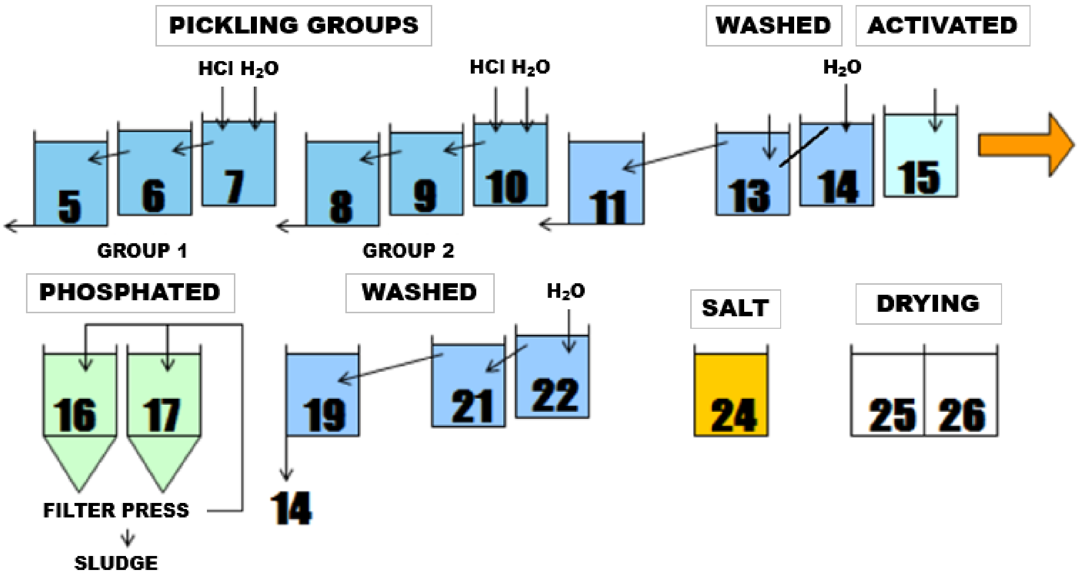

Figure 6. *Description of the pickling line.*

The pickling process involves several tanks through which the wire rod passes for a specific duration, totalling one and a half hours per roll. Each tank plays a crucial role in the generation of acid gases, which are essential for the process. The tanks are explained as follows:

- **Tanks 5,6,7,8,9 and 10**. These tanks comprise two groups of hydrochloric acid operating in parallel, gradually increasing the acid concentration.

  Within these groups, the oxides present on the surface of the wire rod are dissolved as the acid penetrates through the cracks. Additionally, the mechanical effect produce by the hydrogen gas bubbles aids in detaching calamine particles. These bubbles are formed as a result of the reaction between the acid and the base metal. Typically, it takes a minimum of 3 minutes to remove 80% of the calamine, while longer durations are required to remove the remaining calamine.

  The followings reactions occur during this chemical pickling process:

$$Fe_2O_3 + 6\ HCl \rightarrow 2\ FeCl_3 + 3H_2O \quad \text{(reaction 1)}$$

$$Fe_3O_4 + 8\ HCl \rightarrow FeCl_2 + H_2O \quad \text{(reaction 2)}$$

$$FeO + 2\ HCl \rightarrow FeCl_2 + H_2O \quad \text{(reaction 3)}$$

$$Fe + 2\ HCl \rightarrow FeCl_2 + H_2 \quad \text{(reaction 4)}$$

  As the iron content increases in the pickling baths, the solubility of the oxides decreases but the attack on the steel intensifies.

  Inhibitors are employed to mitigate excessive acid consumption, prevent large hydrogen releases, and control the metal’s attack rate. However, the effectiveness of inhibitors also depends on the concentration and temperatures of the tank.

- **Tanks 11, 13, 14, 19, 21 and 22.** These interconnected tanks serve as washing tanks. Three of them (13, 14 and 22) received water from a public water supply. The purpose of this tank is to eliminate residual HCl, prevent contamination, and maintain pH control, which is initially highly acidic. This pH can be achieved by increasing the water flow into the tank. The water used for washing undergoes treatment in the treatment plant to ensure its quality.

- **Tank 15**. This tank is known as activation or refining tank. Its primary function is to generate crystallization cores on the oxide-free surface phosphatization. Similar to the washing tanks, pH control is maintained within a basic range. The renewal of these tanks is carried out partially, as the amount of activation required varies based on the wire rod's diameter and production volume.

- **Tanks 16 or 17**. These tanks are used for phosphating. The formation of phosphate crystal occurs through a two-reaction system. The first reaction involves the attack of phosphate ($FePO_4$), while the second reaction replaces Fe with Zn, resulting in the formation of zinc phosphate ($Zn_3(PO_4)_2$). This phosphate layer chemically adheres to the metal surface and acts as a barrier between the steel and the wire drawing machine, preventing wire seizure during the drawing process.

- **Tank 24.** This tank serves as the salt carrier and is responsible for chemically neutralizing acid salts. Its primary role is to transport the drawing soap, minimizing wear on the material during drawing, and ensuring the stability of the emulsion by protecting the bath from potential negative effects of saline drag polymers.

- **Tanks 25 and 26.** These tanks are dedicated to drying the wire rod. This stage is crucial as inadequate drying between coils can lead to rust formation due to residual humidity.

Upon completion of the pickling process, the steel attains a specific layer distribution, as illustrated in Figure 7:

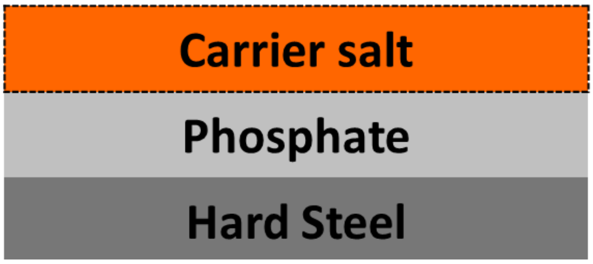

Figure 7. *Layer distribution after undergoing the pickling line.*

To effectively handle the gases regenerated during the pickling process, the HCl, phosphate and carrier salt tanks are equipped with a side suction mechanism. These systems have a maximum combined flow rate of 21,000 m^3/h for capturing acid gases. This side extraction (Figure 8) includes suction hoods and automatic lids that open only during loading or unloading occurs. The aspirated gases are then conveyed through a network of pipes to a gas washer, commonly known as a scrubber. This scrubber is specifically designed to minimize the emissions of acid gases, thus contributing to environmental sustainability.

Figure 8. *Side extraction system for capturing gases during the pickling process.*

1.5. Scrubber

Scrubbers, also known as gas washers, are used as a purification system to eliminate undesirable contaminants from industrial exhaust streams. There are two main methods for removing particulates from the gas stream, depending on the specific process [5]:

- **Dry gas scrubber**: this method involves introducing a solid substance, typically in powder form, into the exhaust gas to remove harmful components. This solid substance, often a reagent, serves various purposes depending on the targeted material. It can neutralize harmful substances or initiate reactions that transform them into different precipitates.

