



People's Democratic Republic of Algeria  
Ministry of Higher Education and Scientific Research  
University of Kasdi Merbah-Ouargla  
Faculty of Mathematics and Sciences of Matter



Thesis submitted within the completion of the requirements for  
Master's Academic Degree in Chemistry

Domain: Matter Sciences

Specialisation: chemistry

Option: Environmental Chemistry

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Entitled:

***Physicochemical Characterization of Incineration Fume Washing Water  
from Special Waste and Dangers Special Waste Incinerators: Development  
of a Treatment Process: Case Study of "Transco Company"***

Publicly supported on: 10 /06 /2025

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University Year: 2024/2025

# *Dedication*



**All thanks to God for allowing me to reach this moment of knowledge, and I dedicate this to specific people.**

**I dedicate this work to my esteemed family, especially my father, who has provided me with great support, both psychologically and financially, and has given me the strength to continue. I hope to hold your head high throughout my life.**

**And to those whose prayers were my light in the darkness of exams, to those whose words were a balm that soothed my stress, I hope, my mother, that the result of my graduation is the fruit of your hard work, and that your eyes see what you have always prayed to God for.**

**All my success is an extension of your love and patience. And to my five sisters who have stood by me through every moment of my suffering. I love you more than myself.**

**And to the best of the Environmental Chemistry class: Rekia, Marona, Halima, Aisha, Ilham, Nesrine, Akila, Saadia, Razika, Retaj, Hakma, Safaa, Anfal, Ahlam, Maroua, Yahia, and Imad.**

**Finally, I dedicate this work to my sister of the road and life who taught me a lot, Imane.**

***Douaa Toumi***





# Acknowledgements

*I would like to express my sincere gratitude to Dr Khaoula Chaouche for organising this valuable scientific trip and for her continuous support and encouragement throughout this work. My heartfelt thanks also go to Dr Amina Benbay for her kind assistance.*

*I extend my sincere appreciation to the esteemed members of the examination committee for their valuable scientific insights. Special thanks are addressed to Professor Louiza Zenkhri, Chair of the Committee, for her guidance and meticulous follow-up, and to Professor Ali Douadi for his constructive feedback and scientific contributions.*

*I also thank all the professors of the Chemistry Department for their guidance and support during my studies.*

*My sincere thanks go to Mr Ahmed Kourichie, Head of Department at TRANSCO, for his warm welcome, cooperation, and professional guidance. I am equally grateful to the Centre for Agricultural and Biological Research and Studies (CRAPC) for providing the necessary resources for this research.*

*I extend my appreciation to the National Office of Sanitation (ONS), the National Agency for Water Resources (NAWR), the Coy Routasat Laboratory, the Berkstone Basin Laboratory (LBK), and ECFERAL for their cooperation.*

*Special thanks go to Ines Benchabane Zima for her exceptional support, Dr Noura Mabrouki for her assistance with English editing, Mr Zaid Rahmani for facilitating fieldwork activities, and Mr Hakim Belkhalfa for his invaluable support*

**DOUAA TOUMI**



## *List of Abbreviations*

<b>N°</b>	<b>Designation</b>
AAS	Atomic Absorption Spectrometer
AOPs	Advanced Oxidation Processes
BOD <sub>5</sub>	Biochemical Oxygen Demand
Cd	Cadmium
Co	Cobolt
CM	Carbon Monoxide
COD	Chemical Oxygen Demand
Cu	Copper
COVs	Volatile Organic Compounds
DO	Dissolved Oxygen
EC	Electrical Conductivity
IFWW	Incineration Flue Wash Water
PCBs	Polyaromatic Compounds Biphenyls
pH	Hydrogen Potential
T	Temperature
TiO <sub>2</sub>	Titanium Dioxide
TSS	Total Suspended Solids
UV	UV-Visible Spectrophotometer
UNEP	United Nations Environment Program
USD	United State Dollars
WHO	World Health Organization
WTE	Waste to Energy
WWAP	World Water Assessment Programme
XRF	X-ray Fluorescence

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# Abstract

This study aims to conduct a comprehensive physico-chemical characterisation of flue gas washing wastewater generated from medical and hazardous waste incinerators operated by TRANSCO in Ouargla, southern Algeria, before and after treatment, with the development of an appropriate treatment process. The analyses included key parameters such as pH, electrical conductivity, chemical oxygen demand (COD), five-day biological oxygen demand (BOD<sub>5</sub>), nitrogen compounds, and heavy metal concentrations.

The results revealed that raw washing water exhibits high pollution levels, characterised by strong acidity, high turbidity, and elevated concentrations of sulfates, nitrates, and certain toxic elements, particularly sulfur and zinc, likely originating from the nature of incinerated waste or combustion-related chemical reactions. In contrast, highly toxic metals such as lead, arsenic, mercury, nickel, and cadmium were below detection limits.

XRF and AAS analyses confirmed the presence of critically high concentrations of sulfur and several heavy metals, with sulfur exceeding 8000 ppm and iron levels surpassing permissible limits by more than 20 times, along with significant exceedances of nickel, lead, copper, and cobalt. Four treatment methods were evaluated: natural, chemical, biological, and an integrated multi-stage treatment, which demonstrated the best performance with a removal efficiency of approximately 88%. The study recommends adopting advanced or hybrid treatment systems to comply with environmental discharge standards and ensure sustainability.

## Keywords:

Incineration Fume Washing Water, Incineration, Special and Dangers Special Waste, Physico-chemical characterisation, Heavy metals, Industrial wastewater treatment, SARL TRANSCO, Chemical / biological oxygen demand (COD/BOD)

# الملخص

تهدف هذه الدراسة إلى إجراء تحليل فيزيائي-كيميائي شامل لمياه غسل أبخرة الحرق الناتجة عن محارق النفايات الطبية والخطرة التابعة لشركة ترانس كو بولاية ورقلة، جنوب الجزائر، قبل المعالجة وبعدها، مع تطوير عملية معالجة مناسبة. شملت التحاليل المعايير الأساسية، وهي: الرقم الهيدروجيني (pH)، التوصيلية الكهربائية، الطلب الكيميائي للأوكسجين (COD)، الطلب البيولوجي للأوكسجين خلال خمسة أيام (BOD<sub>5</sub>)، مركبات النيتروجين، و تراكيز المعادن الثقيلة.

أظهرت النتائج أن مياه الغسل الخام تتميز بمستويات تلوث مرتفعة، تمثلت في حموضة عالية، عكارة كبيرة، وارتفاع تراكيز الكبريتات والنترات وبعض المعادن السامة، خاصة الزنك والكبريت، والتي يُرجَّح أن تكون ناتجة عن طبيعة النفايات المحروقة أو التفاعلات الكيميائية المصاحبة لعملية الاحتراق. في المقابل، كانت تراكيز بعض المعادن الثقيلة شديدة السمية، مثل الرصاص، الزرنيخ، الزئبق، النيكل، والكاديوم، دون حدود الكشف.

كشفت تحاليل XRF وAAS عن وجود تراكيز مرتفعة وخطيرة من الكبريت وبعض المعادن الثقيلة، حيث تجاوز تركيز الكبريت 8000 جزء في المليون، بينما فاق تركيز الحديد الحدود المسموح بها بأكثر من 20 مرة، مع تسجيل تجاوزات ملحوظة في تراكيز النيكل، الرصاص، النحاس، والكوبالت. تم تطبيق أربع طرق معالجة مختلفة، شملت المعالجة الطبيعية، الكيميائية، البيولوجية، والمعالجة المتكاملة متعددة المراحل، والتي أظهرت أفضل أداء بكفاءة إزالة بلغت حوالي 88%. وتوصي الدراسة باعتماد تقنيات معالجة متقدمة أو هجينة للامتثال للمعايير البيئية وتحقيق الاستدامة.

## الكلمات المفتاحية:

مياه غسل غازات المداخن، الحرق، النفايات الطبية والخطرة، الخصائص الفيزيائية والكيميائية، المعادن الثقيلة، معالجة مياه الصرف الصناعي، شركة ترانس كو، الطلب الكيميائي/البيولوجي على الأوكسجين (COD/BOD)

# Résumé

Cette étude vise à réaliser une caractérisation physico-chimique approfondie des eaux de lavage des fumées issues des incinérateurs de déchets médicaux et dangereux exploités par la société TRANSCO dans la wilaya de Ouargla, au sud de l'Algérie, avant et après traitement, tout en développant un procédé de traitement adapté. Les analyses ont porté sur des paramètres essentiels, notamment le pH, la conductivité électrique, la demande chimique en oxygène (DCO), la demande biologique en oxygène sur cinq jours (DBO<sub>5</sub>), les composés azotés et les concentrations en métaux lourds.

Les résultats ont montré que les eaux de lavage brutes présentent des niveaux de pollution élevés, caractérisés par une forte acidité, une turbidité importante et des concentrations élevées en sulfates, nitrates et certains éléments toxiques, en particulier le soufre et le zinc, probablement liés à la nature des déchets incinérés ou aux réactions chimiques associées au processus de combustion. En revanche, certains métaux lourds hautement toxiques, tels que le plomb, l'arsenic, le mercure, le nickel et le cadmium, se sont révélés inférieurs aux limites de détection.

Les analyses par XRF et AAS ont confirmé la présence de concentrations élevées et préoccupantes de soufre et de plusieurs métaux lourds, avec une teneur en soufre dépassant 8000 ppm et des concentrations en fer supérieures de plus de 20 fois aux valeurs limites autorisées, ainsi que des dépassements notables pour le nickel, le plomb, le cuivre et le cobalt. Quatre méthodes de traitement ont été évaluées : traitement naturel, chimique, biologique et traitement intégré multi-étapes. Ce dernier a montré les meilleures performances, avec un rendement d'élimination d'environ 88.%

L'étude recommande l'adoption de systèmes de traitement avancés ou hybrides, le renforcement des compétences techniques et l'application des normes environnementales internationales afin d'assurer la conformité réglementaire et la durabilité environnementale.

## Mots-clés :

Eaux de lavage des fumées, Incinération, Déchets médicaux et dangereux, Caractérisation physico-chimique, Métaux lourds, Traitement des eaux usées, SARL TRANSCO, DCO/DBO

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# *General Introduction*

### General introduction

Water is an integral component of the natural environment. It plays a key role in continuously reshaping the Earth's surface [1]. However, both the quality and quantity of water are under significant threat. In recent years, the quality of surface water has experienced considerable degradation primarily due to urban and industrial development [2]. Effluents from urban areas, as well as industrial waste, are often discharged directly into watercourses. Numerous studies worldwide have documented the impact of industrial and urban discharges on the quality of surface water [2].

The growth of the global population, industrial expansion and advancements in medical technology have led to a sharp increase in the generation of various types of waste, posing significant risks to both human health and the environment. In 2024, the world's population reached 8.2 billion, representing a 0.9% increase from the previous year, an estimated rise of 71 million people [3]. Consequently, global solid waste production was increase from 2.1 billion tons in 2023 and will increase to 3.8 billion tons by 2050 (UNEP).

The medical waste management sector is also expanding rapidly. In 2023, the global market was valued at approximately 9.60 billion USD and will expected to reach 15.37 billion USD by 2031 (Data Bridge Market Research). According to the World Health Organization, approximately 85% of healthcare waste is non-hazardous, while the remaining 15% is hazardous, including infectious, toxic or radioactive materials (WHO).

Like many nations, Algeria is committed to improve its waste management systems. Reducing waste generation and ensuring environmentally safe disposal methods are essential to achieve this goal. The management of hazardous medical waste has become an increasingly critical environmental and public health issue. These waste types often contain toxic, infectious or chemically reactive components that require specialized treatment to prevent adverse impacts on ecosystems and human health [4].

Among the various disposal methods, incineration is widely considered as an effective technique for reducing the volume and hazardous nature of waste through thermal decomposition at high temperatures in the presence of oxygen [5]. The process generates various by-products, including bottom ash, flue gas and wash water from the cleaning of flue gas treatment systems. This liquid can contain a concentrated mixture of pathogenic chemical contaminants. If released into the environment without adequate treatment, it may contaminate surface and groundwater resources and pose serious health hazards to

humans and animals [6]. To address these risks, a comprehensive characterization of the washing water is essential. This includes analyzing its physico-chemical properties, such as pH, conductivity, chemical oxygen demand (COD), biological oxygen demand (BOD) and concentrations of specific contaminants like heavy metals and toxic organics [7].

This study focuses on the characterization of the physico-chemical properties of wash water generated during the flue gas cleaning process in incineration systems. Such as wastewater, particularly from the treatment of medical and hazardous waste.

In this context, the following research question arises:

- ❖ What are the physico-chemical parameters that define the composition of incineration flue gas wash water produced by TRANSCO?
- ❖ What are the primary causes behind the acidic nature of wash water resulting from incineration processes?
- ❖ How can an improved treatment strategy be developed to enable the safe and sustainable reuse of incineration wash water?

### Hypothesis

- ▶ The acidic nature of the wash water is primarily due to the dissolution of flue gases such as sulfur dioxide ( $\text{SO}_x$ ) and nitrogen oxides ( $\text{NO}_x$ ), resulting from the nature of the incinerated materials.
- ▶ Incineration wash water contains elevated concentrations of heavy metals (e.g., mercury, cadmium), which originate from the combustion of hazardous and medical waste.
- ▶ An integrated treatment approach combining physical, chemical and biological methods is more effective in achieving a higher-quality treatment process suitable for reuse.

Considering the context and objectives, this study is structured into four chapters to provide a comprehensive understanding of the subject matter:

### Theoretical Aspect

- ∞ **Chapter I:** General information about Waste and treatment methods.
- ∞ **Chapter II:** wastewater and method of treatment.

### Practical Aspect

- ∞ **Chapter III:** Methods and Materials.
- ∞ **Chapter IV:** Results and Discussion .

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# *Theoretical Aspect*

***Chapter I: General  
information about  
Waste and treatment  
methods***

***In this chapter we will discuss  
general information about solid  
waste, especially hazardous waste  
and special hazardous waste. and  
methods of treatment***

## Introduction

Waste is one of the best indicators of a society's economic status and lifestyle. The growth of production and the ever-faster generation of waste have become a global problem; therefore, finding a solution has become increasingly significant [1]. Medical waste generation has increased significantly worldwide over the recent decades. In Algeria, huge quantities of waste are currently stored at companies' levels and are waiting for their disposal [2]. This conflict highlights the need for integrated waste management systems that prioritise short-term disposal and long-term ecological and public health preservation [3]. Figure I.1 below shows the different types of medical, special, and hazardous waste.



Figure I.1: Different types of dangers and special dangers of waste (Internet source).

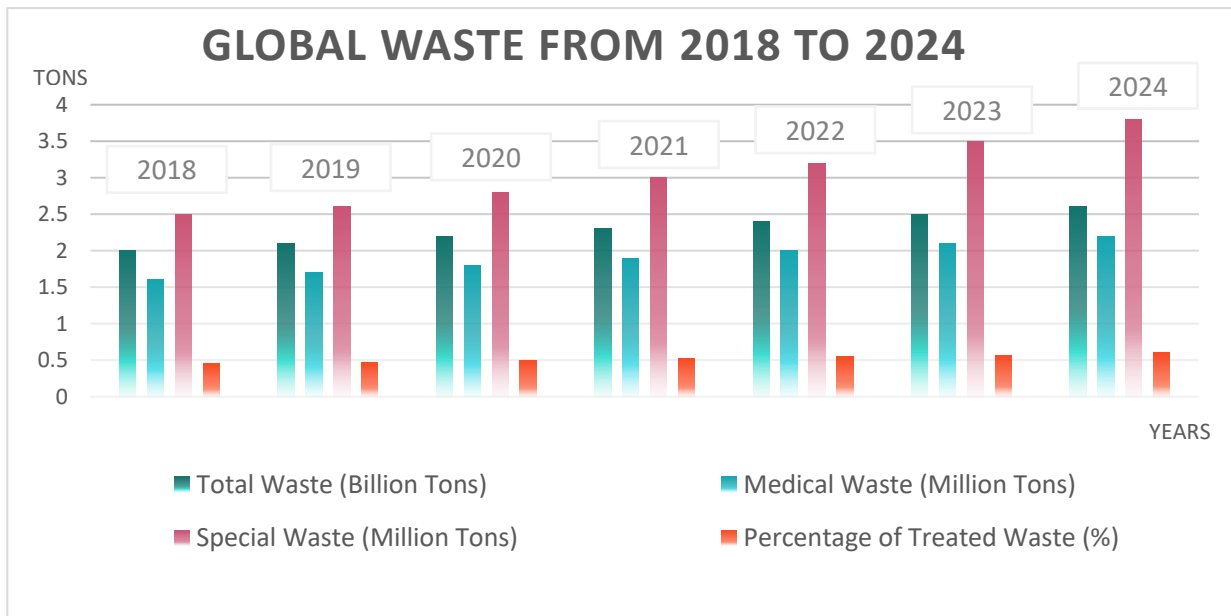
### I.1 Waste definition

Waste is any residue from a production, processing or use, any substance, material, product or, more generally, any property, furniture abandoned or that its owner intends to abandon. In other words, any element that is abandoned is waste. This does not mean that the element is unusable, either as it is or after modification. Only waste that is unusable and must be stored to avoid pollution of the environment [4].

Article 3 of the Algerian Law 1/9 dated 12/12/2001 on management, control and Waste disposal defines waste as: any residue from a process of production, processing or use, any substance, material, product or, more generally, any object, movable property whose owner or holder is unmade, plans to be undone or should be undone or eliminated.

Waste management and disposal is any operation pre-collection, collection, storage, sorting, transport, landfill, treatment, disposal, recycling, waste recovery, recycling and disposal of waste including control of these operations monitoring of landfill sites during the period of their operation or after closing.

The figure I.2 below shows The Growth of Global Waste, Medical Waste, and Special Hazardous Waste Between 2018 and 2024.



**Figure I.2:** Increase in Global Waste, Medical Waste, and Special Dangerous Waste (2018–2024) (WHO).

## I.2. General Information on Healthcare Waste

### I.2.1 Definition

According to the World Health Organization (WHO), healthcare waste includes all waste generated by healthcare facilities, research centers, laboratories, pharmaceutical manufacturing units, vaccine production sites, veterinary treatment centers, as well as home-based healthcare services such as dialysis or insulin injections.

### I.2.2 Classification in Algeria[5]

In Algeria, the classification of medical and pharmaceutical waste is based on its characteristics. As outlined in Executive Decree No. 2003-478, which defines the management procedures for healthcare waste, it is categorized into three main types:

- ✧ Infectious waste.
- ✧ Anatomical waste.
- ✧ Toxic waste.

Figure I.3 below shows Special Hazardous Waste Classification according to Federal Motor Carrier Safety Administration.