- **Wet gas scrubber**: this method operates by spraying a liquid substance into the exhaust gas to remove contaminants. The liquid accumulates at the bottom of the scrubber chamber and is then channelled out for proper disposal.

Wet gas scrubbers are more commonly employed for acid gas control as they effectively process a wider range of contaminants compared to dry gas scrubbers, which are less suitable for air pollution control. Furthermore, wet scrubbers are the only pollution control method capable of simultaneously removing both particulate matter and exhaust gases in a single process [6].

There are also various types of wet scrubbers available, each with different capacities, specific functions, or emissions control capabilities [6]:

- **Venturi scrubber**: This type of gas scrubber that brings the liquid and contaminant gas into contact by spraying them through a Venturi duct. It operates by pushing gases at high velocity and pressure through an hourglass-shaped chamber. The incoming liquid, at lower pressure, is converted into a mist that traps particles and gases in droplets.

- **Jet scrubber:** A variation of the Venturi scrubber, ideal for removing harmful particles and gases for a gas stream, particularly when dealing with sticky, flammable or highly corrosive waste. Jet scrubbers use a sprinkler system to generate high-velocity spraying of the washing liquid, resulting in the impact necessary for removing contaminating particles.

- **Orifice scrubbers**: Similar to Venturi scrubbers, these scrubbers cause gas to spray the liquid at high velocities. However, in orifice scrubbers, the gas passes over a pool of scrubbing liquid, collecting droplets that gradually turn into mist. The gas is impacted by deflectors, causing it to expel the liquid containing the contaminants.

- **Spray or pulverizing towers**: this is the simplest type of scrubber where liquid droplets are produced using spray nozzles and allowed to settle through a rising stream of gases.

- **Cyclone spray chamber**: this scrubber combines cyclone capture techniques with spray towers. Gas enters the chamber tangentially at high velocity, inducing cyclonic action. The smaller droplets size allows for increased collection efficiency, although higher energy is required due to high-pressure drops.

- **Packed column or packed tower scrubbers**: in this type of scrubber, the absorption of the contaminant gas occurs in a countercurrent manner inside a scrubber. The scrubbing liquid is dispersed and uniformly distributed using distributors or full cone atomizers with large passages that can be easily removed for revision or change.

  The retention of droplets, which is inherent the liquid distribution system, is achieved within the same tower using a highly efficiency and low head loss vertical flow devesiculator. This devesiculator prevent the emission of drops into the atmosphere and minimizes losses of the washing solution.

  The washing liquid, contained at the bottom of the tower, is recirculated by a centrifugal pump with excellent chemical and mechanical performance. The liquid level in the tower is maintained at a constant level through a water inlet controlled by an electrovalve that responds to a level indicator with three contacts.

To circulate the air for treatment, a centrifugal fan made of anticorrosive materials is employed. This fan overcomes the pressure losses in the suction circuit and the installed deodorization equipment.

A scheme of the packed tower scrubbers can be seen in Figure 9:

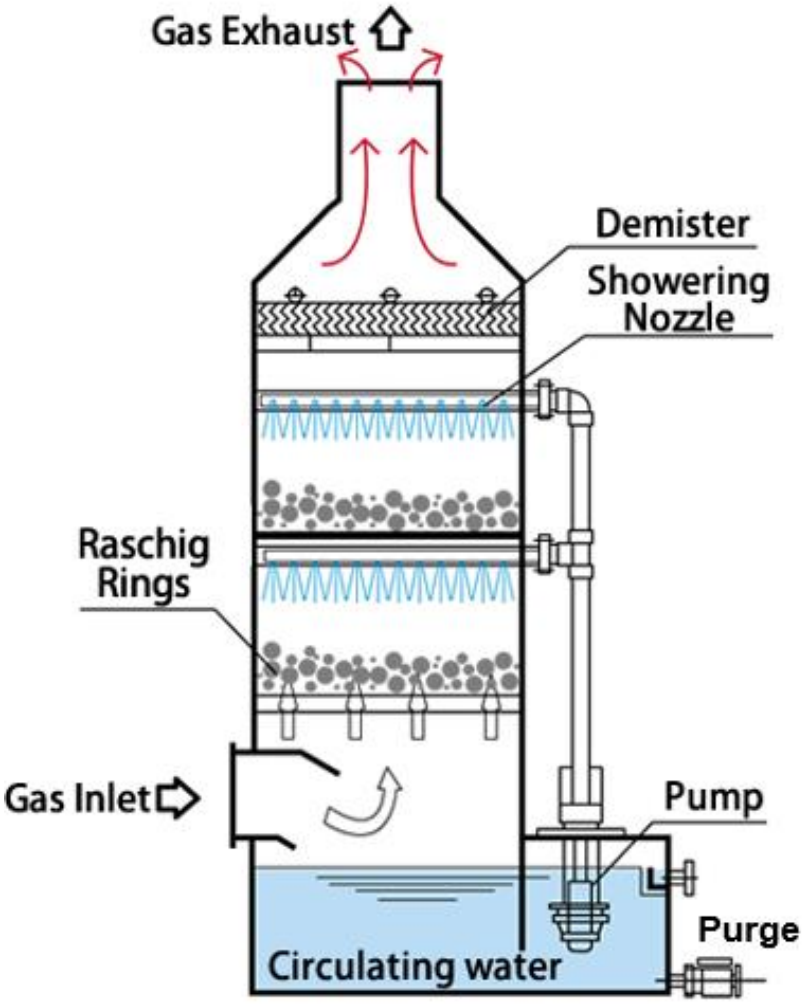

Figure 9. *Packed tower scrubber. [7]*

The packed column scrubber has been selected as the most effective option due to its effectiveness in handling gas steam containing gaseous contaminants.

The objectives of this Final Project Degree revolve around the utilization and application of the packed tower scrubber (refer to Figure 9).

2. Objectives

The primary objective of this final degree project is to install and commission an efficient scrubber system that efficiently manages the gases generated during the pickling process. The system aims to completely remove the emission of polluting gases into the atmosphere, thus contributing to environmental sustainability and ensuring compliance with the authorised limit value for sources 1 and 3. These sources, specifically tanks 5, 6, and 7 (series 1) and tanks 8, 9, and 10 (series 2) of the stripping line, are where HCl gas is extracted. The applicable limit value is established in the Boletín Oficial del Estado within Ley 17/2006, de 11 de diciembre, de control ambiental integrado [8]. By achieving a complete reduction in HCl concentration in the emissions emitted into the atmosphere also, fulfil the objective of TYCSA PSC to become a Net Positive company.

In addition to this primary objective, the project aims to achieve the following goals:

1. Validate the effectiveness of the scrubber system by measuring the concentration of HCl in the exhaust stack.
2. Discharge the wash water used in the scrubber system into the mains water without altering the characteristics of the mains water. Determine, based on the increase in HCl concentration, whether the manufacturer's recommended working flow rate of 0.2 m^3/h is adequate to ensure proper scrubbing of the acid vapours.
3. Assess the maximum continuous operating time before a complete renewal of the scrubber bottom water becomes necessary, due to an elevated HCl concentration in the purge. An increase in concentration leads to the formation of sludge, which can affect the pump impellers and, consequently, the ability to treat the contaminated gas efficiently.

4. Estimate the cost of keeping the scrubbing system operational for one year. In addition to calculating the initial investment for the purchase of the main equipment of the system.

The objective of my internship is within the production department, where the main challenges lie in ensuring safety and quality while maximising production.

Regarding safety, which is the top priority of CELSA GROUP, I have received training in risk assessment as a production technician and the proper use of personal protective equipment (PPE).

As part of my tasks in the department, my work focuses on conducting studies to minimise machine downtime and increase productivity, reducing scrap waste generated during the manufacturing process of various final products, and monitoring the traceability system using the MAPEX system.

3. Methodology

3.1. Scrubber system installation

The packed column scrubber has been selected as the most effective option due to its effectiveness in handling gas steam containing gaseous contaminants, therefore this type of scrubber stands out as an excellent option while choosing between wet scrubbers for removing gaseous pollutants. The choice of tower packing material is made after careful consideration of factors such as gas composition, surface area, material, shape and weight. This ensures chemical compatibility, maximizes gas-liquid contact, and minimizes pressure drop in the gas phase.

Key characteristics of packed column scrubbers include [9]:

- They require minimal installation space.
- They have relatively low capital cost.
- Their construction using glass-fibre reinforced plastic allows then to operate effectively in highly corrosive environments.

- They exhibit relatively low-pressure drops, which refers to the difference in pressure between the exhaust gases entering and exiting the scrubber.
- They can achieve high mass transfer efficiencies, ensuring effective removal of contaminants.
- They are capable of capturing very small particles, including gases, with a particular size as small as 2.5 micrometres.

The components of the scrubber system include the packed column scrubber, the centrifugal pump (Figure 10), the centrifugal fan (Figure 11), and various accessories such as levels, pipes, fittings and valves. These components are supplied and recommended by Fivemasa for the specific conditions of the gas to be treated and the space available, together with pipes, fittings and liquid recirculation valves in PVC and interconnections between scrubber and PP fan, with EPDM gaskets and screws in AISI-304, with pre-assembly in Fivemasa's workshops.

Figure 10. *Centrifugal pump of the scrubber system.*

Figure 11. Centrifugal fan of the scrubber system.

The specific characteristics of the packed column gas scrubber, fan and pump installed in TYCSA PSC are detailed in Table 1.

Table 1. Packed column gas scrubber, fan and pump characteristics.

Packed column gas scrubber	
Washing tower	TLV-2350
Construction material	Stervinyl resin / Glass fiber
Color	White RAL 9010
Diameter	2,350 mm
Height	6,000 mm
Construction thickness	5 mm
Material Contact Rings	Polypropylene
Specific surface	104 m^2/m^3
Free volume	91%
Droplet separator	Vertical flow sheets
Material	Propylene
Capacity of the liquid contained in the bottom	4.8 m^3
Fan	
Model	BHCKK.6-16
Material of parts in contact with the fluid	Polypropylene

Engine coupling	Direct
Flow rate	80 m^3/h
Total manometric head	18 m.c.l
Shaft sealing	Single internal mechanical seal IP-5
Materials of the mechanical seal	Rotor: CSi Stator: CSi Seals: EPDM
Power installed	11 Kw
Engine voltage	380/660 V
Engine angular speed	IP 55
Pump	
Model	MP555-5575
Material of parts in contact with the fluid	Stervinyl resin / glass fibre
Engine coupling	Belts pulleys
Flow rate	21,000 m^3/h
Static pressure	1,500 Pa
Shaft sealing	Leakage-limiting deflector
Power installed	18.5 Kw
Engine voltage	380/660 V
Engine angular speed	2,900 rpm
Protection	**IP 55**

The material for the construction of the packed tower, pump and fan is fiberglass reinforced polyester resin or FRPR, for reinforcement due to its durability, strength and the range of temperature maximum that this material can handle. In addition, FRPR is lightweight, easy to mold and has a high resistance to corrosion, humidity and specially to chemical agents, which makes it suitable for dealing with acid gases [10].

The selection of Raschig rings made of polypropylene for their high chemical resistance is used as filler in the packed tower and is intended to increase the contact between the upwardly propelled acid gas and the downwardly sprayed water in countercurrent.

The configuration and arrangement of the compounds in the gas scrubber system can be seen in Figure 12. This diagram offers a visual representation of the layout of the gas scrubber. The detailed diagram with different perspectives can be observed in full in the appendix in Figure A-1.