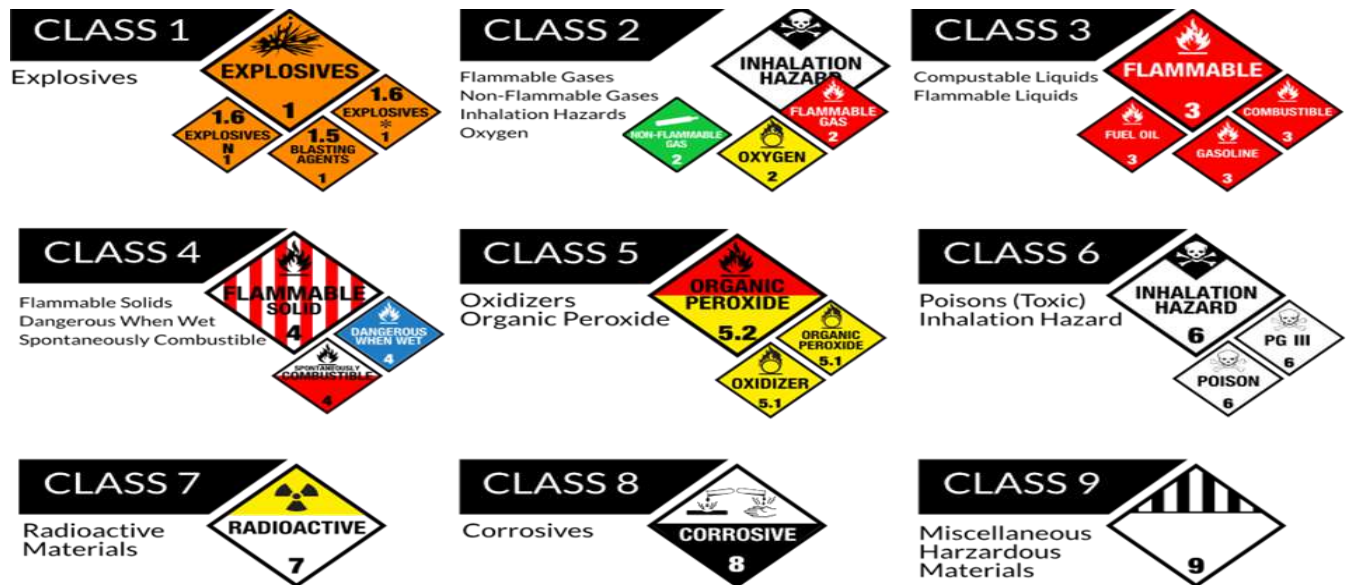


Figure I.3: Classification of special hazardous waste (Federal Motor Carrier Safety Administration).

### I.2.3. Type of waste

Medical waste is generally classified into two main categories:

- **Non-Hazardous Medical Waste:** It's Similar to household waste; it is not contaminated and poses no risk of infection, toxicity, or radiation. It is mainly produced from administrative and cleaning activities within healthcare facilities and is treated as regular municipal waste [6].
- **Hazardous Medical Waste:** It arises from activities involving contamination or potential contamination by infectious, chemical, or radioactive agents. Despite its smaller proportion, it poses serious risks to health and the environment and requires specialized handling and disposal [6].

### I.2.4 Origin of waste

#### ☞ Infectious Waste

**Definition:** Waste containing microorganisms or toxins that can affect human health.

**Special Handling:** Sharp or cutting infectious waste must be placed in rigid, puncture-resistant containers with a closure system before being placed in pre-collected plastic bags (min. thickness of 0.1 mm, yellow in color, single-use, strong, and durable) [7].

### ☞ Anatomical Waste

**Definition:** Human anatomical and biopsy waste from operating and delivery rooms [3].

**Pre-Collection:** Must be placed in a single-use green plastic bag. Biological remains, including excised tissues from surgical procedures, blood, and birth-related waste, must be managed through burial in designated, controlled landfills that comply with Islamic legal (as per Official Journal, 2003).

### ☞ Toxic Waste

**Definition:** Includes residues from pharmaceutical and chemical laboratory products, waste with high concentrations of heavy metals, acids, used oils, and solvents [7].

**Pre-Collection:** Must be placed in single-use red plastic bags that are strong, durable, and chlorine-free during incineration.

Legal Reference: Executive Decree No. 2003-478, dated December 9, 2003, defines the management of healthcare waste.

### ☞ Hospital Waste

**Definition:** Waste from medical diagnostics, monitoring, preventive, and curative treatment activities [6].

**Handling Requirements:** Must be separated from other waste, placed in single-use packaging, with specified maximum storage times. Transport must meet hazardous material requirements (packaging, labelling, and classification by biological risk).

### ☞ Radioactive Waste

**Definition:** Solid or liquid products from in vitro radioactive analysis and physiological products from therapeutic activities or in vivo exploration [7].

**Example:** Nuclear fuel is high-level waste from reactors requiring deep geological storage due to long-lived radioactivity. Contaminated medical gear, like gloves and tools, is low-level waste, treated and stored safely.

### ☞ Waste with High Heavy Metal

**Definition:** refers to waste that contains high concentrations of toxic metals such as mercury (Hg), cadmium (Cd), and lead (Pb), which can cause harmful effects on human health and the environment [8].

**Examples:** Used lead-acid batteries and waste from the electronics industry, Also, furnace ash from metal smelting processes (containing Hg and Cd), and residues from paint or printing industries [7].

### ☞ Pharmaceutical Waste

**Unusable or Expired Medicines:** Unused, expired, or contaminated drugs from hospital departments, including vaccines and serums [3].

**Genotoxic Waste:** Cytotoxic products used in cancer treatment, mutagenic, teratogenic, or carcinogenic substances [3].

### I.3. General Information on Dangerous Special Waste

#### I.3.1 Definition of Dangerous Special Waste

Hazardous special waste is defined as any solid, liquid, or gaseous waste that contains properties that threaten human health and living organisms, such as high toxicity, resistance to decomposition, the ability to transmit infectious diseases, flammability, explosiveness, or corrosiveness, in addition to its dangerous chemical or physical propertie.

These wastes pose significant risks to public health and the environment, whether they exist in pure form or mixed with other substances [9].

#### I.3.2 Sources of Special Waste and Dangerous Special Waste [8]

Industrial waste constitutes the largest share of hazardous waste globally, driven by rapid post-industrialization and inadequate disposal practices. These wastes often contain toxic chemicals that pose long-term environmental risks.

Household waste, though less voluminous, contributes significantly due to improper disposal of products containing hazardous substances such as solvents, batteries, and cleaning agents.

Agricultural chemicals waste, including obsolete pesticides and fertilizers, represent a major environmental threat when poorly stored or disposed of, particularly in low-regulation contexts.

Radioactive waste results from industrial and diagnostic applications, such as X-rays. These materials are hazardous due to their persistence and radiation risks, necessitating strict containment and disposal.



**Figure I.4:** Classification of Hazardous Waste by Source(GY4ES.ORG © 2024)

### I.3.3 Treatment and Elimination of Special and Dangerous Special Waste

The treatment of medical and hazardous special waste is a necessary step carried out before final disposal, aiming to reduce its toxic and dangerous effects on public health and the environment.

The absence of proper treatment for such waste can lead to several harmful consequences, including poisoning from toxic elements, bacterial and fungal infections, the release of toxins into the atmosphere, the leaching of harmful substances into soil and groundwater, and its ability to bioaccumulate in living tissues, and even the destruction of natural habitats.

This type of waste does not simply disappear; rather, it leaves a lasting "footprint" that negatively impacts the surrounding environment and future generations. Therefore, effective treatment of these wastes is an urgent environmental and public health necessity.[10]

Treatment Method	Advantages	Disadvantages
Incineration	<ul style="list-style-type: none"> <li>- Weight and volume reduction</li> <li>- Suitable for all waste types</li> <li>- Heat recovery</li> </ul>	<ul style="list-style-type: none"> <li>- Emissions, e.g., furans and dioxins</li> <li>- Public opposition</li> <li>- High capital and operating costs</li> <li>- High maintenance costs</li> <li>- Restrictions due to emissions regulations</li> </ul>
Autoclave disinfection	<ul style="list-style-type: none"> <li>- Low operation costs</li> <li>- Adequacy for biological testing</li> <li>- Less hazardous residues</li> </ul>	<ul style="list-style-type: none"> <li>- No change in waste characteristics</li> <li>- Inapplicable for all waste types</li> <li>- Unknown air emissions</li> </ul>
Microwave disinfection	<ul style="list-style-type: none"> <li>- Volume reduction</li> <li>- No liquid discharge</li> </ul>	<ul style="list-style-type: none"> <li>- High capital cost</li> <li>- Weight increase</li> <li>- Inapplicable for all waste types</li> <li>- Risk of exposure</li> <li>- Unknown air emissions</li> </ul>
Chemical disinfection	<ul style="list-style-type: none"> <li>- Volume reduction</li> <li>- Time efficient</li> <li>- Removal of waste odour</li> </ul>	<ul style="list-style-type: none"> <li>- High capital cost</li> <li>- Inapplicable for all waste types</li> <li>- Unknown air emissions</li> <li>- Storage and handling of chemicals</li> </ul>

**Figure I.5:** Comparative Analysis of Treatment Methods: Strengths and Limitations (MDPI journals).

## I.4. Incineration

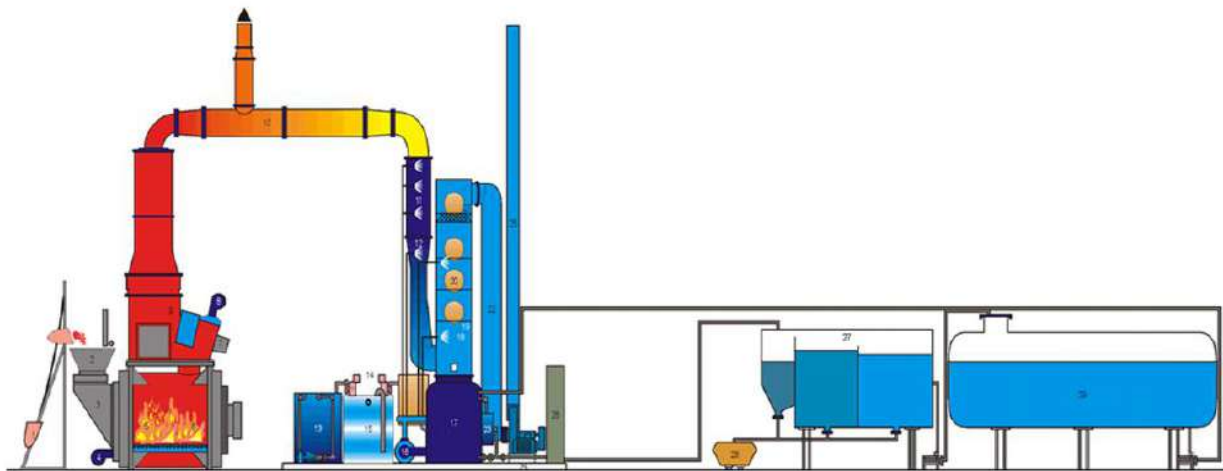
### I.4.1. Definition and Principles of the Incineration Process [11]

The concept of waste incineration goes back to 1876 in Britain when the first rudimentary waste-burning system was introduced. However, it was in 1893 in Germany that the first modern incineration plant was constructed, specifically designed for solid waste disposal. Over time, incineration technology has evolved, incorporating advanced pollution control mechanisms to mitigate the adverse environmental effects associated with combustion byproducts. Incineration is a high-temperature thermal treatment process that ensures complete oxidation and mineralization of organic matter in the presence of oxygen. The fundamental principle of incineration is to maintain sufficient combustion temperature and residence time to achieve efficient waste breakdown and minimize hazardous emissions. The minimum combustion temperature required for effective incineration varies depending on the nature of the waste:

- 850°C for general industrial waste without hazardous properties.
- 1100°C for chlorinated waste.
- 1200°C or higher for chlorinated polyaromatic compounds, such as polychlorinated biphenyls (PCBs).

The residence time for combustion gases at these temperatures is generally at least two seconds, ensuring the complete degradation of toxic compounds. This requirement influences the design specifications of the post-combustion chamber. For solid waste, the rotary kiln parameters, including diameter, length, rotational speed, and inclination, determine the residence time, which typically exceeds one hour. These factors are crucial in ensuring optimal waste combustion and reducing the formation of harmful byproducts.

Thermal incineration of waste produces a range of by-products, including solid residues, gaseous emissions, and liquid effluents, each requiring specific management and treatment protocols.



- |                                   |                                     |                               |                          |
|-----------------------------------|-------------------------------------|-------------------------------|--------------------------|
| 1. Bucket                         | 10. Junction equipped               | 16. Wash water                | 23. Too full             |
| 2. Hopper                         | with a safety register              | 11. recirculation pump        | 24. Fan                  |
| 3. Feeding bag                    | Quench                              | 17. Wash water tank           | 25. Fireplace            |
| 4. Primary air fan                | 12. Venturi                         | 18. Tray column               | 26. Control cabinet      |
| 5. Combustion chamber burner      | 13. Purge water neutralization tank | 19. acid gas absorption trays | 27. Drain Water Decanter |
| 6. Combustion chamber             | 14. Metering pump                   | 20. Door of visit             | 28. Sand filter          |
| 7. Burner post-combustion chamber | 15. Aqueous solution (NaOH) tank    | 21. Devisiculeur              | 29. Wash water tank      |
| 8. Secondary air fan              |                                     | 22. Bonding Sheath            |                          |
| 9. Post-combustion chamber        |                                     |                               |                          |

**Figure I.6:** Diagram of an incinerator ECFERAL

### I.4.2. Key Components of an Incineration Plan [12]

A modern incineration facility comprises several integrated systems, each playing a vital role in ensuring operational efficiency and environmental compliance.

**Waste Reception and Pre-Treatment:** This unit is responsible for receiving, classifying, analyzing, and temporarily storing waste. Pre-treatment includes shredding solid waste and homogenizing liquid waste to ensure uniform feed characteristics and improve combustion stability.

**Kiln Feed System :** This system regulates the controlled introduction of waste into the combustion chamber, optimizing feed rates to maintain efficient thermal degradation and stable combustion dynamics.

**Incineration and Post-Combustion Chambers:** The primary combustion takes place in a rotary kiln, followed by a post-combustion chamber that ensures complete oxidation of residual organic compounds, thereby minimizing toxic emissions.

**Cooling and Flue Gas Treatment:** Gas cooling systems are employed to inhibit the formation of hazardous compounds such as dioxins and furans. Advanced gas cleaning technologies such as electrostatic precipitators, activated carbon filters, and chemical scrubbers are used to remove particulates and neutralize acidic gases prior to atmospheric discharge.

**Process Water Treatment:** This unit treats liquid effluents generated throughout the incineration process. It utilizes physical, chemical, and biological treatment methods to eliminate heavy metals, suspended solids, and dissolved pollutants, ensuring compliance with environmental discharge standards

### I.4.3 Different Types of incinerators manufacturers in China

<p><b>Direct Combustion Incinerators</b>[13]</p> <p>Function by burning waste directly within a high-temperature combustion chamber operating at 800 to 1200°C. During this process, organic materials decompose into gaseous byproducts and residual ash, effectively reducing waste volume.</p>	
<p><b>Advantages</b></p> <ul style="list-style-type: none"> <li>-Simple and cost-effective design, making them easy to install and operate.</li> <li>-Versatile waste processing capability, suitable for various types of municipal and industrial waste.</li> <li>-Compatible with Waste-to-Energy (WTE) systems, allowing for energy recovery in the form of heat or electricity.</li> </ul>	<p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>-Potential emissions of toxic pollutants, such as dioxins and furans, if combustion conditions are not properly controlled.</li> <li>-Generates hazardous fly ash, requiring specialized handling and disposal.</li> <li>-Inefficient for high-moisture waste, as additional energy is needed for drying before</li> </ul>
<p><b>Fluidized Bed Incinerators</b>[14]</p> <p>Utilize a high-temperature combustion chamber containing hot sand or another fluidized medium. Waste is introduced into the chamber while high-pressure air is injected, causing the medium to behave like a fluid. This process ensures uniform and efficient combustion at temperatures ranging from 850 to 1000°C.</p>	
<p><b>Advantages</b></p> <ul style="list-style-type: none"> <li>-More efficient and uniform combustion compared to direct combustion incinerators.</li> <li>-Produces lower emissions of harmful gases, reducing environmental impact.</li> <li>-Well-suited for wet and organic waste, as the fluidised medium enhances heat transfer and combustion efficiency.</li> </ul>	<p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>-More complex design and operation compared to traditional incinerators, requiring specialized expertise.</li> <li>-Not suitable for large-sized or heterogeneous waste, as uniform combustion relies on consistent particle size.</li> <li>-Requires regular maintenance of the fluidized medium (e.g., hot sand), increasing operational</li> </ul>

<p><b>Plasma Arc Incinerators</b> [15]</p> <p>Plasma arc incinerators employ a high-energy plasma arc to generate extreme temperatures exceeding 5000°C. This intense heat breaks down waste at the atomic level, converting it into syngas (synthetic gas) and inert vitrified slag.</p>	
<p><b>Advantages</b></p> <ul style="list-style-type: none"> <li>-Complete combustion with no hazardous residues, minimizing environmental impact.</li> <li>-Generates syngas, which can be used as an alternative fuel source.</li> <li>-Reduces waste volume to inert vitrified slag, which can be safely recycled or used in construction.</li> </ul>	<p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>-Extremely high operational costs due to significant energy consumption.</li> <li>-Complex maintenance and operation, requiring advanced technical expertise.</li> <li>-Requires sophisticated gas treatment systems to manage and neutralize emissions.</li> </ul>
<p><b>Pyrolysis and Gasification Incinerators (Flameless Incineration)</b>[16]</p> <p>Utilize thermal decomposition in a low-oxygen or oxygen-free environment, breaking down organic materials into synthetic gas (syngas), bio-oil, and solid carbon residues. Unlike conventional incineration, which relies on combustion, these processes convert waste into valuable energy sources through controlled heating at high temperatures.</p>	
<p><b>Advantages</b></p> <ul style="list-style-type: none"> <li>-Lower pollutant emissions compared to traditional incinerators, reducing environmental impact.</li> <li>-Generates alternative fuels, such as syngas and bio-oil, which can be used for energy production.</li> <li>-Highly efficient in processing organic and industrial waste, making it a sustainable waste management solution.</li> </ul>	<p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>-Requires additional treatment for the produced gases and oils to ensure environmental compliance.</li> <li>-Not suitable for waste has high moisture content or a high concentration of inorganic materials.</li> <li>-High capital and infrastructure costs.</li> </ul>
<p><b>Induction Heating Incinerators</b> [17]</p> <p>Induction heating incinerators utilize an alternating magnetic field to generate heat in electrically conductive materials, such as metals within waste. This process enables combustion without the need for a direct flame.</p>	
<p><b>Advantages</b></p> <ul style="list-style-type: none"> <li>-Energy Efficiency: Consumes less energy compared to traditional flame-based incinerators.</li> <li>-Precision Control: Allows for accurate temperature regulation, optimizing combustion efficiency.</li> <li>-Lower Emissions: Produces fewer CO<sub>2</sub> emissions than conventional incineration methods.</li> </ul>	<p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>-Limited Waste Compatibility: Ineffective for non-conductive materials like plastics or pure organic waste.</li> <li>-High Operational Costs: Requires specialized equipment and involves significant maintenance expenses.</li> </ul>

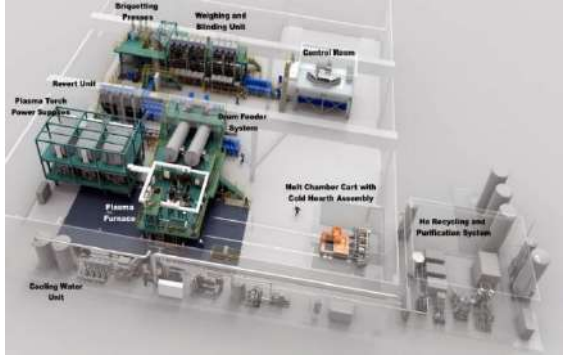
<p><b>A High-Efficiency Waste Treatment Technology</b> [18]</p> <p>Electromagnetic Plasma Arc Incineration is an advanced waste treatment technology that combines plasma arc generation with electromagnetic induction. This process employs a controlled magnetic field to direct a high-energy plasma arc, producing extreme temperatures that facilitate the complete decomposition of waste materials at the molecular level.</p>	
<p><b>Advantages</b></p> <ul style="list-style-type: none"> <li>-Near-Total Waste Destruction: Ensures nearly complete thermal decomposition, leaving no hazardous residues.</li> <li>-Energy Recovery Potential: Enables the production of synthetic gas (syngas), which can be utilized for energy generation.</li> <li>-Reduction in Landfill Dependency: Significantly decreases the volume of waste requiring disposal, contributing to sustainable waste management.</li> </ul>	<p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>-Technological Complexity: Requires advanced engineering expertise and continuous research to optimize efficiency and operational stability.</li> <li>-High Capital and Operational Costs: The infrastructure and maintenance costs are substantial, limiting its widespread adoption.</li> <li>-Intensive Energy Requirements: The process demands significant electrical power, which may offset its environmental benefits if sourced from non-renewable energy.</li> </ul>

Table I.1: Different Types of Incinerator (Websites for Chinese Incinerator Manufacturers)

**I.5. By-products from Incineration** [6]

Incineration does not eliminate waste, it transforms it into

**I.5.1 Gaseous Emissions**

The flue gases produced by incineration contain a wide range of gaseous species. Ideally, the products of complete combustion are carbon dioxide and water. However, these ideal conditions cannot be fully achieved in the case of waste incineration. As a result, combustion also leads to the formation of carbon monoxide and other volatile organic compounds (VOCs). Moreover, at the boiler outlet, not all acidic gases are neutralized, and the most volatile metals remain in the vapor phase.