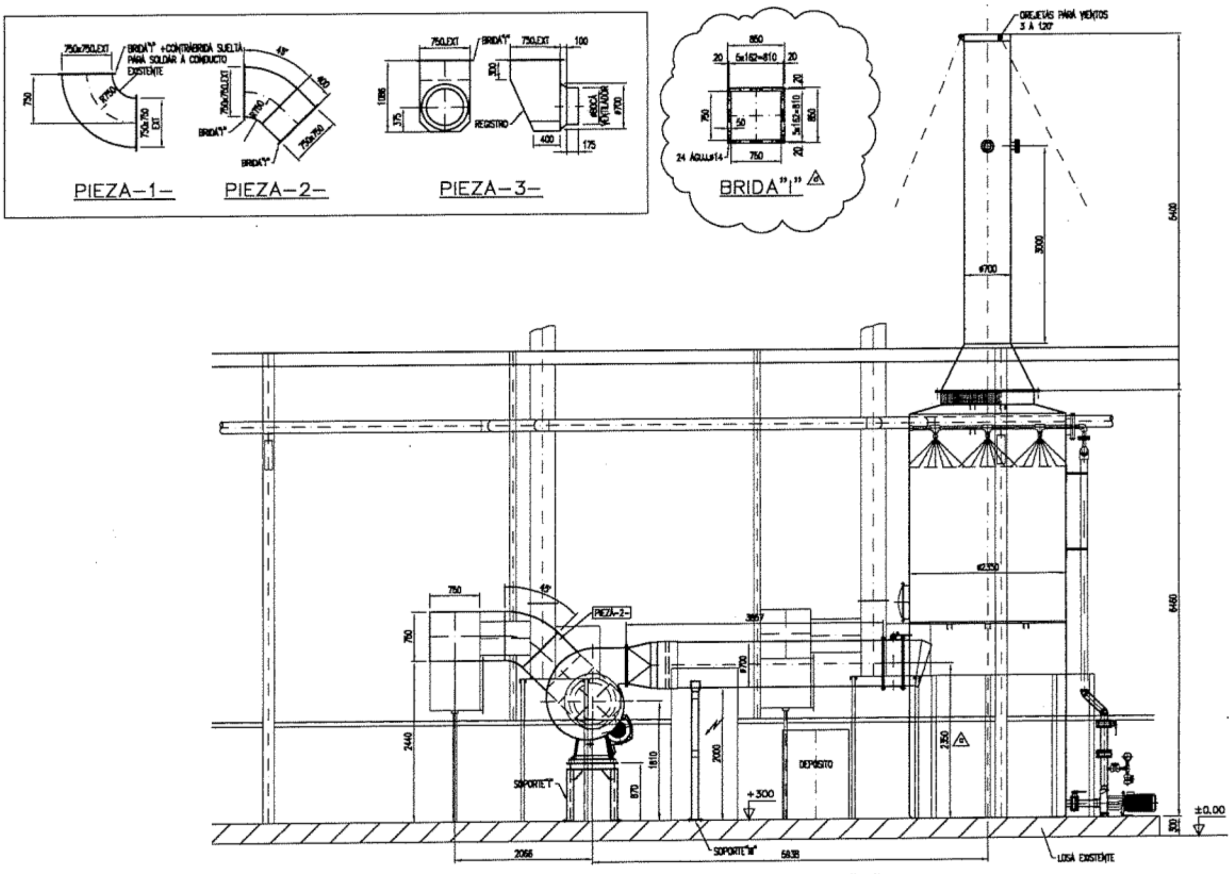

Figure 12. Front view diagram of the scrubber system.

3.2. Effectiveness of the scrubber system

To evaluate the efficiency of the equipment, the concentration of acid in the purge is carefully monitored and the HCl concentration of exhaust stack is measured after commissioning the scrubber. The monitoring of the purge is carried out by measuring a sample of the scrubber purge once a day, Monday to Friday from 2 May to 23 June 2023. For the concentration of acid in the gaseous emission, a measurement is carried out in May by the company Eurocontrol, which carries out the measurements in the stack of the scrubber (Figure 13). The same company carried out the measurement in 2018, however, the scrubber system was not operational and not fully installed. The concentration of hydrochloric acid in the purge is measured using the volumetry method or acid-base titration with sodium hydroxide (NaOH). This method involves the reaction between the acid (HCl) and the base (NaOH), and the resulting total acidity is determined.

***Figure 13**. Stack of the scrubber.*

The acidity of a substance refers to its acidic properties and can be quantified through volumetric methods. In this case, the acid-base reaction between HCl and NaOH is visually observed using and indicator called phenolphthalein. Phenolphthalein is a commonly used indicator that changes the color of the solution to pink in the presence of acid-base reactions.

For the titration process the following materials have been used:

- 100 mL Erlenmeyer flasks.
- 5 mL Glass pipet.
- 50 mL Self-flushing burette.
- Liquid dispensers.

In addition to the 5 mL sample, the following chemicals from ChemLab (Belgium) are used for acid-base titration:

- 30% potassium oxalate.

- 25% potassium fluoride.
- 0.1 N NaOH.
- Phenolphthalein.

During the titration process, the 5 mL sample is supplemented with 20 mL of 30% potassium oxalate and 50 mL of 25% potassium fluoride. These substances act as complexing agents in the titration. Additionally, 10 drops of the indicator are added before the titration with 0.1 N NaOH.

To stablish a baseline, an initial titration is performed using tap water as a blank. The obtained values from this titration serve as a reference for evaluating the acidity present in the purge.

The acidity of the purge is calculated using Equation 1:

$$\text{Acidity}\left(\frac{\text{g}}{\text{mL}}\right) = \frac{V_{\text{NaOH used}} \cdot N \cdot P_{eq}}{V_{\text{sample}}} \qquad \text{(equation 1)}$$

Where:

$V_{\text{NaOH used}}$ is the volume of NaOH used in the volumetry in mL.

N is the normality of NaOH (0.1 N)

P_{eq} is the equivalent weight expressed in grams of predominant acid in the sample, i.e. HCl.

V_{sample} is the volume of the sample in mL.

To express the acidity as a percentage, the value obtained from Equation 1 is multiplied by 100.

Equation 2 is used to calculate the equivalent weight:

$$\text{Equivalent weight} = \frac{\text{Molecular weight}}{\text{Number of ions H}^+} = \frac{36\ \text{g/mol}}{1} = 36\ \text{g} \qquad \text{(equation 2)}$$

To convert the obtained value of g/mL, it is necessary to divide it by 10^3, or Equation 3 can be used to calculate the concentration in mg/Nm^3. This conversion allows for a direct comparison with the value measurement in 2018.

$$\text{Concentration of HCl}\left(\frac{\text{mg}}{\text{Nm}^3}\right) = \text{Acidity}\,\frac{\text{g}}{\text{mL}} \cdot \frac{1\ \text{mL}}{10^6\text{Nm}^3} \cdot \frac{10^3\ \text{mg}}{1\ \text{g}} \qquad \text{(equation 3)}$$

To calculate the performance of the scrubber system, it is necessary to make a comparison between the initial concentration of acid in the gas generated by the tanks from the pickling line without the scrubber back in 2018, and the concentration of acid in the emissions with the scrubber system fully installed and commissioned. This can be calculated using the Equation 4.

$$\%\ \text{Efficiency} = \frac{[\text{HCl}]_{\text{in}}^2 - [\text{HCl}]_{\text{out}}^2}{[\text{HCl}]_{\text{in}}^2} * 100 \qquad \text{(equation 4)}$$

4. Results

4.1. Choice of technology employed

Each region has its own set of regulations regarding air emission control. In Europe, Directive 2010/75/EU serves as the legal framework that links Best Available Techniques (BAT) to industrial emissions and air emission limits. BAT defines the ideal practices for industrial activities, ensuring that they have either no or the least possible negative impact on the environment when implemented using the best achievable techniques [11].

For the chemical sector, the BREF provides BATs for common wastewater and waste gas treatment and management systems. The BREF is a comprehensive document that consolidates information on the Best Available Techniques (BAT) for preventing and controlling environmental pollution by European industries. Its purpose is to guide all those involved in industrial activities by providing ecological and environmental moderation guidelines. It informs environmental authorities about the emission limit values that must be ensured and offers companies guidance on the necessary documentation for environmental permit applications [12].

The BREF convers BAT exhaust gas treatment technologies for reducing particulate matter, volatile liquid substance vapours, gaseous air pollutants and odours. Various technologies are available for exhaust gas treatment, depending on the specific pollutant to be removed. These technologies are summarized in Table 2 [11]:

Table 2. *Selection of waste gas emission abatement techniques per pollutant to be removed.*

Technologies for gas recovery	Dry matter	Wet matter	Inorganic particles	Particularly organics	Gaseous or vaporous inorganic compounds	Gaseous or vaporous organic compounds	Odour
Membrane separation (pre)						x	
Condenser (pre)					(x)	x	
Cryocondensation (pre)					(x)	x	(x)
Adsorption (FT)					x	x	x
Wet gas scrubber (water) (FT)	(x)	(x)	(x)	(x)	x	x	x
Wet gas scrubber (alkaline) (FT)	(x)	(x)	(x)	(x)	x	x	x
Wet gas scrubber (alkaline-oxidation) (FT)	(x)	(x)	(x)	(x)			x
Wet gas scrubber (acid) (FT)	(x)	(x)	(x)	(x)	x	x	x

Pre = mainly as a pretreatment plant.

FT = treatment technique used as final treatment technique.

x = primary pollutants.

(x) = secondary pollutants.

Among the techniques listed in Table 2, particular attention should be given to those that reduce emissions of inorganic components and are specifically designed for treating hydrochloric acid contaminated gas. Based on these considerations, the selection is narrowed down to two of the BAT: adsorption and various wet gas scrubbers. Adsorption involves the use of adsorbents like activated carbon (AC), zeolite, polymer, silica gel or sodium aluminum silicate. However, some of these adsorbents such as zeolite or AC, are not suitable for wet gas streams, and others, like polymers, can be quite expensive. Furthermore, implementing adsorption requires additional equipment for regenerating the saturated adsorbent, making it more suitable for discontinuous rather than continuous processes [13].

The alternative option is to use a scrubber for reducing emissions. This technique is widely used, and depending on the pollutants to be removed, various aqueous scrubbing liquids can be employed, like water, alkaline solution, oxidizing solution or oxidative alkaline solution. Alkaline solutions are typically used when the gas to be treated has a pH between 8.5-9.5 and a low feed concentration, while oxidizing solutions are effective for recovering NOx from concentrated aqueous gases. Another option for the same purpose is water, which is highly efficient, particularly for high concentrations in the feed. Using water as the contact liquid reduces maintenance and operating costs [13] [14] [15].

In comparison, implementing and maintaining a gas scrubber is simpler than implementing adsorption, making it the recommended technology for treating acid gases [15] [16]. The ease of maintenance and operation is a critical factor favoring the selection of a water gas scrubber, as it can be efficiently managed by a single worker. This advantage further reinforces the suitability of a water gas scrubber as the preferred choice for effectively treating acid gases while ensuring that maintenance and operating efforts remain manageable [17].

4.2. Packed column wet gas scrubber

The packed column wet gas scrubber was chosen primarily for its exceptional ability to effectively remove particulates and exhaust gases in a single process. By introducing water into the gaseous stream, it effectively separates air pollutant molecules from the gas. Unlike dry scrubbers, which have limited effectiveness in controlling air pollution and are restricted to specific gaseous pollutants, the packed column scrubber demonstrates superior performance in handling acid gases emitted from the pickling line tanks.

Several key features influenced the choice of the packed column scrubber. Firstly, it provides a cost-effective solution with relatively low capital costs. Additionally, its vertical configuration requires minimal installation space, making it practical and efficient within the facility. The scrubber's design allows it to capture gases and handle gas vapors containing gaseous contaminants, ensuring effective removal of pollutants with high mass transfer efficiencies.

Moreover, the scrubber’s construction using glass-fibre reinforced plastic enables it to operate effectively even in highly corrosive environments. It also exhibits low-pressure drops, resulting in minimal pressure difference between the exhaust gases entering and leaving the scrubber. These features further enhance the scrubber’s effectiveness in controlling air pollution.

4.3. Scrubber system installation

Once the scrubber, along with all its components, is securely mounted on a level and appropriately sized concrete plinth, a series of preliminary controls and verifications are conducted before initiating the start-up process. These controls and verifications are crucial to ensure the proper functionating of the machinery and the effective sealing of equipment and piping.

The preliminary controls are carried out into two groups:

- **Machines** (the pump and the fan): this inspection involves assessing the cleanliness of the interior of the machines and piping to ensure there are no residual impurities from the assembly process. it is also essential to verify that the direction of rotation of each machine is correct, ensuring optimal performance. Another critical aspect is the operation of the full cone sprayer (Figure 14). It should be free from any obstructions or impurities that could hinder the uniform distribution of the washing liquid. Through verification of these aspects ensures that the liquid is efficiently dispersed throughout the scrubber, maximizing its effectiveness.

Figure 14. Full cone sprayer of the scrubber system.

- **Accessories** such as levels, pipes and valves: during this preliminary control, the wash tank is filled with water until the level is sufficient to completely submerge the pump impellers. This step allows for the examination of the tightness of vessels, pipes, valves and seals. A level indicator (Figure 15) is used to ensure proper coverage of the pump's impellers. It is important to note that the pump suction valve should be fully open, while the pump delivery valves should be partially open, around 50%, to prevent exceeding the motor relay's capacity during pump startup and to avoid any potential damage to the pump from having the valve completely closed.

Figure 15. *Liquid level and fittings such as valves and piping of the scrubber system.*

Pre-testing is then carried out using water and air to verify the proper functioning of machinery and the integrity of the equipment and piping. These verifications are carried out in the following sequence:

I. The pump is operated with water for one hour to observe the establishment and maintenance of the water level and flow regime. The impulsion valve is adjusted to achieve desired flow rate of 21,000 m^3/h. During this step, the tightness of pipes, joints and other accessories in the discharge system is also re-verified.

II. The fan is activated while keeping the butterfly valve partially closed during the initial minutes of machine start-up. This controlled start-up process ensures smooth operation of the fan.

4.4. Start-up of the scrubber system

Before starting the operation of the system with the gas to be purified and the supplied liquid (water), it is essential to ensure that the liquid level in the tank is below the level required to fully submerge the impeller of the recirculation pump.

When starting the pump and fan, it is important to follow the guidelines mentioned in the previous section regarding the position of valves and dampers. Subsequently, the flow of the scrubber's irrigation liquid should be adjusted to match its design value.

If observable liquid droplets are carried towards the vent outlet, it indicates that the gas flow being transported exceeds the system's design capacity. In such cases, the butterfly valve or damper should be gradually closed until the phenomenon disappears.

The purge rate established for the system is directly proportional to the concentration of and the air flow rate to be treated. For example, to handle a gas flow rate of 21,000 m^3/h at 20ºC and an estimated HCl concentration of 1,000 mg HCl/Nm^3, a purge of 4.8 m^3/day could be established, requiring daily emptying of the scrubber. However, to enable continuous operation as recommended by the manufacturer, an emptying rate of 0.2 m^3/h has been employed.