**I.5.2 Solid Residues**

Solid residues include fly ash, which consists of toxic fine particles and represent approximately 3% of the total mass of waste fed into the incinerator. Bottom ash, collected at the bottom of the combustion chamber, accounts for about one-third of the total mass of waste incinerated. This ash



appears as a greyish, friable mass containing various metal fragments, non-combustible mineral residues, and unburnt materials resulting from incomplete combustion of certain constituents, particularly those that are poorly combustible or too moist at the time of their introduction into the furnace.

### I.5.3 Liquid Residues

In an incineration plant, water is used for the quenching and cooling of bottom ash, and may also be involved in the flue gas treatment system. Approximately 0.3 to 0.8 m<sup>3</sup> of water is required to quench the bottom ash generated from one ton of waste.



A study conducted on a German incinerator indicates that this water is basic and contains concentrations of heavy metals. However, the water from the flue gas scrubbing system has entirely different characteristics and therefore requires proper treatment before being discharged.

### I.6. Technical Description of the Purge Water Washing and Neutralization System

This system is installed downstream of the incinerators and is responsible for treating the combustion gases from waste before they are released into the atmosphere. The flue gas scrubber is a "wet" treatment process designed to capture various pollutants in their wet phases. Water is used in this process for several key reasons:

- **Capturing Particulates:** Water helps wet the airborne particulates in a turbulent environment, making it easier to collect and trap them.
- **Neutralizing Acids:** Water, combined with a neutralizing reagent, is used to convert acids into harmless compounds.
- **Removing Heavy Metals:** If acids are present in the flue gases, water, along with a neutralizing reagent, helps wash away heavy metals, minimizing their environmental impact.

The use of water is essential in this process to efficiently remove various pollutants before the gases are released into the atmosphere.[19]

### I.7. Advantages of Incineration [20]

- Incineration is a versatile waste treatment method suitable for various types of waste, including hazardous, non-hazardous, solid, and liquid forms.
- It significantly reduces waste volume (by about 90%) and mass (by around 70%).

- The process enables energy recovery through heat and electricity generation, supporting urban heating networks and reducing reliance on fossil fuels.
- Compared to landfilling, incineration emits fewer greenhouse gases, especially methane. Additionally, it allows for the recovery of valuable metals.

### I.8. Health and Environmental Impacts of Incineration [21]

Waste and its management pose a major environmental challenge. Thermal treatment, such as **incineration**, is often considered a response to the threats posed by poorly managed or unmanaged waste streams.

While incineration eliminates waste in its original form, the matter is not destroyed, but transformed, sometimes into more toxic substances than the original materials. Waste contains a variety of natural or synthetic organic materials (e.g., paper, plastics, textiles, kitchen and biodegradable waste, garden waste) and inorganic components (e.g., glass, metals).

Each of these components may contain toxic heavy metals such as lead, cadmium, chromium, mercury, and nickel at hazardous concentrations. Beyond heavy metals, the incineration process releases a wide range of pollutants through **fly ash, bottom ash** (slag), **Liquid Residues**, and **gaseous emissions**, including dioxins, furans, nitrogen and sulfur oxides, hydrochloric acid, among others, posing a serious risk to public health, including:

- Increased rates of cancer (in both children and adults),
- Negative impacts on the respiratory and cardiovascular systems.
- Immune system disorders, exacerbated allergies, and Birth defects.

### I.9. Conclusion

In this chapter, we explored the different types of waste. Algeria's current waste management policy remains unclear, with no specific directions and uncertainty about which technology to adopt. As waste production continues to rise, hazardous waste remains stored on industrial sites, posing environmental and health risks.

Incineration plays a vital role in waste management, particularly for hazardous and healthcare waste, where conventional disposal methods may pose significant risks.

While incineration has effectively addressed waste treatment challenges, it has also introduced a new issue that has emerged, particularly **ash** and **washing water**.

What are the proposed solutions for **treating and reusing the washing water** from waste **incinerators**?

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***Chapter II: wastewater  
and method of treatment  
on water***

***To answer the question in  
the first chapter We decided to  
talk about generalities about  
wastewater and deferent method  
of treatment***

## II.1. Introduction

Water is an indispensable resource that sustains ecosystems, supports human life, and drives industry and agriculture. The demand for fresh water has continuously grown with the global population. Of the water on Earth, 97% is saline and only 3% is freshwater [1]. Only 0.5% of this freshwater is available for human use, and exists in liquid form in rivers, lakes, ponds, and groundwater [2]. The severity of water scarcity has been underscored by the United Nations World Water Assessment Program (WWAP); that is, the number of people residing in regions that experience water scarcity for at least 1 month annually is currently 3.6 billion and could increase to 4.8–5.7 billion by 2050 [3].

Human activities such as industrial processes, agricultural practices, and domestic usage contribute significantly to water pollution. These activities lead to the continuous production of wastewater, which requires effective treatment to prevent environmental degradation.

Discharge of untreated wastewater remains a global issue. According to a WWAP report (2017) [4], 80% of global wastewater is untreated and discharged. Jones et al, have reported that 48% of global wastewater is untreated [5].

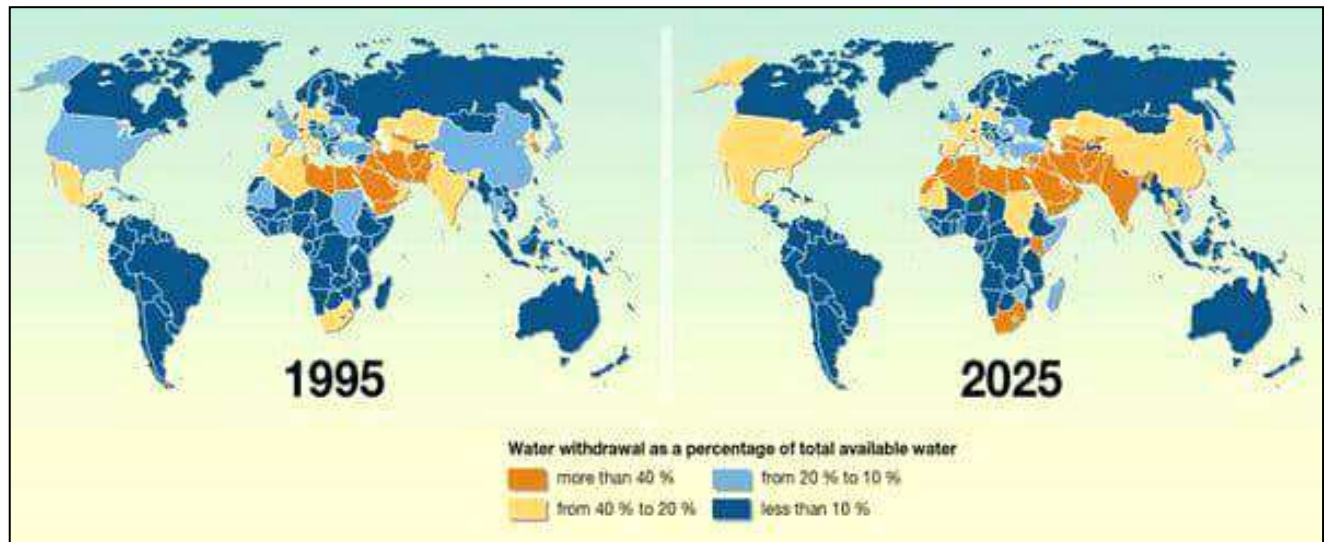
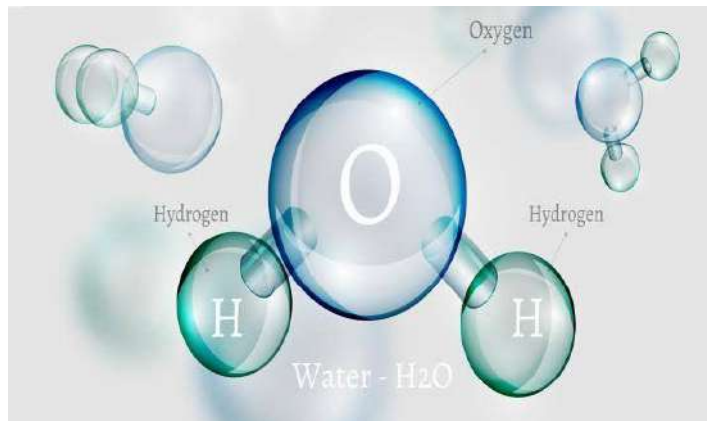


Figure (II. 01): Water withdrawal of total available water from 1995 to 2025 (Berkey Water Filters).[6]

## II.2. Definition of water

Water (H<sub>2</sub>O) is a stable chemical compound of hydrogen and oxygen. It exhibits strong wetting and capillary properties, making it essential in many physical and biological processes. In the environment, Water serves as an effective medium for the transport of various pollutants. It can incorporate airborne solid particles, e.g. emissions from waste incineration, and residues from surrounding environments. Additionally, it may contain trace concentrations of heavy metals and dissolved mineral salts. This

capacity underscores water's dual role in conveying both naturally occurring substances and contaminants of anthropogenic origin, thereby influencing environmental and public health dynamics.



**Figure (II. 02):** water molecule (H<sub>2</sub>O)

### II.3. What is Water pollution

Water pollution is defined as the deterioration of water quality due to unfavorable changes in its physical, chemical, and biological properties, primarily caused by human activities. According to Law No. 03-10 of July 19, 2003, water pollution involves the introduction of substances into aquatic environments that alter their natural characteristics. Contaminated water is often a byproduct of domestic, industrial, and agricultural processes, rendering it unsuitable for human consumption and essential uses such as irrigation. The World Health Organisation (WHO) highlights that polluted water, due to its altered composition, poses serious health risks and serves as a major vector for waterborne diseases, including diarrhea, cholera, dysentery, typhoid fever, and poliomyelitis. These diseases contribute to over 500,000 deaths globally each year, emphasizing the critical need for effective water quality management [7].

#### II.3.1. Industrial Discharge Standards for wastewater.

Industrial effluent discharge standards vary by country and local regulations. In Algeria, these standards are defined by legislative and regulatory texts aimed at protecting the environment and public health. They set maximum limits for various physico-chemical and biological parameters before **wastewater** can be discharged into the environment

- ✓ Law No. 83-17 of July 16, 1983, establishing the Water Code.
- ✓ Ordinance No. 96-13 of June 15, 1996, amending and supplementing Law No. 83-17.
- ✓ Executive Decree No. 93-160 of July 10, 1993, regulating the discharge of liquid effluents from industrial sources.

- ✓ Executive Decree No. 06-141 of April 19, 2006, defining the limit values for industrial liquid effluent discharges in the People's Democratic Republic of Algeria. The Table 1.2 below shows different standards for discharge in Algeria and International lows.

Table II.1: International Discharge Standards

Characteristics	Standards Used (WHO)
pH	6.5-8.5
BOD <sub>5</sub>	<30 mg/L
COD	<90 mg/L
TSS (Total Suspended Solids)	<20 mg/L
NH <sub>4</sub> <sup>+</sup> (Ammonium)	<0.5 mg/L
NO <sub>2</sub> (Nitrite)	1 mg/L
NO <sub>3</sub> (Nitrate)	<1 mg/L
P <sub>2</sub> O <sub>5</sub> (Phosphates)	<2 mg/L
Temperature	<30°C
Color	Colorless
Odor	Odorless

Table II.2: Algerian Standards for Discharges

Parameters	Units	Limit Values
Temperature	°C	30
pH	-	6.5-8.5
BOD <sub>5</sub>	mg/L	30
COD	mg/L	120
TSS (Total Suspended Solids)	mg/L	35
Total Nitrogen	mg/L	30
Total Phosphorus	mg/L	10
Furfural	mg/L	50
Hydrocarbons	mg/L	10
Lead	mg/L	0.5
Iron	mg/L	3
Mercury	mg/L	0.01
Copper	mg/L	0.5
Zinc	mg/L	3

#### II.4. Sources of water pollution

An essential element for all existence and fundamental to the economy of humanity, but an element whose reserves cannot increase, water must not be wasted. Pollution, a break with the natural balance and with the laws of life, is a waste of the present that foreshadows a theft for the future [8]. The phenomenon of pollution is linked to the origins of life, and man has experienced very early the concern not to pollute water.

- ❖ **Domestic pollution:** from homes, it is transported by the sewage system to the treatment plant. Domestic effluents are a mixture of water containing human waste. The latter contains degradable organic matter and mineral matter, either in dissolved or suspended form [9]. Domestic wastewater is divided into
  - **Household water:** Household water: this is water from cooking and washing. It is loaded with fat.

- **Black water:** This is water from toilets (WCs). It is loaded with nitrogenous matter and fecal germs.
- ❖ **Industrial pollution:** It is characterized by its diversity depending on the use of water. Industrial wastewater varies from one industry to another. They may contain organic matter, phosphorus, nitrogen, solvents, heavy metals, hydrocarbons, etc. [10].
- ❖ **Agricultural pollution:** it results from livestock farming and land cultivation, Agricultural wastewater is the potential cause of diffuse pollution [11]. His pollution is characterized by High levels of mineral salts (nitrogen, phosphorus, etc.) from fertilizers and slurries (livestock farming) Presence of chemical treatment products (pesticides, herbicides, etc.) [12].
- ❖ **Rainfall pollution:** from rainwater runoff. Rainwater is a significant source of pollution for watercourses, particularly during stormy periods [13]. It is in direct contact with the atmosphere and the soil, so it becomes loaded with impurities and runs off into watercourses, causing their contamination.

Also Acid rain, or acid deposition, is a broad term that includes any form of precipitation with acidic components, such as sulfuric or nitric acid that fall to the ground from the atmosphere in wet or dry forms. This can include rain, snow, fog, hail or even dust that is acidic.

## II.5. Wastewater characteristics

Wastewater has physical, chemical and biological characteristics

### II.5.1. Organoleptic parameters

- ▶ **Color:** The color of wastewater is due to the presence of natural organic compounds or industrial pollutants [14]. The color of the water can be caused by the presence of Iron and Magnesium. Industrial wastewater can be colorless, as it can have several colors due to the type of discharge.
- ▶ **Turbidity:** Turbidity is caused by fine suspended solids, microorganisms, and colloidal matter, reducing water clarity by obstructing light penetration. It serves as an indicator of water quality and pollution [14].
- ▶ **Odor:** Fresh wastewater has a mild, neutral odor and is influenced by the presence of microorganisms or chemical contamination [14].

### II.5.2. Physical parameters

- **Dissolved Oxygen (DO):** Dissolved oxygen is the concentration of molecular oxygen ( $O_2$ ) physically dissolved in water, essential for aquatic life and water quality assessment[15].

- **Temperature:** Temperature significantly affects biological and chemical reactions, with the optimal range for biological treatment being around 20°C [16-17]. It is affected by Conductivity and salt solubility regulation [18].
- **Hydrogen Potential (pH):** Indicates the acidic, neutral, or basic nature of water, impacting metal toxicity and treatment efficiency. In domestic and urban water supplies, the pH typically falls within the range of 6.8 to 7.8, deviations beyond this threshold may indicate industrial pollution, signaling potential environmental concerns [19-21].
- **Electrical Conductivity:** Electrical conductivity measures the total concentration of dissolved salts, providing insight into water quality and contamination levels [22].
- **Suspended Solids (SS):** These are organic and inorganic particles that reduce water clarity and consume dissolved oxygen [23-24]. Suspended solids (SS) are particles not dissolved or in colloidal form, retained by filtration. They contribute to turbidity, indicating the pollution level in urban and industrial effluents [25].

### II.5.3 chemical parameters

- ❖ **Biochemical Oxygen Demand (BOD<sub>5</sub>):** Biochemical Oxygen Demand (BOD<sub>5</sub>) quantifies the amount of oxygen, expressed in mg/L, required by microorganisms to decompose biodegradable organic matter over five days under controlled conditions at 20 °C. This parameter is a critical indicator of organic pollution in wastewater, with the oxygen consumption measured after five days serving as the BOD<sub>5</sub> value, reflecting the degree of contamination [19].
- ❖ **Dissolved Oxygen (DO):** Dissolved oxygen (DO) is a critical parameter for assessing water quality, as it directly influences aquatic ecosystems and serves as an indicator of pollution levels. It is typically measured in situ using an oximeter. DO concentrations vary depending on the source of water, with domestic wastewater typically containing 2 to 8 mg/L [26].
- ❖ **Biodegradability:** Based on the K coefficient, wastewater can be classified as follows:

$K < 1.5 \rightarrow$  Highly biodegradable (easily oxidised by microorganisms).

$1.5 < K < 2.5 \rightarrow$  Moderately biodegradable.

$2.5 < K < 3 \rightarrow$  Poorly biodegradable.

$K > 3 \rightarrow$  Non-biodegradable.

A high K coefficient suggests the presence of compounds that inhibit microbial activity, such as heavy metals, detergents, phenols, and hydrocarbons. The value of K is a key determinant in selecting the appropriate treatment approach biological treatment for biodegradable effluents and physicochemical treatment for non-biodegradable ones [27].

❖ **Ammonium ( $\text{NH}_4^+$ ):** Ammonium ions ( $\text{NH}_4^+$ ) play a fundamental role in the nitrogen cycle and are commonly present in wastewater due to organic matter decomposition. Their elevated concentrations in surface water serve as an indicator of pollution, often resulting from wastewater discharge into natural water bodies [28].

❖ **Nitrate Ions ( $\text{NO}_3^-$ ):** Nitrates represent the final oxidation stage of organic nitrogen compounds, and their presence in polluted water indicates an advanced stage of self-purification. The major sources of nitrates include:

Natural processes → Dissolution of nitrate-containing minerals (typically <1 mg/L).

Agricultural runoff → Excess application of nitrogen-based fertilisers, contributing up to 60% of total nitrate pollution [28].

❖ **Nitrite Ions ( $\text{NO}_2^-$ ):** Nitrite ions ( $\text{NO}_2^-$ ) serve as an intermediate stage in the nitrogen cycle, forming through either:

- The oxidation of ammonium ( $\text{NH}_4^+$ ) into nitrites.
- The partial reduction of nitrates ( $\text{NO}_3^-$ ) back into nitrites.

Unlike nitrates, there are no significant natural sources of nitrite ions in water. Their presence is primarily linked to biological activity and pollution events [28].

❖ **Nitrogen :** Nitrogen in domestic wastewater exists in two primary forms:

- Organic nitrogen → Derived from proteins and biological matter.
- Ammoniacal nitrogen → Present as  $\text{NH}_3$  (ammonia) and  $\text{NH}_4^+$  (ammonium).

The nitrogen content in wastewater plays a critical role in eutrophication processes and must be carefully monitored [30].