A visual representation of a fully installed and properly functioning scrubber system at TYCSA PSC is provided in Figure 16:

Figure 16*. Scrubber system installed and operating at TYCSA PSC.*

4.5. Effectiveness of the scrubber system

To assess the efficiency of the installed and commissioned scrubber system, a measurement of the HCl concentration in the gas emission released into the atmosphere through the system's stack is carried out in May 2023, yielding a result of 0.07 mg HCl/Nm^3. This measurement was performed by the company Eurocontrol, which also analyzed the chemical compounds in the emissions in 2018, obtaining an emitted acid concentration of 17.16 mg HCl/Nm^3. Unfortunately, more recent measurements prior to the installation of the scrubber were not available, as measurements are taken every 5 years according to the Guide to the state regulations on air emissions [18], which includes Law 34/2007 [19] and Royal Decree 100/2011 [20]. This 5-year measurement interval is applicable because sources 1 and 3, corresponding to hydrochloric acid vat extractions, are categorized in group C, according to TYCSA PSC's Integrated Environmental Authorization [8].

To establish a reference efficiency value, the efficiency was calculated using the atmospheric emissions data from 2018, where an initial concentration of 1,000 mg HCl/Nm^3 was assumed, and a measured concentration of 17.16 mg HCl/Nm^3 was obtained.

The efficiency value without the scrubber was compared to the efficiency obtained after the installation and commissioning of the scrubber. With the scrubber in place, the final concentration in the gas emitted to the atmosphere was measured as 0.07 mg HCl/Nm^3 in May 2023, using the same initial HCl concentration as in 2018.

These efficiencies can be calculated using Equation 4, as described in the methodology.

$$\%\ \text{Efficiency}_{\text{without scrubber}} = \frac{1{,}000^2 - 17.16^2}{1000^2} * 100 = 99.97\% \quad (\text{equation 5})$$

$$\%\ \text{Efficiency}_{\text{with scrubber}} = \frac{1{,}000^2 - 0.07^2}{1{,}000^2} * 100 = 99.99\% \quad (\text{equation 6})$$

The commissioning of the equipment has resulted in a performance improvement of 0.02%, bringing it closer to the objective of achieving a net positive outcome with emissions reaching 0 mg HCl/Nm^3. This improvement is calculated as the difference between the results from Equations 5 and 6.

In address objectives 2 and 3 regarding the possibility of discharging the used water into the mains water and the time required to empty and clean the bottom of the scrubber, respectively, it is necessary to measure the total acidity and the HCl concentration in the system purge. For this purpose, multiple samples were collected, including a blank sample using tap water for the acid-base titration. The obtained volume values of NaOH for each sample are detailed in Table 3. Furthermore, Table 3 provides the corresponding values of HCl concentration and total acidity for each sample, calculated using equations 1, 2 and 3:

***Table 3**. Experimental data obtained.*

	V_{NaOH} used (mL)	Total acidity (mg/mL)	[HCl] (mg/Nm^3)
Blank	7.4	5.33	5.33E-03
1	6.8	4.90	4.90E-03
2	6.8	4.90	4.90E-03
3	7.6	5.47	5.47E-03
4	7.4	5.33	5.33E-03
5	7.7	5.54	5.54E-03
6	6.7	4.82	4.82E-03
5	8.4	6.05	6.05E-03
6	7.6	5.47	5.47E-03
7	7.8	5.62	5.62E-03
8	7.6	5.47	5.47E-03
9	6.9	4.97	4.97E-03
10	7.4	5.33	5.33E-03
11	7.7	5.54	5.54E-03
12	7.6	5.47	5.47E-03
13	7.4	5.33	5.33E-03
14	7.7	5.54	5.54E-03
15	7.5	5.40	5.40E-03
16	7.4	5.33	5.33E-03
17	7.7	5.54	5.54E-03
18	7.4	5.33	5.33E-03
19	7.5	5.40	5.40E-03
20	8.2	5.90	5.90E-03
21	7.1	5.11	5.11E-03
22	7.9	5.69	5.69E-03
23	7.7	5.54	5.54E-03
24	7.9	5.69	5.69E-03
25	7.6	5.47	5.47E-03
26	7.8	5.62	5.62E-03
27	6.7	4.82	4.82E-03

28	7.8	5.62	5.62E-03
29	7.4	5.33	5.33E-03
30	7.6	5.47	5.47E-03
31	7.2	5.18	5.18E-03
32	7.7	5.54	5.54E-03
33	8.1	5.83	5.83E-03
34	7.4	5.33	5.33E-03
35	7.1	5.11	5.11E-03
36	7.6	5.47	5.47E-03
37	7.4	5.18	5.18E-03
Average	**7.5**	**5.41**	**5.41E-03**

A graphical representation of the total acidity results obtained is illustrated in Figure 17:

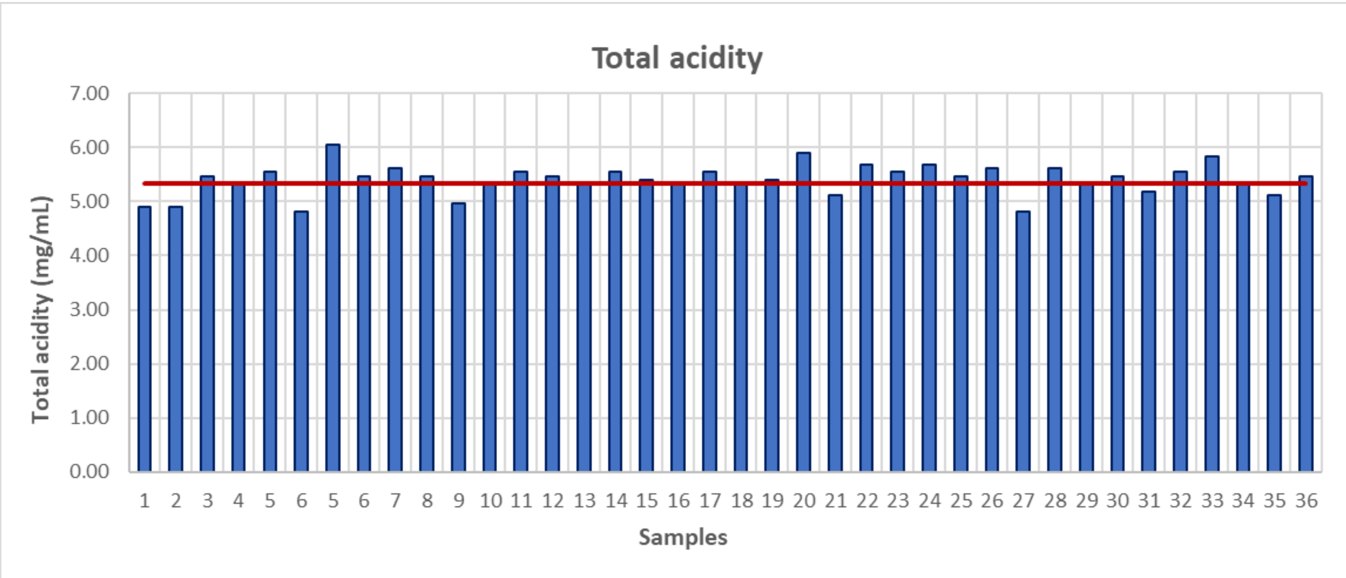

__Figure 17__. Experimental results on total acidity.
Columns: total acidity (mg/mL) measured in each sample.
Line: total acidity (mg/mL) measured in the blank using mains water.