❖ **Phosphorus :** Phosphorus in wastewater exists in two distinct forms:

- Organic phosphorus → Originating from biological sources (e.g., human waste) and industrial effluents.
- Inorganic phosphorus → Primarily ortho- and polyphosphates, originating from detergents, phosphate fertilizers, and industrial discharges.

The average phosphorus discharge per capita is approximately 4g per day. Phosphorus quantification in raw wastewater is crucial for determining the feasibility of biological treatment processes [31].

❖ **Chlorides and Sodium :** Chlorides and sodium are present in wastewater due to various natural and anthropogenic sources:

- Natural sources → Seawater intrusion (~27 g/L NaCl) and saline soil leaching.
- Human contributions → Urinary excretion (~10 to 15 g/L NaCl per day per individual).
- Industrial activities → Potash mining, oil refining, electroplating, and food processing industries.

Elevated chloride and sodium levels can lead to corrosion of sewer infrastructure and interfere with biological treatment processes, particularly when wastewater systems interact with brackish groundwater [29].

#### II.5.4. Biological Parameters in Wastewater

Biological parameters are fundamental in wastewater analysis as they provide insight into microbial contamination and its implications for water quality and public health. These microorganisms, originating mainly from faecal sources, include viruses, bacteria, protozoa, and helminths, some of which are pathogenic and pose significant health risks [32].

► **Microbial Groups in Wastewater:**[32].

- **Viruses:** (e.g., hepatitis, poliovirus) are small pathogens causing viral infections.
- **Bacteria:** include beneficial types (e.g., nitrifiers) and pathogens such as *E. coli*, *Salmonella* spp., and *Vibrio cholerae*.
- **Protozoa:** like *Giardia lamblia* and *Cryptosporidium parvum* are responsible for intestinal diseases.
- **Helminths:** including *Ascaris lumbricoides* and *Schistosoma* spp., can cause chronic parasitic infections.

► **Indicator Organisms:** To monitor microbial contamination, indicator organisms are used as proxies:

- **Total and Fecal Coliforms** :indicate general faecal contamination.
- **Escherichia coli** :serves as a key indicator of recent faecal pollution.
- **Enterococci** :are applied for assessing water safety, especially in recreational waters.

#### II.6. Wastewater Treatment

Typically, Wastewater Treatment is designed to treat wastewater cost-effectively while achieving a desired water quality [33]. Wastewater treatment often requires the sequential use of various wastewater treatment techniques, each of which is suitable for removing certain contaminants. A wastewater treatment process generally consists of preliminary, primary, secondary, and tertiary stages [34-35]. The flow of a general wastewater treatment process and the corresponding treatment techniques used are shown in Figure II.3.

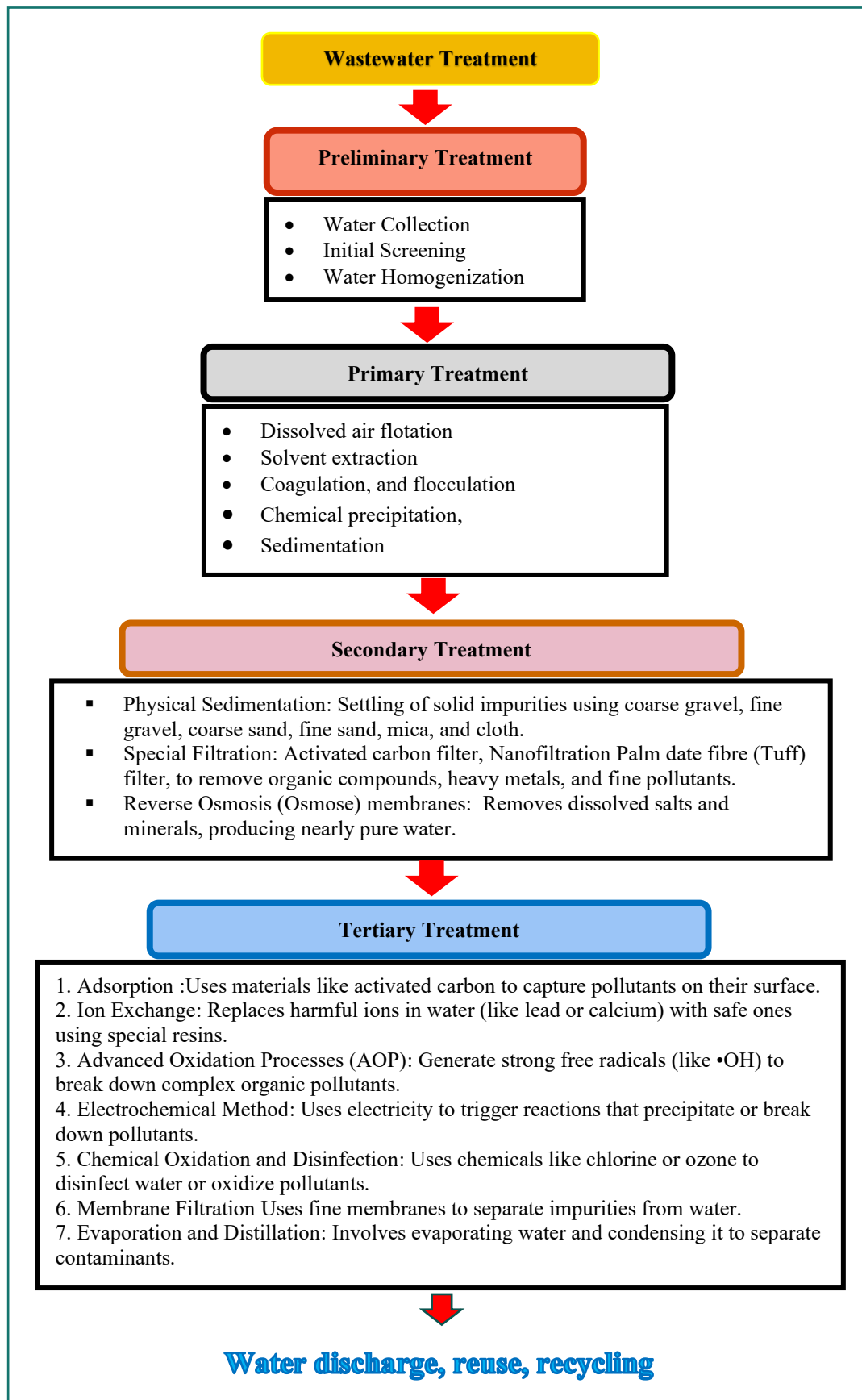


Figure II.3: The general flow of a wastewater treatment process and the techniques used

### II.6.1. Physical Methods

Physical treatment methods rely on mechanical properties to separate contaminants, including screening, comminution, grit removal, sedimentation, membrane filtration, and membrane distillation [36].

Sedimentation, a widely used and cost-effective method, significantly reduces total suspended solids (TSS), biological oxygen demand (BOD), and chemical oxygen demand (COD), achieving removal efficiencies of 50%–70% for TSS and 25%–40% for BOD<sub>5</sub> [37]. Although effective, sedimentation tanks may require large volumes due to long settling times for fine particles.

### II.6.2. Chemical Methods

Chemical treatments utilize inorganic compounds (e.g., aluminum and iron salts) and organic polymers to enhance contaminant removal. Common processes include coagulation, flocculation, precipitation, chemical oxidation, and advanced oxidation processes (AOPs). Coagulation destabilizes colloidal particles, while flocculation promotes their aggregation into larger flocs, which can then be separated [38].

Mixing speed and time significantly influence floc formation and stability [39]. Other key parameters affecting performance include pH, coagulant/flocculant dosage, temperature, and ionic composition [40]. Natural coagulants derived from biological sources are increasingly being considered as eco-friendly alternatives to conventional chemicals [41].

### II.6.3. Biological Methods

Biological treatment employs microorganisms such as bacteria, fungi, yeast, and algae to degrade organic and, to a lesser extent, inorganic pollutants [42].

This method is particularly effective for industrial wastewater with high organic loads, including effluents from food processing, paper manufacturing, and textile industries. It is also suitable for treating petrochemical wastewater due to its cost-effectiveness and high pollutant removal efficiency [43].

### II.6.4. Pathogen Removal in Treatment Processes:

Advanced disinfection (e.g., chlorination, UV, membranes) for pathogen elimination [32]. Monitoring these parameters is essential for assessing treatment performance and protecting environmental and public health [32].

**II.7 Conclusion**

In this chapter, we reviewed the various types of wastewaters and examined discharge standards in both Algeria and around the world, with a particular focus on post-treatment requirements. Given that wastewater often contains a wide range of pollutants, the identification of effective treatment methods remains a key priority within global environmental protection strategies.

The primary objective of the following chapter is to characterise the Physicochemical parameters of the fume-washing water generated from the incineration of medical waste and special hazardous waste, and to determine the most suitable treatment approach for managing this type of effluent.

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# *Practical Aspect*



## *Chapter III: Methods and Materials.*

*In this chapter, we discussed the  
definition of the station and the  
methods and materials used in  
this work*

### III.1. Introduction

In this chapter, we explore the study site and detail the equipment and materials used. The research focused on analysing the Physicochemical characterisation of Incineration Fume Washing Water from Special Waste and dangerous special Waste, both before and after applying various treatment methods.

Washing Water was conducted in collaboration with several specialised laboratories to ensure comprehensive and reliable results. The following institutions contributed to the analytical phase:

- ✓ CRAPC, Ouargla – (19/12/2024 to 14/05/2025) Centre for Research in Analytical Chemistry and Physics.
- ✓ ECFRAL, El Harrach, Algeria – (21/12/2024 to 25/12/2024) Boiler and Sheet Metal Manufacturing Company.
- ✓ NSO Laboratories, Touggourt and Ouargla – (17/02/2025 to 19/02/2025) National Sanitation Office.
- ✓ LACOQ, Rouissat – Quality Control Laboratory. (19/02/2025)
- ✓ NAWR Laboratory, Ouargla – (22/03/2025) National Agency for Water Resources.
- ✓ HBK Laboratory – (28/04/2025 to 04/05/2025) Berkaoui Basin Laboratory.

Each laboratory provided specific expertise and analytical capabilities, contributing to a robust evaluation of parameters such as pH, conductivity, total dissolved solids, chemical oxygen demand (COD), biological oxygen demand (BOD), heavy metals, and other relevant indicators.

### III.2. General Company Overview: SARL TRANSCO [1]



Figure III.1: SARL TRANSCO Source : (OFFRE DE SERVICE)

SARL TRANSCO is a private Algerian company established in 2017, A company founded by Mr Ahmed KORICHI, located next to the Technical Landfill Centre in Bab Mendil, Ouargla. covering a total area of 15,000 m<sup>2</sup>. specializing in the treatment, sorting, incineration, disinfection, and recycling of various types of waste, including hazardous industrial, petrochemical, pharmaceutical, and medical waste.

### III.2.1. Corporate Objectives

- ✓ To contribute to environmental preservation through the deployment of environmentally sound technologies.
- ✓ To provide integrated solutions for the treatment and disposal of hazardous and non-hazardous waste streams.
- ✓ To offer specialized waste management services to the oil and gas, healthcare, and industrial sectors.
- ✓ To promote circular economy practices by recovering and recycling waste into reusable materials.

### III.2.2. Material Infrastructure and Technical Capabilities

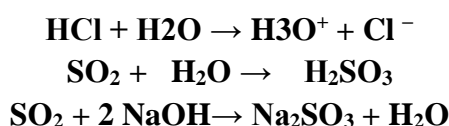
SARL TRANSCO is equipped with a comprehensive infrastructure, including:

1. **Administrative Facilities** :IT office, reception area, sanitary installations, kitchen, and green space.
2. **Dedicated Waste Storage Area** :A secured waste storage zone of 8,000 m<sup>2</sup>.
3. **Advanced Treatment and Recycling Equipment:**
  - Medical waste sterilizer (BANALISEUR) with a capacity of 1000 kg/h.
  - 20high-temperature hazardous waste incinerators (ROTOMAC) with a capacity of 52 kg/h.
  - Rotary kiln incinerator with a throughput of 500 kg/cycle, optimized for high-moisture waste treatment.
  - Fully automated tyre recycling line with a capacity of 1000 kg/h.
  - PET recycling machine with a capacity of 250 kg/h.
  - Medical waste balling and sterilization presses.
4. **Support equipment:** diesel forklift (3T), mini loader (Caterpillar), 6x4 tractor, transport trucks (JMC, MAN), and operational vehicle (Dacia).
5. **Human Resources and Technical Workforce:** The company employs a qualified and multidisciplinary team, comprising:
  - Environmental engineers and waste treatment specialists.
  - Trained operators for incineration and sterilization units.

- Skilled logistics personnel for waste handling and transport operations.
- 6. **Types of Waste Incinerated at TRANSCO Company:** At TRANSCO, different types of waste are incinerated or processed through dedicated systems:
  - **Sterilization System with 1000 kg Capacity:** It is a device used for treating medical waste, including infectious and hazardous healthcare materials waste through thermal sterilization, and it is commonly used to reduce the hazardous nature of the waste before final disposal.
  - **NAR 5000 Incinerator:** Dedicated to the combustion of **pharmaceutical** and **petroleum-based waste**, ensuring the safe disposal of chemically hazardous substances.
  - **Recycling Unit:** Responsible for **sorting and collecting** recyclable materials such as **glass, cardboard, plastic, and paper**. These materials are recovered for **valorization** (re-use or recycling) **after a proper decontamination process**.

### III.3.3. Water Pathway in Incineration–Wet Combustion System [2]

1. **Pre-combustion:** In certain systems, high-calorific solid waste is moistened with water before incineration to reduce flame temperature and prevent thermal explosions. This practice is commonly implemented in the preparation chamber of the TRANSCO incinerator, where water is sprayed using nozzles.
2. **During Combustion:** Water is not introduced directly into the furnace during combustion. Instead, the inherent moisture content of the waste or the pre-applied water evaporates. The generated steam plays a role in heat transfer and facilitates some oxidation reactions within the combustion process.
3. **Washing Water of Incineration Fume:** The primary Role of Water is to cool hot gases exiting the incinerator at approximately 1100°C, which enter the scrubber tower, where cold water is sprayed as a fine mist through nozzles. The water plays a crucial role in reducing the gas temperature (quenching) to around 180°C. It also dissolves gaseous pollutants such as hydrochloric acid (HCl) and sulfur dioxide (SO<sub>2</sub>), in addition to removing suspended particulate matter. The volume of water used typically ranges from 3 to 5 litres per cubic meter of gas, depending on the gas flow rate. The resulting scrubber water becomes laden with heavy metals, including mercury (Hg), lead (Pb), and cadmium (Cd), organic pollutants, acidic substances such as HCl and hydrofluoric acid (HF), as well as fine particulate ash (fly ash). This wastewater requires subsequent treatment to ensure environmental protection.



### III.4. Measured Physical and Chemical Parameters

To determine the quality of industrial water, a series of measurements was conducted for a set of physicochemical water pollution parameters. Samples were collected from both the inlet and the outlet of the TRANSCO station to evaluate the effectiveness of the treatment process.

Analyses were conducted on the wash water condensate from incinerator fumes, before and after treatment.

#### III.4.1 Sampling Procedure

Sampling waterways is a crucial and essential process for obtaining accurate analytical results. A total of 82 litres of Fume Washing Water was treated. Sampling was conducted 15 times between December 2024 and May 2025. The treatment process was conducted over three consecutive months, from March to May 2025. To ensure the reliability of the data, it is crucial to avoid altering the physical or chemical properties of the water during sample collection. The sampling and storage tank for incinerator wash water at the Transco facility is a deep vertical concrete structure with the following dimensions:

- Depth: 1 meter, Width: 1.3 meters, Length: 2.2 meters
- Volume =  $1 \times 1.3 \times 2.2 = 2.86 \text{ m}^3$

This tank is designed to collect and hold large volumes of contaminated wash water generated. For controlled and representative sampling, the flow velocity through the sampling pipe should be 0.2 to 0.5 m/s. This avoids disturbance of settled solids at the bottom while ensuring a reliable sample volume. We take a 1-litre plastic bottle and rinse it three times with tap water, followed by distilled water. A small amount of that water is then used to rinse the inner surfaces of the bottle. Finally, the bottle is filled with the sample and sealed tightly.

#### III.4.2 Physical parameters



Figure III.2: Sampling Basin for Incinerator Flue Gas Washing Water – TRANSCO.

### ▪ Dissolved Oxygen (O<sub>2</sub>)

#### Theoretical Principle:

- Represents the concentration of oxygen available for aquatic organisms.
- It indicates water quality and the extent of organic pollution.
- Measured by an oximeter or via the Winkler titration method.

#### Experimental Procedure:

**Device:** Oximeter HACH HQ 30 d.

- Calibrate the device.
- Rinse the probe with distilled water.
- Immerse it in 100 mL of the sample with stirring.
- Record DO concentration, saturation, and partial pressure.

### ▪ Temperature (°C)

#### Theoretical Principle:

- It affects reaction rates and the solubility of gases in water.
- Often measured simultaneously with other parameters.

#### Experimental Procedure:

**Device:** Multimeter sensor HACH device

- Immerse the sensor in the sample.
- Wait for stabilization.
- Read the temperature directly.

### ▪ pH

#### Theoretical Principle:

- Measures hydrogen ion concentration; an indicator of acidity/basicity.
- Uses a calibrated glass electrode.

#### Experimental Procedure:

**Device:** pH meter

- Calibrate with buffer standards.
- Rinse the electrode.
- Immerse the 100 mL sample under stirring.
- Read and record pH value.

### ▪ Electrical Conductivity (EC)

#### Theoretical Principle:

- Reflects ionic strength and total dissolved solids.
- Calibrated using standard KCl solution.



Figure III.3: Oximeter HACH HQ 30 d.



Figure III.4: pH meter

**Experimental Procedure:****Device:** Conductivity Meter(OHAUS)

- Calibrate with 0.01 mol/L KCl.
- Rinse electrode, immerse in a stirred 100 mL sample.
- Record EC (in mS/cm).

- **Turbidity**

**Theoretical Principle:**

- Indicates the presence of suspended particles.
- Measured by light scattering.

**Experimental Procedure:****Device:** Turbidimeter(HACH)

- Fill the cuvette with a sample.
- Place the device, and read the result in NTU.

**III.4.3 Chemical parameters**

- **Total Suspended Solids (TSS)**

**Theoretical Principle:**

Quantifies solids retained by a microfiltration membrane, expressed in mg/L.

**Experimental Procedure:****Device:** HACH-type

- Weigh dry filter paper.
- Filter 100 mL of the sample.
- Dry at 105°C, reweigh.
- $TSS = (\text{Final weight} - \text{Initial weight}) / \text{Sample volume}$ .

- **Chemical Oxygen Demand (COD)**

**Theoretical Principle:**

Measures the oxygen equivalent of organic matter oxidised chemically (often using dichromate) in COD measurement, a capsule containing the commercial reagent (LCK 114) is used to facilitate the oxidation reaction and allow accurate spectrophotometric analysis.

**Experimental Procedure:****Device:** Spectrophotometer HACH DR 3900

- Add 2 mL of sample.
- Heat at 148°C, cool, homogenize.
- Read COD in mg/L.



Figure III.5: Conductivity Meter



Figure III.6: Turbidimeter device



Figure III.7:HACH-type



Figure III.8: Spectrophotometer device

### ▪ Biological Oxygen Demand (BOD<sub>5</sub>)

#### Theoretical Principle:

As oxygen is used, carbon dioxide (CO<sub>2</sub>) is produced and absorbed by sodium hydroxide (NaOH) placed in a sealing cap.

The resulting decrease in pressure is proportional to the amount of oxygen consumed by microorganisms over 5 days at 20°C.

Indicates biodegradable organic load is displayed directly on the device.