Figure 17 illustrates the measurement of total acidity in each sample compared to the blank sample, which was obtained using mains water. Evaluating the total acidity, involves comparing the values obtained in each sample with the total acidity of the mains water, where the discharge will occur.

The total acidity value for the blank sample was determined to be 5.33 mg/mL, while the average total acidity value for the samples is 5.41 mg/mL. The difference between the two values is minimal (0.08 mg/mL), further supporting the conclusions that the scrubber system's purge will not substantially alter the total acidity of the water in case of discharge into mains water. This outcome is a favorable because an increase in water acidity can disrupt the water chemistry balance and mobilize pollutants, potentially causing toxic conditions that can harm aquatic organisms. It is important to note that the purge water is collected in a sump, and when the sump reaches its capacity, the water is directed to the plant's treatment facility.

The results of the concentration of HCl in the purge are presented in Figure 18:

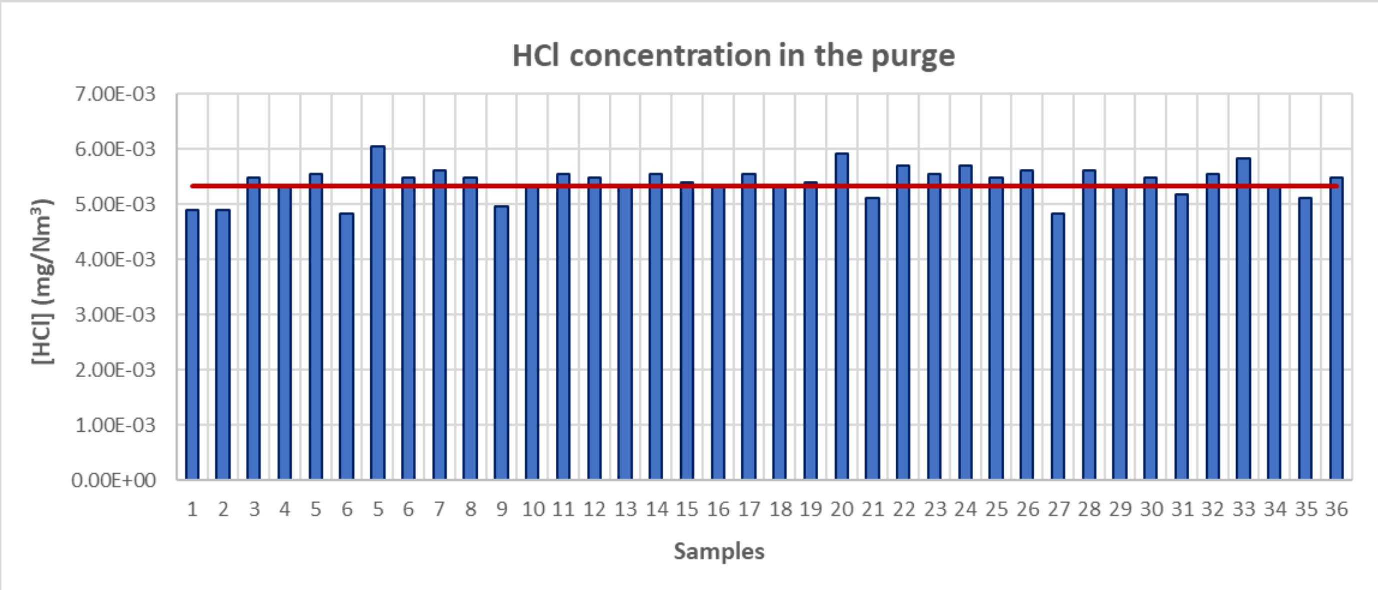

Figure 18*. Experimental results for HCl concentration in the purge.*
Columns: HCl concentration (mg HCl/Nm^3) of each sample.
Line: HCl concentration (mg HCl/Nm^3) in the blank using mains water.

Unlike Figure 17, which compares the total acidity of the purge samples with that of the mains water, Figure 18 focuses on the HCl concentration data of the samples in comparison to the acid concentration in the blank sample. The average HCl concentration in the samples is $5.41 \cdot 10^{-3}$ mg HCl/Nm^3, while the concentration in the blank sample is $5.33 \cdot 10^{-3}$ mg HCl/Nm^3. These values indicate that the HCl concentration in the purge is extremely low and similar to the acid concentration found in the mains water. Consequently, discharging the purge into the mains water would not result in toxic conditions or a decline in aquatic organism populations.

The similarity in HCl concentration between the samples and the blank (Figure 18) demonstrates that there is no significant increase in HCl concentration during the measurements. This eliminate the need to establish a period, referred to in partial objective 3, for a complete emptying and subsequent flushing of the packed tower wet scrubber, as no sludge is generated that would cause a failure of the pump impellers and thus a decrease in the amount of scrubbing liquid to treat the contaminated gas. However, as a precautionary measure, a thorough cleaning will still be performed once a year during the annual maintenance shutdown.

Moreover, the recommended purge rate of 0.2 m^3/h by the manufacturer is suitable for treating 21,000 m^3/h of acid gas since there is no increase in HCl concentration in the purge.

4.6. Economic assessment

An economic assessment has been conducted to determine the cost of installing the scrubber system for reducing acid emissions into the atmosphere. The cost of main equipment used in the installed system is presented in Table 4.

***Table 4**. Cost of main equipment of the installed system.*

Equipment	**Cost (€)**
Packed column	39,110
Pump	4,559
Fan	18,900
Accessories	7,180
Conductions	1,251
Total	71,000

Additionally, the cost of maintaining the system in operation for one year has been calculated. This includes the energy cost required by the pump and the fan based on their power consumption, as well as the cost of the water needed to maintain the water level in the scrubber at 4.8 m^3. The data considered for estimating the energy and water requirements, along with the obtained values, are summarized in Table 5.