Figure III.9 : OxiTop WTW DBO

#### Experimental Procedure:

**Device:** OxiTop WTW DBO

- BOD<sub>5</sub> is calculated using the formula:

$$\text{BOD}_5 = \text{COD} \times 0.85$$

- The appropriate sample volume is selected from a reference table.
- The incubation bottle is filled with the required volume, and a NaOH pellet and inhibitor are placed inside the OxiTop cap.
- The bottle is tightly sealed and placed in an incubator at 20°C for 5 days.
- After incubation, the pressure drop is read from the device screen, which corresponds to the BOD<sub>5</sub> value in mg/L.

**Table III 01:** Coefficient of variation of the BOD<sub>5</sub> value concerning the sample volume used

Measurement Range	Sample Size	Coefficient	Inhibitor
0-40	432	1	9
0-80	365	2	7
0-200	250	5	5
0-400	164	10	3
0-800	97	20	2
0-2000	43.5	50	1
0-4000	22.7	100	0.5

### ▪ Ammonium (NH<sub>4</sub><sup>+</sup>)

#### Theoretical Principle:

Detected via Nesslerization, forming a yellow complex (425 nm), indicates recent organic pollution.

#### Experimental Procedure:

**Device:** spectrophotometer HACH DR 3900 + LCK 303

- Add 0.2 mL of sample, wait 15 min.



Figure III.10 :spectrophotometer HACH

- Read the ammonium concentration (mg/L).

- **Nitrites ( $\text{NO}_2^-$ )**

**Theoretical Principle:**

Detected by the Griess reaction, forming a pink azo dye (540 nm). Intermediate in nitrification.

**Experimental Procedure:**

**Device:** spectrophotometer **HACH DR 3900 + LCK 338**

- Add 2 mL of sample, wait 10 min.
- Read the nitrite concentration(mg/L).

- **Nitrates ( $\text{NO}_3^-$ )**

**Theoretical Principle:**

Measured via UV absorption (220 nm) or the Griess method after cadmium reduction. Reflects oxidized nitrogen.

**Experimental Procedure:**

**Device:** spectrophotometer HACH DR 3900 + LCK 340

- Add 1 mL of sample + 2 mL reagent, wait 10 min.
- Read the nitrate value(mg/L).

- **Sulfates ( $\text{SO}_4^{2-}$ )**

**Theoretical Principle:**

Turbidimetric method via  $\text{BaCl}_2$  precipitation. Turbidity sulfate concentration.

**Experimental:**

**Device:** Use a spectrophotometer with barium chloride reagent and read the Sulfates value (mg/L) at an appropriate wavelength.

- **Orthophosphorus ( $\text{PO}_4^{3-}$ )**

**Theoretical Principle:**

Detected as a molybdenum blue complex (880 nm), an indicator of eutrophication.

**Experimental Procedure:**

**Device:** spectrophotometer HACH DR 3900 + LCK 350

Add 0.4 mL sample + 0.5 mL reagent.

Wait 10 min, read the absorbance.

- **Heavy Metals ( $\text{Pb}^{2+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$ , etc.)**

Trace-level quantification of toxic metal ions due to their deleterious ecological and human health impacts necessitates sensitive analytical techniques.

### 1. Atomic Absorption Spectrometry (AAS)

Elemental analysis based on atomization of acidified samples in a flame or graphite furnace, measuring characteristic atomic absorption at element-specific wavelengths, calibrated with standard solutions.

The Tube Testing Method was adopted to conduct all heavy metal analyses in the industrial wastewater from the Bab

Mendil station in Ouargla.

A sample analysis was carried out using an Atomic Absorption Spectrometer (AAS) at the Crapsey

Laboratory, with additional analysis performed on February 4, 2025, for further verification.

#### **Procedure:**

- 100 mL of the industrial water sample is added to 10 mL of concentrated nitric acid ( $\text{HNO}_3$ ) in a beaker.
- The mixture is placed on a magnetic stirrer and heated to  $120^\circ\text{C}$ .
- Once evaporation begins, an additional 10 mL of  $\text{HNO}_3$  is added, and the mixture is allowed to reduce in volume to approximately 50 mL.
- The resulting solution is filtered through filter paper into a volumetric flask, and the volume is brought up to the calibration mark with distilled water.
- The solution is gently shaken to ensure homogeneity.
- An aliquot of the prepared sample is transferred into a test tube and analysed using the AAS to determine the concentration of heavy metals.

### 2. X-Ray Fluorescence (XRF)

Non-destructive multi-elemental analysis via excitation of sample atoms by primary X-rays inducing characteristic secondary emission;

samples prepared as dried pellets or thin films, enabling simultaneous qualitative and quantitative assessment.



**Figure III.11** :Atomic Absorption Spectrometer (AAS)



**Figure III.12** :XRF X-ray fluorescence ECFERAL El Harrach

**Description:**

The device shown in the image is a Thermo Scientific Niton Handheld XRF Analyzer, mounted on a Mobile Test Stand. This type of equipment is used for non-destructive analysis of sample compositions, whether solid or liquid, using specialized techniques.

**Procedure**✓ **Powering On:**

Ensure the device is securely mounted on the stand.

Turn on the device using the power button and wait for the main interface to appear.

✓ **Selecting the Analysis Mode:**

From the screen menu, select the appropriate analysis mode based on the sample type (Metals, Alloys, Soil, Environmental, etc.).

The program can be customized according to the sample nature (solid or liquid).

✓ **Sample Preparation:**

Solid samples: Placed directly under the analysis window.

Liquid samples: Prepared in a special cup, then positioned on the stand beneath the analyzer.

✓ **Starting the Analysis:**

Press the analysis button (located either on the screen or the handle).

The device emits a high-energy X-ray beam that interacts with the sample.

This produces a fluorescent signal that is detected and analyzed by the system.

✓ **Reading the Results:**

Results appear on the screen within seconds.

The output includes a list of detected elements along with their concentrations (in ppm or%).

**III.5. Method of Treatment**

Based on all the elements discussed above, four treatment methods were selected, each differing in nature, effectiveness, and the complexity of their implementation requirements.

**III.5.1. Natural Treatment [3]"This reference after revision"**

**Description:** This method relies on the use of lime, or "Chelabo" (a local clay-based coagulant), and natural clay in varying proportions to determine the optimal formulation. It was selected for its low cost, simplicity, and potential to valorise and utilise local natural resources without requiring advanced technical expertise. We use only lime or Chelabo in the treatment.



Figure III.13: Natural Treatment

**Effectiveness:**

- **Lime or Chelabo:** These compounds increase the pH of the water, facilitating the precipitation of several heavy metals (e.g.,  $\text{Fe}^{3+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Cd}^{2+}$ ) in the form of insoluble hydroxides. Additionally, they help reduce turbidity and enhance the physical sedimentation process.
- **In heavy metal removal:** Effective in removing lead, zinc, and cadmium via alkaline precipitation mechanisms.
- **Clay:** Possesses high adsorptive capacity for both organic and inorganic pollutants. It enhances flocculation and sedimentation processes, contributing to the efficient removal of suspended solids and heavy metals.
- **Mechanism:** Clay interacts with metal ions through surface adsorption and ion exchange.

**Materials Used:**

- 5 litres of contaminated wastewater.
- 2.5 grams of lime.
- Chelabo solution: 2.5 grams of powdered Chelabo dissolved in 1 litre of water
- 30 grams of natural clay

**Protocol:**

Date of Experiment: March 20, 2025

**pH Adjustment:** pH was adjusted using Chelabo solution or lime, based on preliminary experiments.

**Reagent Addition:** Treatment materials were gradually added to the wastewater under continuous stirring for 30 minutes. Afterwards, the mixture was left undisturbed for 6 hours before filtration, proceeding to the second phase, in which clay was added to enhance the treatment process.

**Sedimentation:** The mixture was left to settle undisturbed for 2–3 hours in a sedimentation vessel.

**Filtration:** The treated water was filtered to separate the precipitated solids before analysis.

### III.5.2. Chemical Treatment photocatalyst[4]"This reference after revision"

#### Description:

This method involves the use of alum, activated carbon, and the photocatalyst titanium dioxide ( $\text{TiO}_2$ ). It is effective for removing organic compounds and certain heavy metals, but it requires specialized equipment and advanced technical expertise.

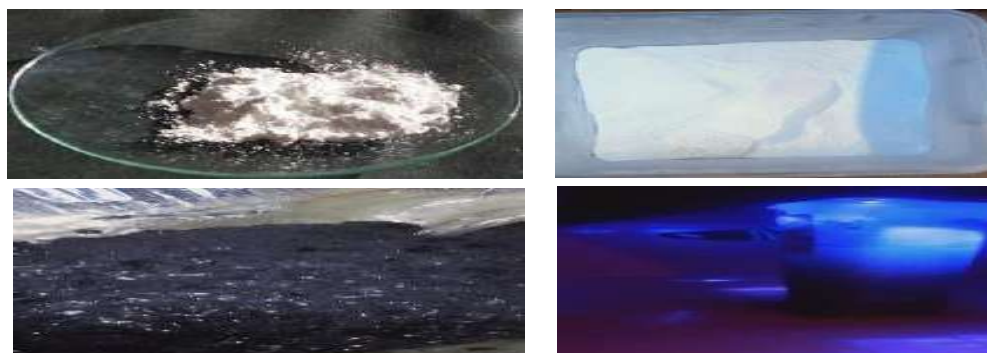


Figure III.14 Chemical Treatment photocatalyst

#### Effectiveness:

- **Alum (Aluminum Sulfate):** Facilitates coagulation and flocculation, promoting the precipitation of suspended solids and heavy metals.
- **Activated Carbon:** Adsorbs organic compounds and heavy metal ions such as  $\text{Hg}^{2+}$ ,  $\text{Pb}^{2+}$ , and  $\text{Cu}^{2+}$  due to its high surface area and porous structure.
- **$\text{TiO}_2$  (Photocatalyst):** When exposed to ultraviolet (UV) light,  $\text{TiO}_2$  generates reactive hydroxyl radicals ( $-\text{OH}$ ) capable of degrading pollutants complex. This process also facilitates the subsequent removal of metal-organic complexes.

#### Materials Used (for 5 litres of contaminated water):

- Alum: 125 grams
- Activated Carbon: 50 grams
- $\text{TiO}_2$  (Photocatalyst): 1.25 grams
- UV Light Source
- Sedimentation container and filtration setup

#### Protocol:

Date of Experiment: April 29, 2025

#### Coagulation:

Add 125 grams of alum to 5 litres of contaminated water. Stir for 15 minutes to promote floc formation.

#### Adsorption:

Add 50 grams of activated carbon and continue stirring for 1 hour to enhance pollutant adsorption.

**Photocatalysis:**

Add 1.25 grams of TiO<sub>2</sub> and expose the mixture to UV light for 2–3 hours to initiate photodegradation.

**Sedimentation/Filtration:**

Allow the solution to settle or filter to remove suspended solids before conducting water quality analysis.

**III.5.3. Biological Treatment**[5]"This reference after revision"**Description:**

This method utilizes the microalgae *Spirulina platensis* for its biological capacity to absorb pollutants. It is a moderately cost-effective approach that requires a cultivation tank, proper lighting, and aeration.



Figure III.15 Biological Treatment

**Effectiveness:**

- **Microalgae Properties:** Microalgae possess cell walls rich in carbohydrates and proteins, enabling biosorption of heavy metals and organic pollutants.
- **Heavy Metal Removal:** Effective in removing Zn<sup>2+</sup>, Cu<sup>2+</sup>, Pb<sup>2+</sup>, and Cd<sup>2+</sup> via biosorption and ion exchange mechanisms. Also contributes to the reduction of nitrate and phosphate levels.

**Materials Used:**

- 5 litres of contaminated water
- 30-litre cultivation tank
- Light source and air pump
- Nutrient medium: 10 liters of water + 3 grams of clay (kalabo)
- *Spirulina platensis* biomass at a concentration of 20 grams

**Protocol:**

Date of Experiment: May 3, 2025

**Preparation:**

Set up the biological cultivation system with appropriate lighting and aeration. Inoculate the system with *Spirulina* culture.

**Condition Monitoring:**

Maintain and monitor environmental conditions (pH, temperature, light) for 5–7 days to ensure optimal growth.

**Treatment:**

Add the contaminated water and allow the treatment process to proceed for 10–15 days.

**Filtration:**

Filter the treated water to separate the algal biomass before conducting further water quality analysis.

**III.5.3. Integrated Multi-Stage Treatment System [6]"This reference after revision"**

An integrated treatment System was developed that combines several techniques in a precise sequence, aiming to achieve an effective and comprehensive treatment of highly polluted industrial water, particularly the washing water of incinerator exhaust gases. Despite its relative cost, the system provides treated water of sufficient quality and quantity for industrial reuse.

Date of Experimentation: May 7th, 2025

**A. Advanced Chemical Treatment Using Coagulant**

This method involves mixing the contaminated water with ferric chloride ( $\text{FeCl}_3$ ) to initiate coagulation and chemical precipitation processes. It replaces synthetic polymers due to their unavailability.



**Figure III.16** Integrated Multi-Stage Treatment System

**Effectiveness:**

Ferric chloride ( $\text{FeCl}_3$ ) serves as a powerful coagulant that interacts with organic matter and suspended solids to form precipitates that can be easily settled. It generates iron hydroxides that bind to heavy metals such as  $\text{Pb}^{2+}$ ,  $\text{Cd}^{2+}$ , and  $\text{As}^{3+}$ .

**Materials and Equipment:**

- Volume: 15 litres of polluted water
- Two sedimentation tanks (30 L each)
- $\text{FeCl}_3$  (10–20 g)
- Natural clay (referred to as "Clabo"): 2.5 g/L

**Protocol:**

- Add "Chelabo" powder to adjust water pH to the optimal range (6.5–7.5).
- Gradually add  $\text{FeCl}_3$  and Clabo with continuous stirring for 45 minutes.
- Let the mixture settle for 3 hours.
- Transfer the supernatant to the next stage using an air pressure pump.

**B. Multi-Layer Physical Filtration**

This stage includes sequential filtration through several layers (filter cloth, fine sand, coarse sand, small gravel, large gravel) to eliminate suspended solids and coarse particles.

**Effectiveness:**

Improves the efficiency of downstream stages by reducing organic and solid load. It removes suspended particles, potentially carrying adsorbed heavy metals, reduces turbidity, and enhances water clarity and odour.

**Materials and Equipment:**

- 80-litre filtration tank
- Special filter cloth
- Fine sand
- Coarse sand
- Small gravel
- Large gravel

**Protocol:**

- Pass the water through multiple filtration layers (filter cloth, wet fine sand, coarse sand, small gravel, large gravel).
- Use a hydraulic pressure pump.
- Open outlet valve to allow water to pass through each filtration layer.

### C. Filtration Using Activated Carbon and Natural Nanomaterials (Wood Shavings + Palm Fibres)

Activated carbon, wood shavings, and palm fibres are used as natural filtering materials with high adsorption properties for fine pollutants and heavy metals ( $Zn^{2+}$ ,  $Pb^{2+}$ ,  $Ni^{2+}$ ).

#### **Activated Carbon Filtration Efficiency:**

- Adsorption of toxic organic compounds
- Reduction of colored and odorous compounds
- Partial adsorption of heavy metals such as  $Hg^{2+}$ ,  $Cu^{2+}$

#### **Natural Nanofiltration Efficiency:**

- Wood shavings: Rich in lignin and cellulose, offering excellent adsorption of heavy metals and organic compounds
- Palm fibres: Effective in removing organic matter and nano-sized particulates due to their fibrous structure
- These materials reduce toxic compounds and ultra-fine suspended particles.

#### **Materials and Equipment:**

Separate filtration units containing activated carbon, wood shavings, and a palm fibre circulation pump.

#### **Protocol:**

- Pass the pre-treated water through the different filtration units
- Allow 3 hours for effective contact and filtration
- Transfer water to the UV treatment unit
- 

### D. Ultraviolet (UV) Light Treatment

This final treatment stage simulates a UV-based disinfection process using violet LED lighting as a cost-effective method for eliminating microorganisms and degrading toxic organic compounds (such as dioxins and furans) into non-toxic byproducts like  $CO_2$  and  $H_2O$ .

#### **Effectiveness:**

- Photodegradation of dioxins and complex organic compounds into safer compounds
- Biological disinfection (elimination of bacteria, viruses, and parasites)
- Improvement of water quality for reuse or safe discharge
- Reduction of electrical conductivity (EC)

**Materials and Equipment:**

- Violet LED lamp
- Transparent treatment tank (30 L capacity)
- Small circulation pump or manual stirring rod
- Simple timer to control exposure duration
- Opaque cover to prevent light leakage

**Protocol:**

- Transfer pre-treated water to a transparent 30 L tank
- Place the violet LED light source above or inside the tank
- Expose the water to the violet light for 1 to 2 hours
- Stir the water continuously using a small pump to ensure uniform exposure
- After exposure, collect a sample for final physicochemical analysis

**E. Final Expected Outcome:**

An effective and comprehensive multi-stage treatment capable of removing heavy metals, BOD<sub>5</sub>, COD, and turbidity. The resulting water exhibits significantly improved quality, making it suitable for industrial reuse or environmentally safe discharge. The system offers an integrated solution for both organic and inorganic pollutant removal with high precision and efficiency.

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***Chapter IV: Results and  
Discussion.***

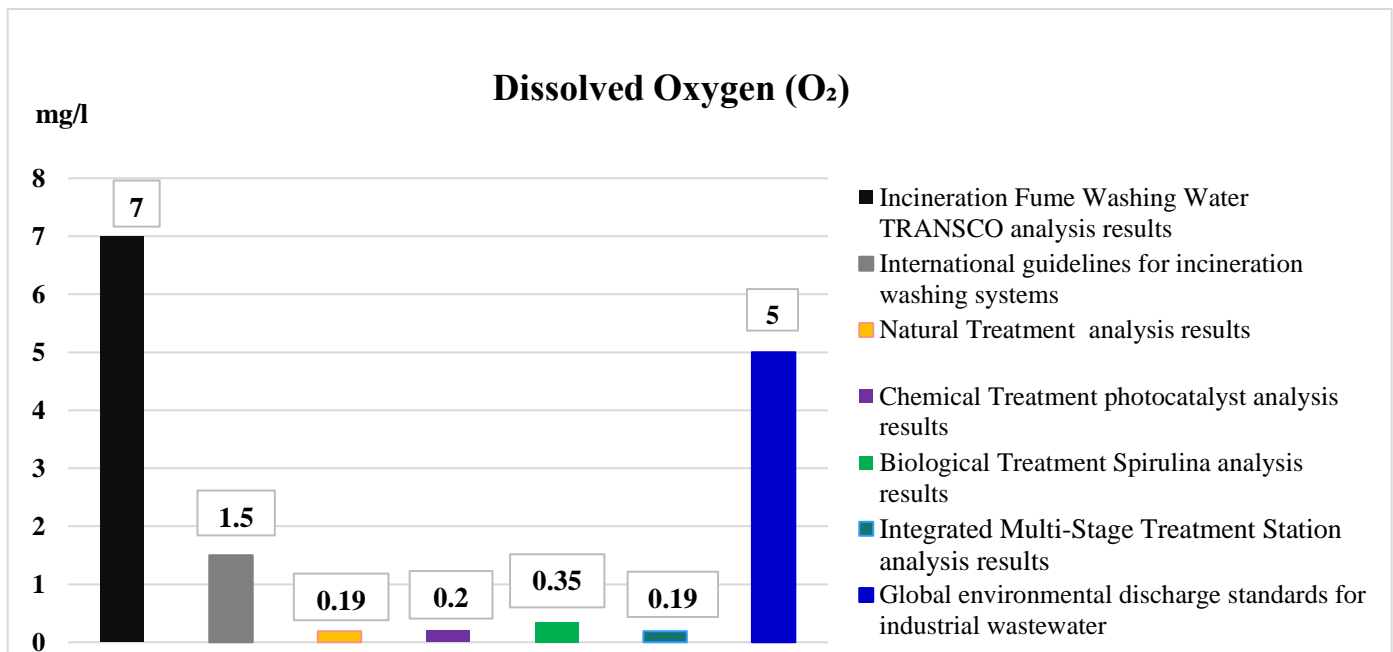
***In this chapter, we discussed  
and analyzed the obtained  
results.***

## IV.1 Introduction

In this chapter, we present the results obtained from laboratory analyses of the physical and chemical properties of the washing water from the flue gases of the medical, special, and hazardous waste incinerator, both before and after treatment. These results are compared with international standards for incinerator wastewater and treated industrial wastewater permitted for environmental discharge. Each parameter will be discussed individually according to the established plans to evaluate the efficiency of the proposed treatment methods. The data includes measurements taken from the washing water in its raw and treated forms.

## IV.2. Physical Characteristics

### IV.2.1 O<sub>2</sub> dissolved:



**Figure (IV. 01):** The Dissolved Oxygen measures for fume washing water of the TRANSCO company before and after treatment.

The dissolved oxygen (DO) level in the raw washing water from the incinerator flue gases was **7 mg/L**, which significantly exceeds both the international standards for incineration washing systems **1.5 mg/L** and the global environmental discharge standards for industrial wastewater **5 mg/L**.

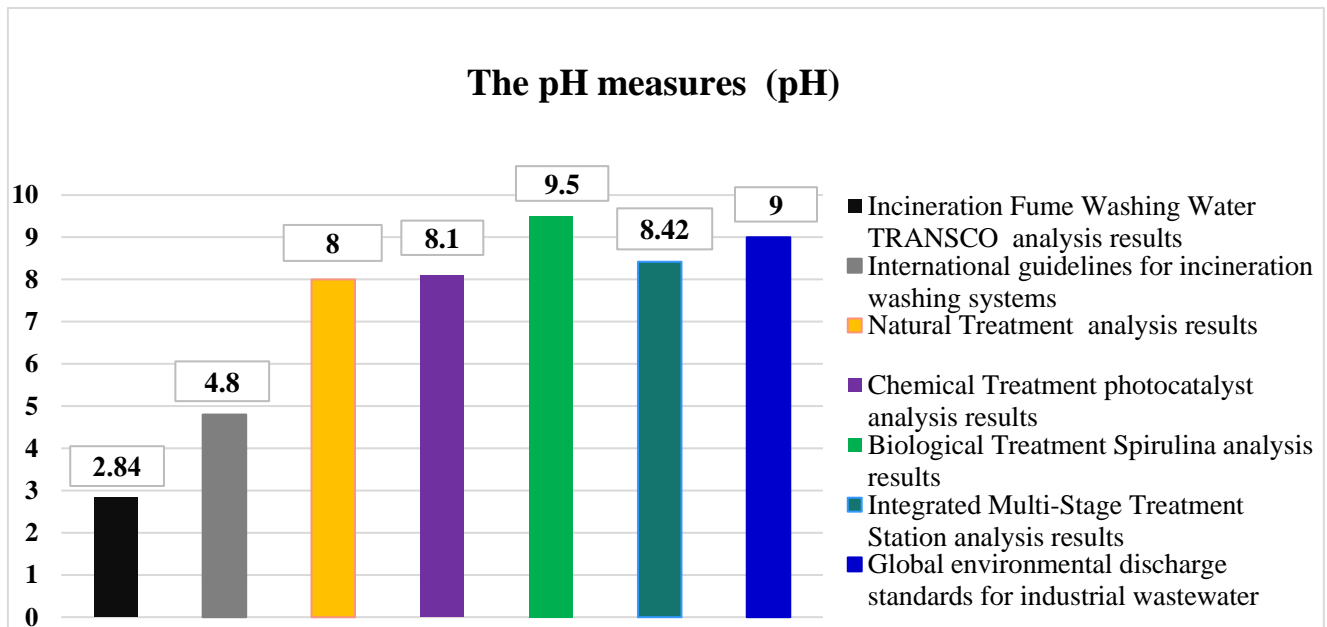
### Treatment Results:

- ▶ Natural treatment led to a decrease in DO concentration to **0.19 mg/L**, which is far below acceptable limits, indicating insufficient oxygen levels that may compromise biological stability in case of discharge without considering this factor.

- ▶ Chemical treatment using photocatalysis slightly improved the DO concentration to 0.2 mg/L, but it remains inadequate.
- ▶ Biological treatment using Spirulina increased the DO concentration to 0.35 mg/L, showing some improvement, yet still below the required standard.
- ▶ The integrated multi-stage treatment station yielded a similar result to the physical treatment, with a DO level of 0.19 mg/L.

These results indicate that although raw water initially contains a high level of dissolved oxygen, this can be attributed to the location of the washing water collection tank being in the open air, which allows a higher dissolved oxygen concentration, but most single-stage treatments significantly reduce it. This may be due to high chemical or biological oxygen demand during the treatment process. None of the methods, whether applied individually or in combination, achieved the global discharge standard of 5 mg/L, highlighting the need for optimisation, particularly in terms of re-aeration after treatment.

#### IV.2.2 pH:



**Figure (IV. 02):** The pH measures for fume washing water of the TRANSCO company before and after treatment.

The pH level represents the degree of acidity or alkalinity of water and is a key indicator in assessing the suitability of industrial wastewater for treatment or discharge. The analysis results of the washing water from incinerator flue gases revealed a very low pH value of 2.84, indicating a highly acidic nature. This value is below the international guidelines for flue gas scrubbing

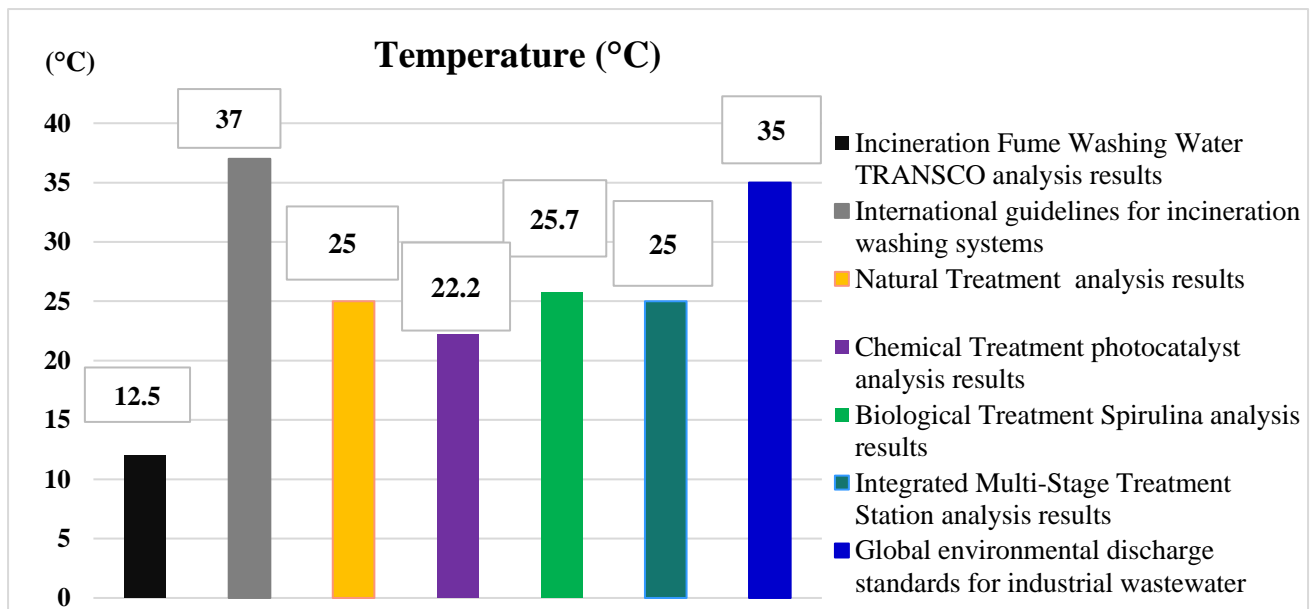
systems, which set the minimum acceptable pH at 4.8. Moreover, global standards for industrial wastewater discharge specify an ideal pH value of 9.

#### Treatment Results:

- ▶ **Natural treatment** increased the pH to 8.0, a notable improvement. It complies with the internationally required level.
- ▶ **Chemical treatment** using photocatalysis raised the pH to 8.1. It complies with the desired standard.
- ▶ **Biological treatment** using *Spirulina* improved the pH to 9.5, surpassing the international standard, demonstrating the effectiveness of this method in achieving good chemical balance.
- ▶ **Multi-stage treatment** elevated the pH to 8.42, which is relatively acceptable with global benchmark.

The acidity in the raw water is primarily due to the acidic gaseous nature of the pollutants emitted from the combustion process. These gases readily dissolve in the scrubbing water, forming strong acids that significantly, drastically lower the pH level. All treatment methods effectively improved the pH. However, the biological method exceeded the environmental standard of 9. This indicates the need for a final neutralization step or enhancement of the treatment process integration to ensure the treated water complies with environmental discharge requirements.

#### IV.2.3 Temperature:



**Figure (IV. 03):** The Temperature measures for fume washing water of the TRANSCO company before and after treatment.

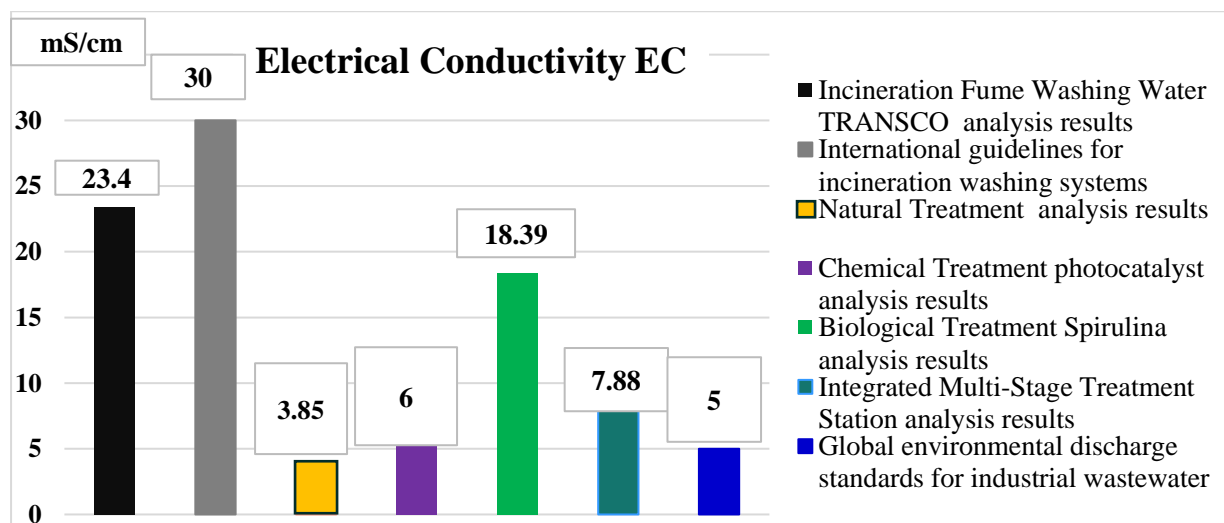
Temperature is a key physical parameter that directly influences chemical and biological processes in water treatment systems. It affects the efficiency of microbial activity, oxygen solubility, and the stability of organic compounds. In the case of incineration, flue gas washing water, the initial temperature was measured at **12°C**, which is relatively low. This is likely due to seasonal weather conditions, as the washing water is collected in open-air tanks.

#### **Treatment Results:**

- ▶ **Natural treatment** raised the temperature to **25°C**, likely due to ambient conditions during exposure.
- ▶ **Chemical treatment** using photocatalysis reduced the temperature slightly to **22.2°C**, possibly due to cooling effects or treatment under shaded conditions.
- ▶ **Biological treatment** using **Spirulina** increased the temperature to **25.7°C**, which is favourable for biological activity and indicates a stable microbial environment.
- ▶ **Integrated multi-stage treatment** stabilised the temperature at **25°C**, reflecting a balanced thermal profile.

Although the raw water temperature was initially low, all treatment methods increased it to a range of **22–26°C**, which is well within environmentally acceptable limits. Temperature does not pose a concern in this case. All values fall within the permitted range, and the treatment systems demonstrate an effective ability to maintain thermal balance without compromising environmental or operational standards.

#### **IV.2.4 Electrical Conductivity (EC):**



**Figure (IV. 04):** The Electrical conductivity measures for fume washing water of the TRANSCO company before and after treatment.

Electrical conductivity (EC) is an important indicator of the concentration of dissolved ions in water, reflecting the presence of salts, acids, bases, and inorganic compounds. High EC values usually indicate elevated levels of pollution or accumulation of chemical substances, which may negatively affect treatment efficiency and the suitability of the water for discharge or reuse.

In the case of incineration flue gas washing water, as shown in Figure IV.4, the EC value was recorded at **23.4 mS/cm**, which is considered very high. This suggests a large quantity of dissolved ions, likely due to the absorption of acidic gases and fine particulates during the washing process.

International guidelines for incineration washing systems is a maximum EC of **30 mS/cm**, meaning the raw water is still within the internationally acceptable limit, though approaching the upper threshold.

Global environmental discharge standards for industrial wastewater recommend a maximum EC of **5mS/cm**.

#### **Treatment Results:**

- ▶ **Natural treatment reduced EC to 3.85 mS/cm**, which is below both international and global standards. And that is the most effective in reducing EC to environmentally acceptable levels.
- ▶ **Chemical treatment using photocatalysis lowered EC to 6 mS/cm**, meeting international guidelines but slightly exceeding the global discharge standard.
- ▶ **Biological treatment using Spirulina reduced EC to 18.39 mS/cm**, a partial improvement, but still significantly above the acceptable discharge level. And it's the least effective in reducing electrical conductivity, possibly due to the residual mineral salts added to support the growth of Spirulina algae.
- ▶ **.Integrated multi-stage treatment achieved an EC of 7.88 mS/cm**, showing considerable improvement compared to raw water, but still not meeting the global environmental standard.

Although all treatment methods contributed to reducing EC to varying degrees, only natural treatment successfully brought it within globally accepted limits.

This highlights the need for additional ion removal techniques (such as membrane filtration or ion exchange).

## IV.2.5 Turbidity (NTU):

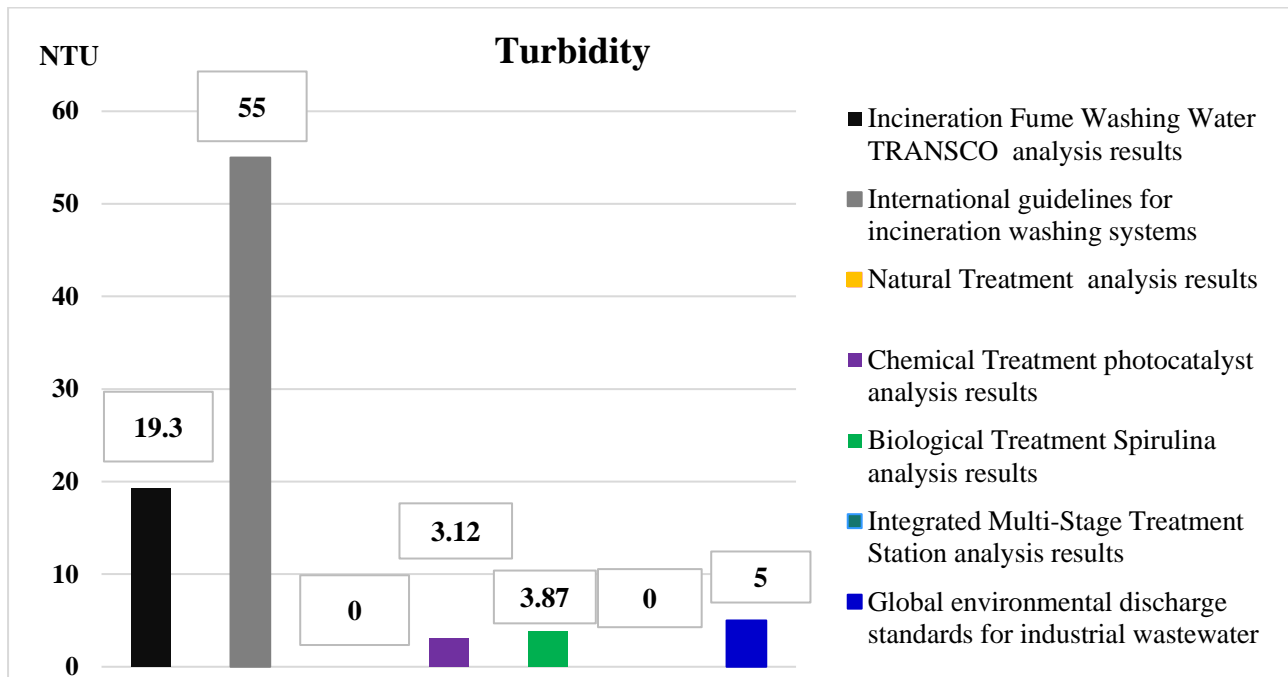


Figure (IV. 05): The Turbidity measures for fume washing water of the TRANSCO company before and after treatment.

Turbidity indicates the presence of suspended, non-dissolved materials in water, such as silt, fine particles, microorganisms, and oils. It is a key indicator of water clarity and quality. High turbidity levels negatively affect the efficiency of biological and chemical treatment processes and reduce the overall quality of treated water.

According to Figure IV. 05 the turbidity value in the raw water sample from the incineration flue gas washing was recorded at **19.3 NTU**, which is relatively high, though within the internationally acceptable limit of **55 NTU**, but it exceeds the global environmental discharge standard of **5 NTU** for industrial wastewater.

**This elevated turbidity can be attributed to:**

The presence of fine ash particles or solid pollutants is carried by the flue gases.

Chemical reactions during the washing process result in the formation of insoluble precipitates.

**Treatment results:**

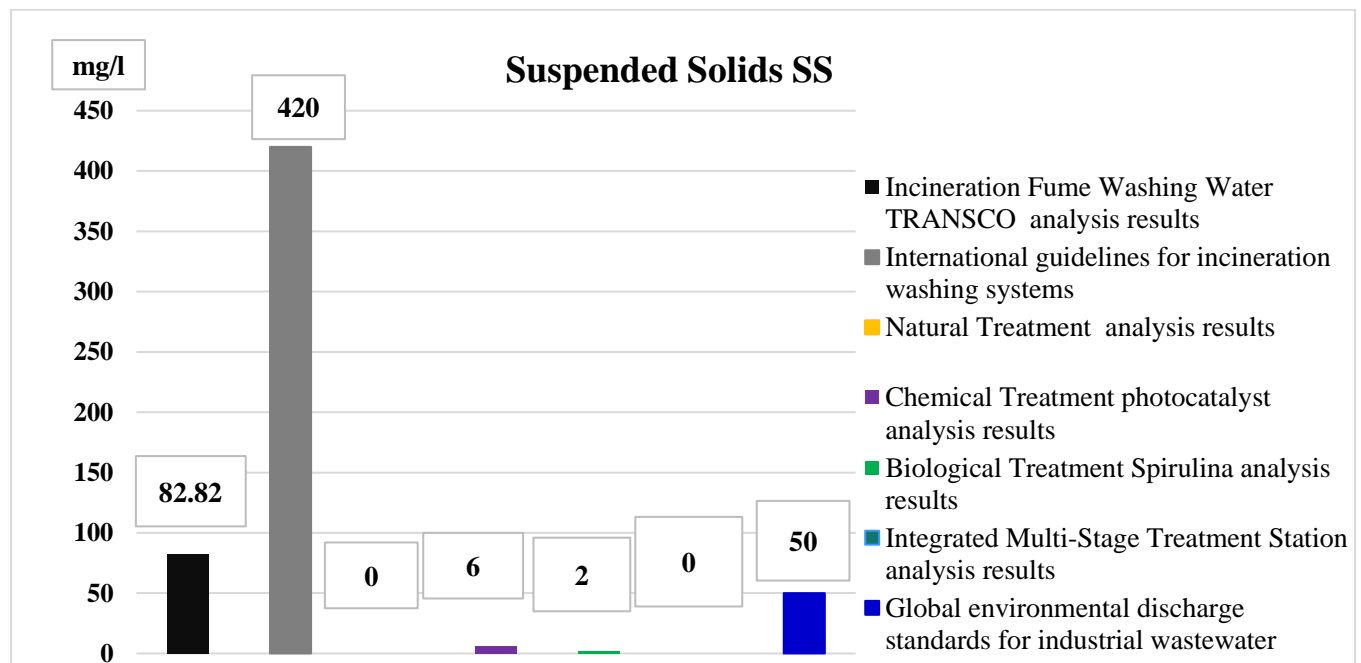
- ▶ Natural treatment: Reduced turbidity to **0 NTU**, which is considered ideal and complies fully with both international and global standards.
- ▶ Chemical treatment using photocatalysis: Reduced turbidity to **3.12 NTU**, which is below the global discharge standard of **5 NTU**, indicating that this method is also effective.