Table 5. *Cost of maintaining the system in operation for one year.*

Equipment	Power installed (kWh)	Price (€/Kwh)	Cost (€/year)
Fan	11	0.107996	10,263.94
Pump	18.5	0.107996	17,262.08
Equipment	**Water consumption (m^3/day)**	**Price (€/m^3)**	**Cost (€/year)**
Packed column	4.8	0.00019	7,879.68
		Total (€/year)	35,405.70

In order to achieve TYCSA PSC's objective of becoming a Net positive company, the equipment required for the installation of the packed column wet scrubber amounted to 71,000 €. Additionally, the estimated annual cost to maintain the operation of the scrubber system is 35,406 €/year, which enables them to effectively eliminate acid emissions into the atmosphere.

5. Conclusions

The selected technique for reducing the concentration of HCl in atmospheric emissions at TYCSA PSC is the packed column wet scrubber, chosen after evaluating the best available techniques outlined in the BREF for acid gas emission reduction. The packed column scrubber is not only effective but also easy to maintain, making it a favorable choice. It can be efficiently managed by a single worker, minimizing maintenance and operational efforts.

The installed packed column wet scrubber at TYCSA PSC has demonstrated an impressive efficiency of 99.99%. This remarkable efficiency is evident in its ability to reduce the HCl concentration in the gases emitted from the pickling line tanks from an initial level of 1,000 mg HCl/Nm^3 to an extremely low concentration of 0.07 mg HCl/Nm^3, as measured in May 2023. The successful commissioning of this equipment has allowed TYCSA PSC to achieve its goal of becoming a Net positive company, as the emission value of 0.07 mg HCl/Nm^3 is negligible and can be considered effectively zero, ensuring no acidic emissions are released into the atmosphere.

Moreover, the average HCl concentration obtained after obtaining the total acidity of the samples is $5.41 \cdot 10^{-3}$ mg HCl/Nm^3, which closely aligns with the concentration value of $5.33 \cdot 10^{-3}$ mg HCl/Nm^3 obtained in the blank test conducted with mains water. The minimal difference of only $8.53 \cdot 10^{-5}$ mg HCl/ Nm^3 further confirms that the purge from the scrubber system is suitable and will not significantly alter the HCl concentration of the water if discharged into the mains water, thus preventing the creation of toxic conditions. It is important to note that the purge water is collected in a sump, and once the sump reaches its capacity, the water is directed to the plant's treatment facility.

Based on the measurements, it has been determined that it is not necessary to set a period for total emptying and subsequent cleaning of the packed tower wet scrubber as there is no significant increase in HCl concentration during the measurements. However, as a precautionary measure, a complete emptying and cleaning of the system will be performed once a year during the annual maintenance shutdown in order to avoid pump impeller failure in the event of sludge build-up at the bottom of the packed tower.

To pursue the objective of becoming a Net positive company, TYCSA PSC has made a significant investment of 71,000 € in acquiring the essential equipment for the implemented purification system. Additionally, the estimated annual operational cost to ensure the system's continuous operation amounts to 35,406 € per year.

6. References

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7. Appendix

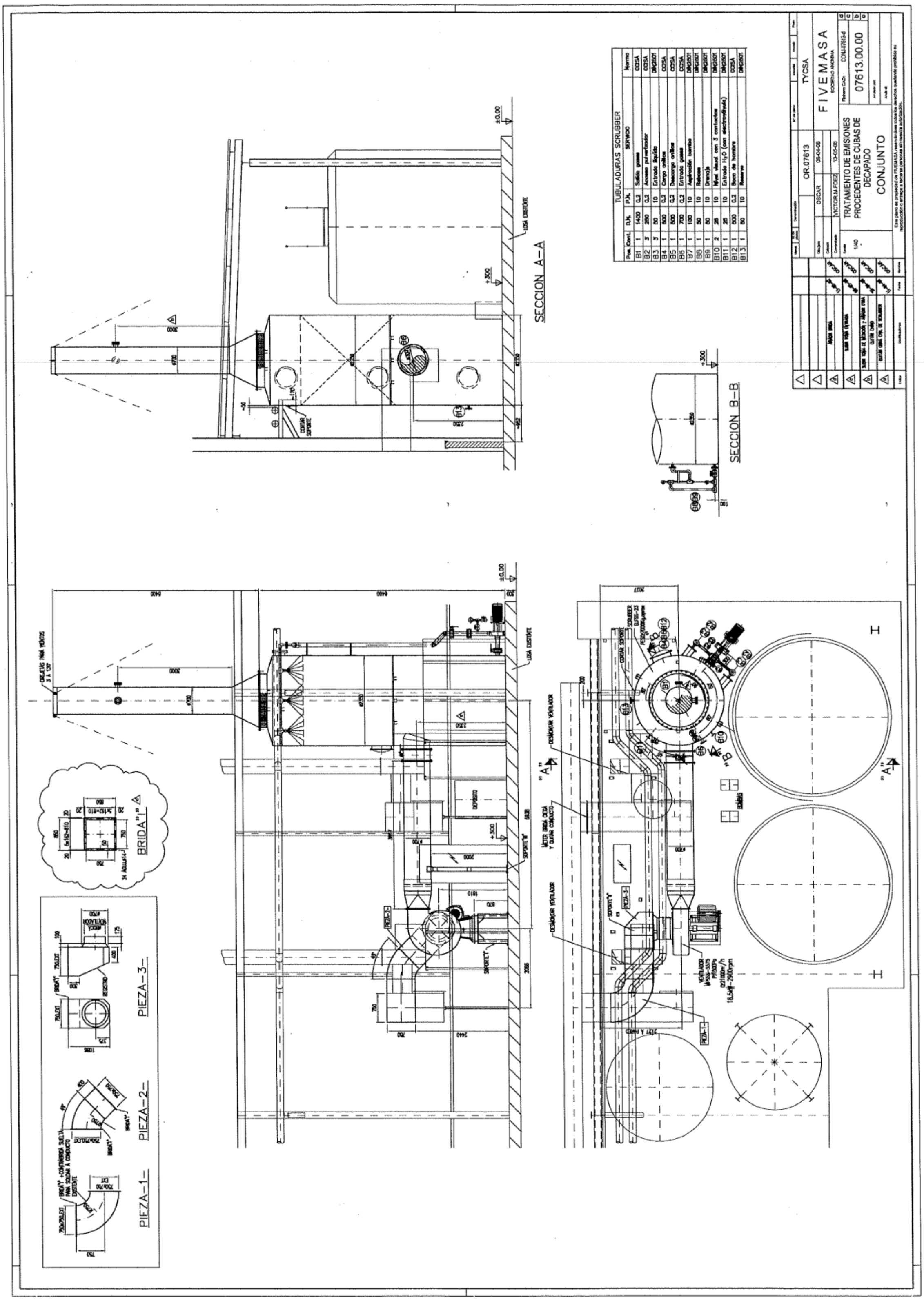

Figure A-1. Packed bed scrubber system layout.