- ▶ Biological treatment using Spirulina: Brought turbidity down to 3.87 NTU, which falls within the environmental threshold, showing acceptable efficiency.
- ▶ Integrated multi-stage treatment: Achieved a turbidity of 0 NTU, matching the optimal result of the physical treatment.

All treatment methods succeeded in reducing turbidity to levels below the globally permitted limit of 5 NTU. The physical treatment and multi-stage treatment showed the highest effectiveness by eliminating turbidity, which appears to be the best option for achieving superior water clarity and quality. The chemical and biological treatments were also effective, but did not fully eliminate turbidity.

### IV.3. Chemical Characteristics

#### IV.3.1 Suspended Solids SS:



**Figure (IV. 06):** The Suspended Solids SS measures for fume washing water of the TRANSCO company before and after treatment.

Suspended Solids (SS) are one of the key indicators of water quality. They represent undissolved particles such as ash, organic materials, and inorganic residues. High levels of SS indicate poor water clarity, can hinder the effectiveness of chemical and biological treatments, and are considered a crucial parameter in assessing the suitability of water for environmental discharge.

In the case of TRANSCO fume washing water, the SS value reached approximately 82.82 mg/L, which is well below the international guideline limit for incineration washing systems with 420 mg/L, but exceeds the global environmental discharge standard for industrial wastewater of 50 mg/L. This

indicates a moderate pollution load requiring effective treatment to meet permissible environmental limits.

This elevated value is attributed to residual ash carried with combustion gases, and the inorganic particles are captured during the washing process.

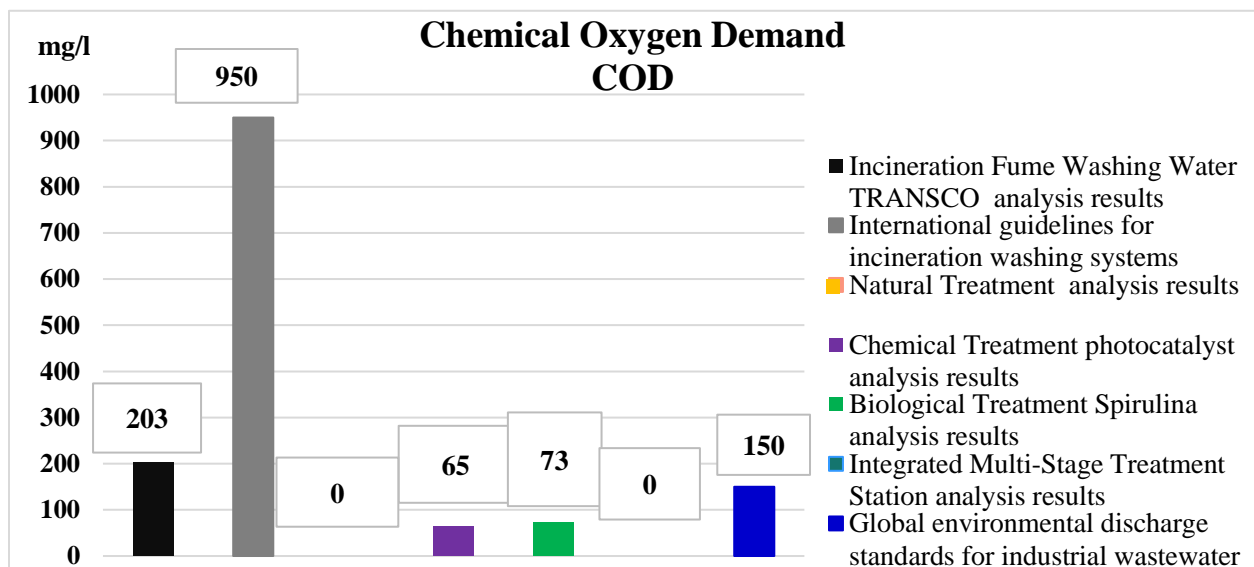
#### **Treatment Results:**

- ▶ **Natural Treatment:** Reduced Suspended Solids SS to **0 mg/L**, indicating complete removal and full compliance with all standards.
- ▶ **Chemical Treatment (Photocatalysis):** Lowered Suspended Solids SS to **6 mg/L**, which is well below the environmental standard, demonstrating high efficiency.
- ▶ **Biological Treatment using Spirulina:** Reduced Suspended Solids SS to **2 mg/L**, also within the permissible environmental limit.
- ▶ **Integrated Multi-Stage Treatment:** Achieved an ideal result of **0 mg/L**, comparable to physical treatment.

All treatment methods proved highly effective in reducing suspended solids below the global permissible limit. Natural and integrated treatments showed the highest efficiency by achieving total Suspended Solids SS removal. Chemical and biological treatments were also highly effective, although they did not achieve complete removal.

#### **IV.3.2 Chemical Oxygen Demand COD:**

Chemical Oxygen Demand (COD) is a key indicator of water quality, as it reflects the amount of oxygen required to chemically oxidize organic and inorganic substances in water. High COD values usually indicate a high concentration of pollutants, which can be detrimental.



**Figure (IV. 07):** The COD measures for fume washing water of the TRANSCO company before and after treatment.

According to Figure IV. 07 a COD value of **203 mg/L** was recorded. This is lower than the international guidelines for incineration washing systems with **950 mg/L** but exceeds the global environmental discharge standard for industrial wastewater with **150 mg/L**, indicating a moderate organic load that must be reduced before discharge.

This elevated COD may be explained by residual organic compounds resulting from incineration. The pollutants are absorbed during the gas washing process and by-products between acidic gases and water.

#### **Treatment results:**

- ▶ **Natural (physical) treatment:** Completely removed COD, reducing it to **0 mg/L**, fully complying with both international and global environmental standards.
- ▶ **Chemical treatment (photocatalysis):** Reduced COD to **65 mg/L**, which is **within the globally permitted discharge limit**.
- ▶ **Biological treatment using *Spirulina*:** Lowered COD to **73 mg/L**, also **within the environmental discharge limit**.
- ▶ **Integrated multi-stage treatment:** Achieved an excellent result, reducing COD to **0 mg/L**.

All treatment methods reduce COD below the global environmental limit. The **natural and integrated multi-stage treatments** were the most effective, achieving complete COD removal. **Chemical and biological treatments** showed significant improvement, though they did not achieve complete elimination. These results suggest that **relying on these treatment methods ensures water quality suitable for environmentally safe discharge**.

### IV.3.3 Biochemical Oxygen Demand (BOD<sub>5</sub>) :

The five-day Biochemical Oxygen Demand (BOD<sub>5</sub>) is a key indicator of the amount of oxygen required to biologically decompose biodegradable organic matter in water by microorganisms. A high BOD<sub>5</sub> value indicates a significant organic load that can negatively impact aquatic environments.

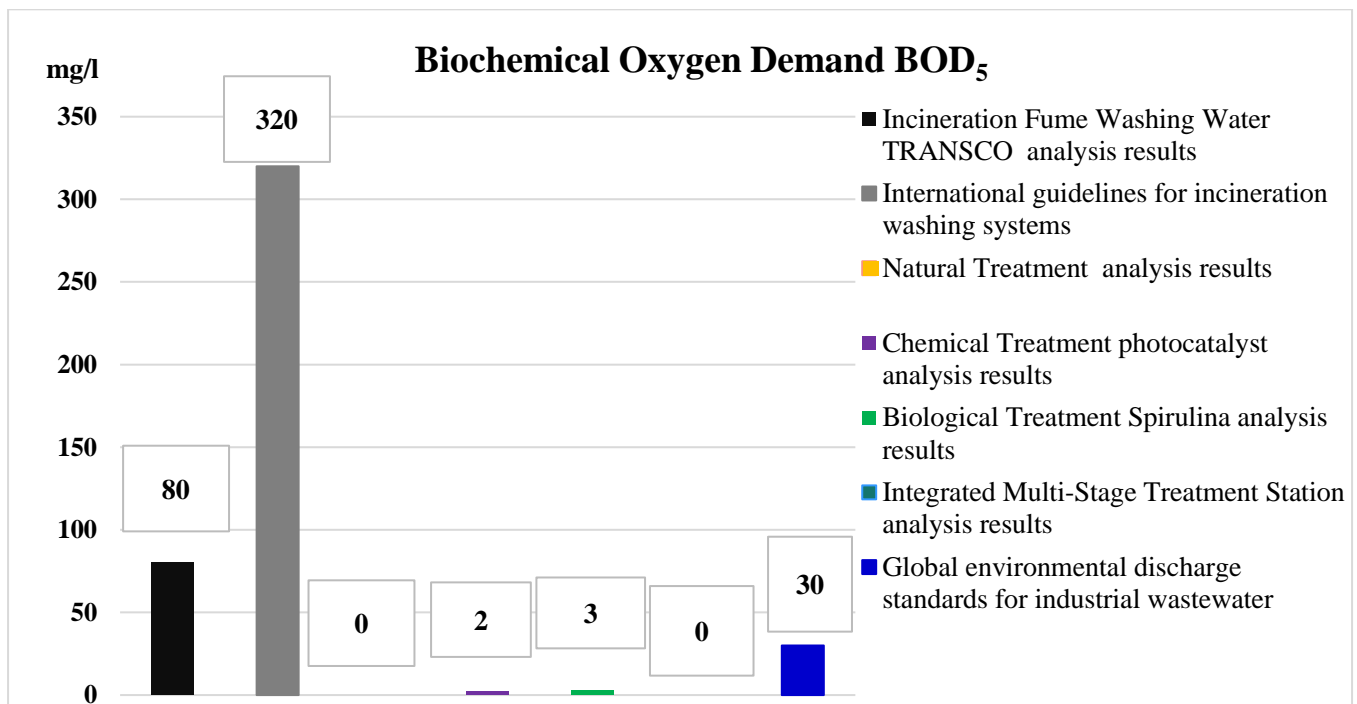


Figure (IV. 08): The BOD<sub>5</sub> measures for fume washing water of the TRANSCO company before and after treatment.

#### In the case of incineration flue gas washing water:

Through the temporal evolution of the BOD<sub>5</sub> in fig (IV. 8), we notice that the value **80 mg/L** was recorded, which is lower than the international guideline for fume washing systems **320 mg/L**, but **exceeds the global environmental discharge standard** for industrial wastewater **30 mg/L**. This indicates a moderate organic pollution load that must be reduced before discharge.

#### Treatment results:

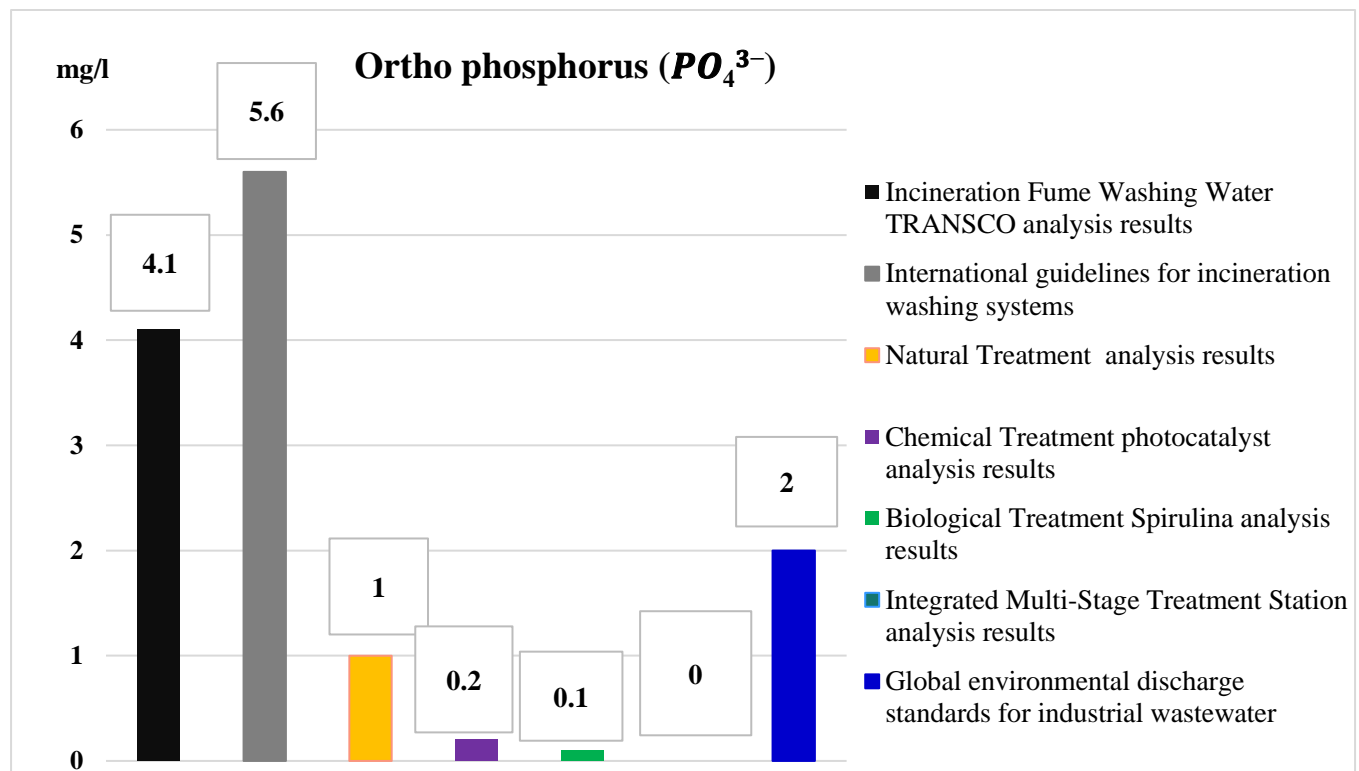
- ▶ **Natural Treatment** reduced BOD<sub>5</sub> to **0 mg/L**, which is ideal and fully compliant with all international standards.
- ▶ **Chemical Treatment (photocatalysis)** reduced BOD<sub>5</sub> to **2 mg/L**, which is well below the globally permitted limit.
- ▶ **Biological Treatment using *Spirulina***: reduced BOD<sub>5</sub> to **3 mg/L**, also within the global environmental standard.

► **Integrated Multi-Stage Treatment:** Achieved the best result, reducing BOD<sub>5</sub> to **0 mg/L**

All treatment methods reduced BOD<sub>5</sub> to below the global environmental limit of **30 mg/L**. Natural and multi-stage treatments were the most effective, eliminating BOD<sub>5</sub>. Chemical and biological treatments showed excellent results, though not zero, but still well within the allowable range.

Relying on natural or integrated multi-stage treatment appears to be the best option to ensure water quality is suitable for safe environmental discharge.

#### IV.3.4 Ortho phosphorus ( $PO_4^{3-}$ )



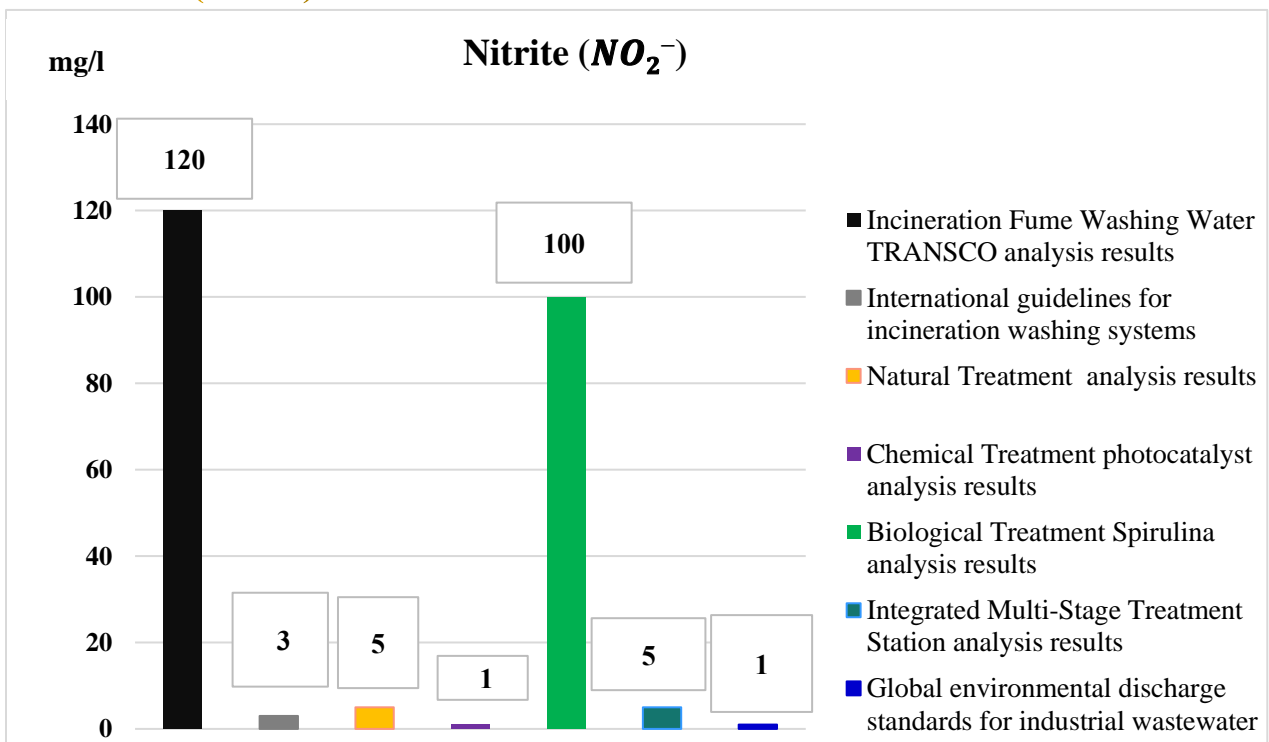
**Figure (IV. 09):** The Ortho phosphorus ( $PO_4^{3-}$ ) measures for fume washing water of the TRANSCO company before and after treatment.

Through the evolution of orthophosphate levels, we observe that the average concentration in the flue gas washing water incineration is **4.1 mg/L**, which is lower than the international guidelines for incineration washing systems **5.6 mg/L** but exceeds the global environmental discharge standard for industrial wastewater of **2 mg/L**. This indicates a moderate level of phosphorus compounds, which may contribute to eutrophication if discharged untreated into natural water bodies.

**Treatment Results:**

- ▶ **Natural Treatment:** Reduced orthophosphate to 1 mg/L, which is below the global environmental standard.
- ▶ **Chemical Treatment (Photocatalysis):** Reduced it to 0.2 mg/L, demonstrating high efficiency.
- ▶ **Biological Treatment using *Spirulina*:** Reduced it further to 0.1 mg/L, also showing excellent performance.
- ▶ **Integrated Multi-Stage Treatment:** Achieved complete removal of 0 mg/L, indicating maximum effectiveness.

All treatment methods successfully reduced orthophosphate levels below the global discharge standard of 2 mg/L. Integrated multi-stage and biological treatments were the most effective, achieving near or total elimination. Even natural and chemical treatments delivered results well within safe discharge limits. Ortho phosphate, a key nutrient that can contribute to water pollution, was effectively treated by all methods. However, the integrated multi-stage system and biological treatment using *Spirulina* proved to be the most efficient. These methods are particularly recommended for preventing nutrient pollution and eutrophication in receiving water bodies.

**IV.3.5 Nitrite ( $NO_2^-$ )**

**Figure (IV. 10):** The nitrite ( $NO_2^-$ ) measures for fume washing water of the TRANSCO company before and after treatment.

Based on the evolution of nitrite levels shown in Figure (IV.10), the average nitrite concentration in the flue gas washing water is approximately **120 mg/L**, which is extremely high compared to both international guidelines for flue gas scrubbing systems (**3 mg/L**) and the global standard for industrial wastewater discharge **1 mg/L**. This indicates significant nitrogen pollution, which could be attributed to incomplete oxidation of nitrogenous compounds during combustion or subsequent washing.

#### **Treatment Results:**

- ▶ **Natural Treatment:** Reduced nitrite concentration to **5 mg/L**, a notable improvement but still above environmental standards.
- ▶ **Chemical Treatment (Photocatalysis):** Reduced nitrite to **1 mg/L**, which is exactly at the permitted environmental limit, making it acceptable.
- ▶ **Biological Treatment Using Spirulina:** Reduced nitrite to **100 mg/L**, which remains very high, indicating low effectiveness in removing this contaminant.
- ▶ **Multistage Treatment:** Reduced nitrite to **5 mg/L**, showing partial improvement, but still not meeting global standards.

Only the chemical treatment using photocatalysis was successful in reducing nitrite levels to the globally accepted limit of **1 mg/L**. Natural and multistage treatments showed partial but insufficient effectiveness in achieving environmental standards.

Biological treatment was the least effective in reducing nitrite. Cause in a Spirulina-based treatment system, the optimal conditions (such as sufficient oxygen and appropriate pH) may not be present to support the activity of Nitrobacter, the bacteria responsible for converting nitrite to nitrate. so nitrite accumulation occurs.

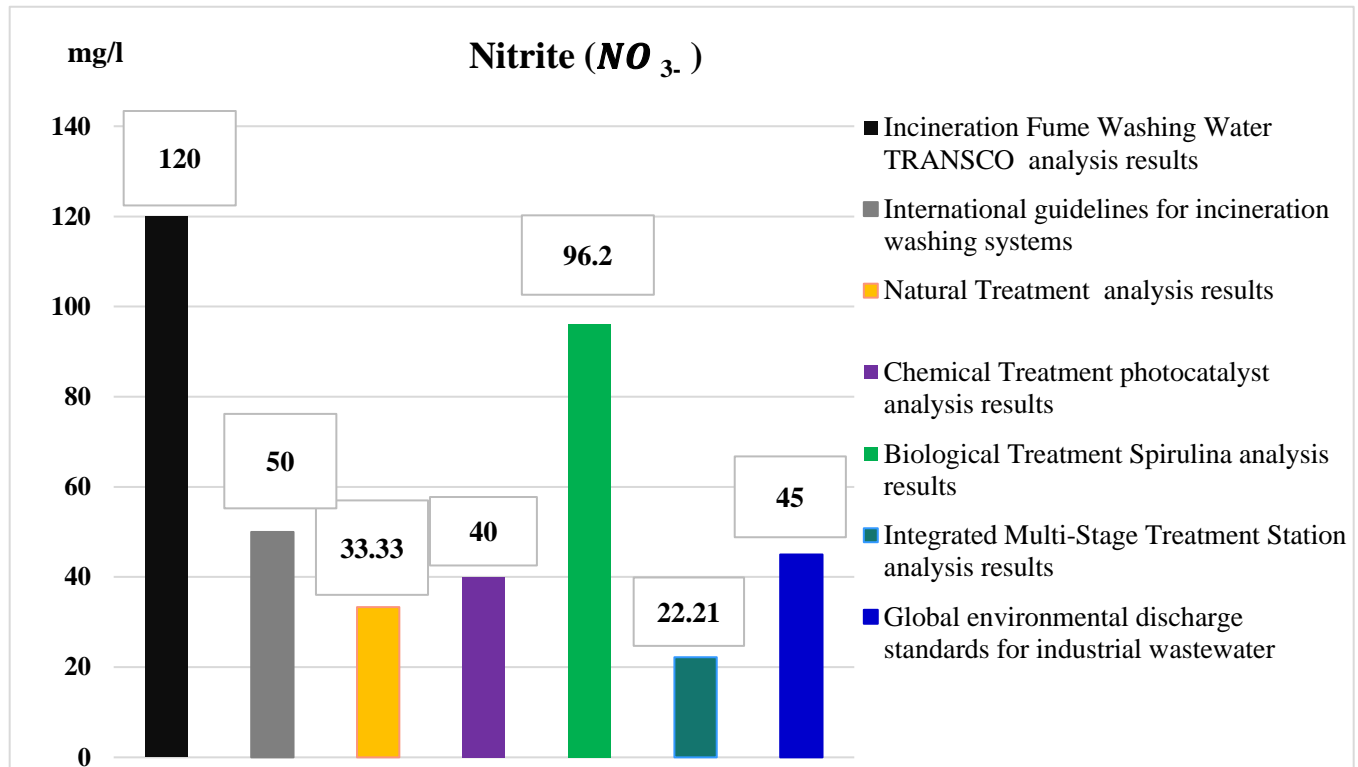
IV.3.6 Nitrate ( $NO_3^-$ )

Figure (IV. 11): The nitrate ( $NO_3^-$ ) measures for fume washing water of the TRANSCO company before and after treatment.

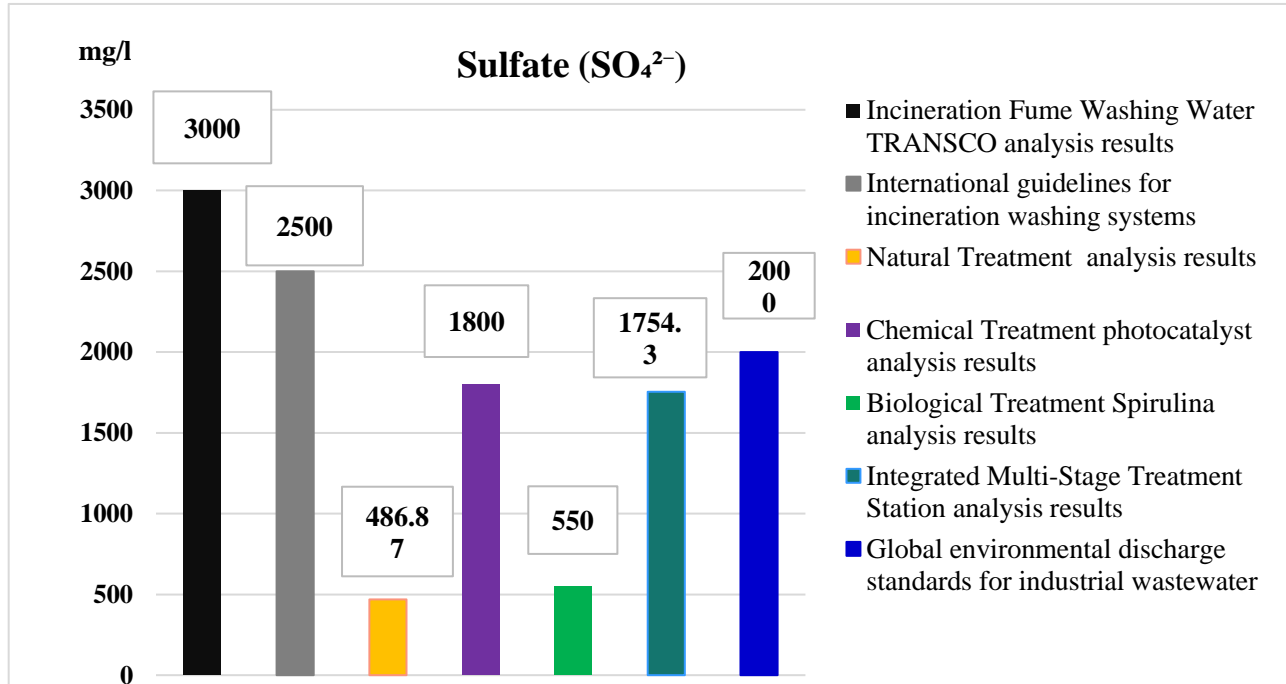
From Figure (IV.11), we observe that the average concentration of nitrate ( $NO_3^-$ ) in the flue gas washing water from incineration processes is approximately **120 mg/L**, which significantly exceeds both the international guideline for incineration washing systems **50 mg/L**, and the global discharge standard for industrial wastewater **45 mg/L**. This high nitrate level suggests substantial nitrogen contamination, likely resulting from the oxidation of nitrogenous compounds during combustion or water washing.

#### Treatment Results:

- ▶ **Natural treatment** reduced nitrate levels to **33.33 mg/L**, which meets both the international guideline and global discharge standards.
- ▶ **Chemical treatment using photocatalysis** achieved a concentration of **40 mg/L**, also within acceptable environmental limits.
- ▶ **Biological treatment using Spirulina** only lowered the concentration to **96.2 mg/L**, indicating **low efficiency** in nitrate removal.
- ▶ **The integrated multi-stage treatment station** yielded **22.212 mg/L**, the **most effective result**, significantly below the regulatory thresholds.

All treatment methods except biological treatment effectively reduced nitrate concentrations to meet or exceed global environmental standards, with the integrated multi-stage system demonstrating the highest efficiency. Conversely, the biological treatment method was the least effective, suggesting a need for optimization or combination with other techniques for nitrate removal.

### IV.3.7 Sulfate ( $\text{SO}_4^{2-}$ )



**Figure (IV. 12):** The Sulfate ( $\text{SO}_4^{2-}$ ) measures for fume washing water of the TRANSCO company before and after treatment.

According to the data in Figure (IV.10), the concentration of sulfate ( $\text{SO}_4^{2-}$ ) in the raw flue gas washing water reaches **3000 mg/L**, which is notably higher than both the international guideline for incineration washing systems of **2500 mg/L** and the global discharge standard for industrial wastewater of **2000 mg/L**. This elevated level reflects significant sulfur-based contamination, likely due to sulfur compounds present in the waste or fuel used during combustion.

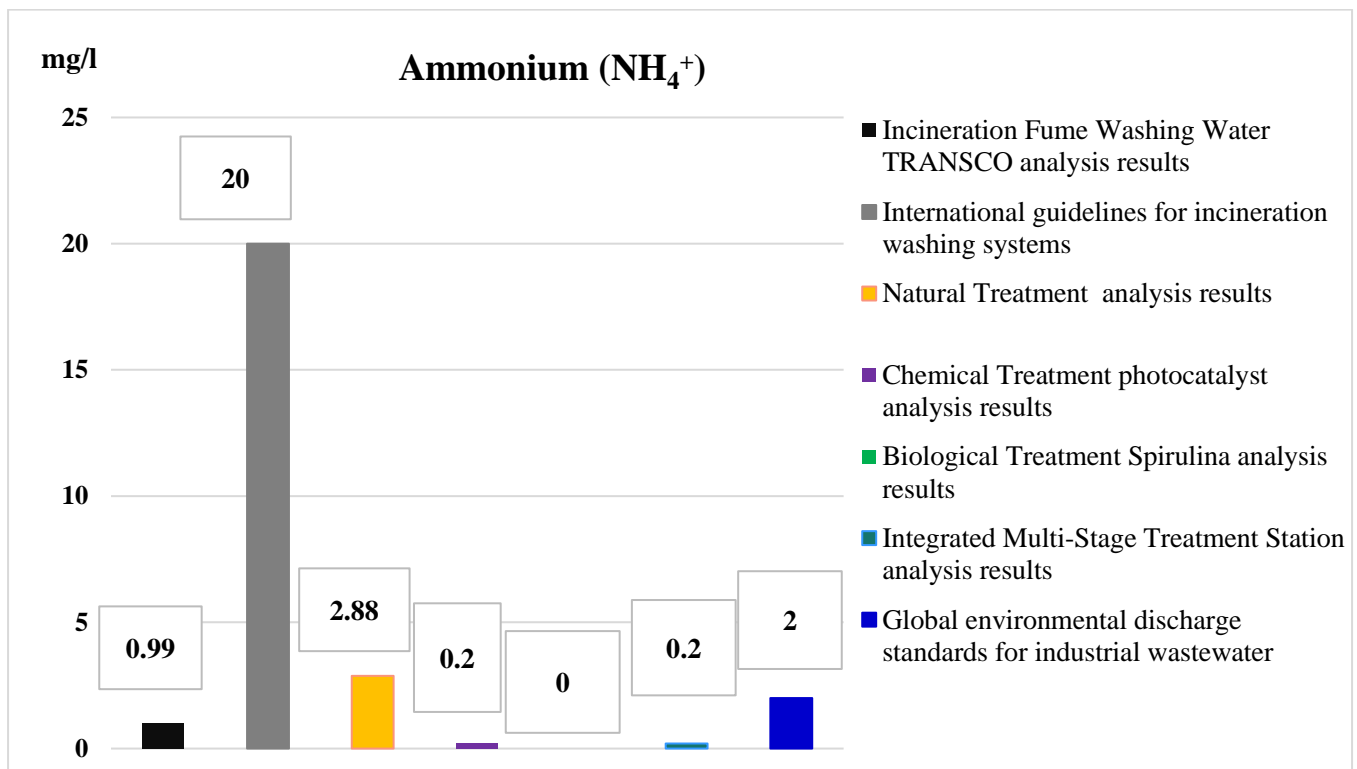
#### Treatment Results:

- ▶ **Natural treatment** reduced sulfate levels to **468.87 mg/L**, representing a substantial reduction and bringing the concentration well below both regulatory limits.
- ▶ **Chemical treatment** using photocatalysis decreased sulfate to **1800 mg/L**, making it compliant with both international and global standards.

- ▶ **Biological treatment** using Spirulina showed a reduction to **550 mg/L**, which is also well within acceptable environmental discharge limits.
- ▶ **Integrated multi-stage treatment** resulted in **1754.3 mg/L**, successfully meeting environmental discharge standards.

All four treatment methods proved effective in reducing sulfate concentrations to within or below environmental standards. The natural treatment demonstrated the highest removal efficiency, followed by biological treatment. While chemical and integrated treatments achieved acceptable results, their performance was slightly less efficient in comparison, suggesting that natural or biological approaches may be particularly well-suited for sulfate removal in this context

### IV.3.8 Ammonium ( $\text{NH}_4^+$ )



**Figure (IV. 13):** The Ammonium ( $\text{NH}_4^+$ ):measures for fume washing water of the TRANSCO company before and after treatment.

Based on the data in Figure IV.13, the initial ammonium concentration in the incineration flue gas washing water is 0.9989 mg/L, which is already well below the international guideline of 20 mg/L and the global environmental discharge standard of 2 mg/L. Despite the relatively low initial level, further reductions were achieved through treatment processes.

### Treatment Results:

- ▶ **Natural treatment** slightly increased the concentration to **2.88 mg/L**, which **exceeds the global standard** and suggests potential **regeneration or release** of ammonium during the process.
- ▶ **Chemical treatment using photocatalysis** significantly reduced the ammonium level to **0.2 mg/L**, well within both international and global standards.
- ▶ **Biological treatment using Spirulina** achieved **complete removal**, reducing ammonium to **0 mg/L**, representing **the highest efficiency** among all methods.
- ▶ **Integrated multi-stage treatment** also reduced the concentration to **0.2 mg/L**, meeting all environmental requirements.

Although the initial ammonium concentration was low and within safe limits, the **biological treatment using Spirulina** achieved complete removal, demonstrating the **best performance**. **Chemical and integrated treatments** were also highly effective. However, the **natural treatment method showed an unexpected increase**, exceeding the discharge limit, which suggests it may be unsuitable for ammonium removal without further optimization.

### **IV.3.9. Identifying Heavy Metal Pollution**

The presence of heavy metals in incineration fume washing water is a critical indicator of industrial contamination and represents a potential threat to both environmental and human health. These metals, such as lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), and others, are persistent, non-biodegradable pollutants that can accumulate in ecosystems and be biomagnified through the food chain.

In this study, the detection and quantification of heavy metals were performed using X-ray fluorescence analysis and was conducted on **21/12/2024**, and Atomic Absorption Spectroscopy (AAS) was conducted on **4/2/2025**. These complementary analytical techniques allowed for the precise identification of both the type and concentration of metallic contaminants.

#### ✓ **Results of Raw Samples of X-Ray Fluorescence (XRF) Analysis**

According to the data in Table IV.1, it's revealed that raw incineration fume washing water contains elevated levels of zinc and sulfur, which are byproducts caused by the composition of the incinerated waste.

Other toxic heavy metals such as lead, arsenic, mercury, nickel, and cadmium were below detection limits, indicating that significant contamination by these metals is not present in the samples.

The very high sulfur concentration (exceeding 8000 ppm in the darker sample) requires targeted removal through specialised sulfate treatment processes.

The high zinc content also necessitates the application of efficient treatment technologies such as ion exchange, chemical precipitation, or nanofiltration to bring concentrations within acceptable environmental limits.

**Table IV.1:** Comparison Table of Heavy Metal Analysis in Incineration Fume Washing Water vs. International Standards for Industrial Wastewater Discharge WHO

Element	Dark Sample (ppm)	Light Sample (ppm)	Permissible Limit (WHO/Industrial) (ppm)	Observation
<b>Zn (Zinc)</b>	42.184	24.948	3–5	Very high in both samples
<b>Pb (Lead)</b>	<LOD	<LOD	0.01	Not detected (Safe)
<b>Hg (Mercury)</b>	<LOD	<LOD	0.001 – 0.005	Not detected (Safe)
<b>Cd (Cadmium)</b>	<LOD	<LOD	0.003	Not detected (Safe)
<b>As (Arsenic)</b>	<LOD	<LOD	0.01	Not detected (Safe)
<b>Ni (Nickel)</b>	<LOD	<LOD	0.02 – 0.07	Not detected (Safe)
<b>Cr (Chromium)</b>	<LOD	<LOD	0.05	Not detected (Safe)
<b>Cu (Copper)</b>	<LOD	<LOD	2	Not detected (Safe)
<b>Fe (Iron)</b>	<LOD	<LOD	0.3	Not detected (Safe)
<b>Mn (Manganese)</b>	<LOD	<LOD	0.1	Not detected (Safe)
<b>Ca (Calcium)</b>	166.952	129.057	Not specified (non-toxic)	Safe, natural concentration
<b>K (Potassium)</b>	265.174	139.510	Not specified (non-toxic)	Safe
<b>S (Sulfur)</b>	8260.134	6630.849	Not specified (elevated)	Very high, requires further evaluation

#### ✓ Results of Raw Samples of Atomic Absorption Spectroscopy (AAS) Analysis

According to the data in Table IV. 2 The chemical analysis of heavy metals in the liquid samples using Atomic Absorption Spectroscopy (AAS) revealed a clear exceedance of international industrial discharge standards.

The highest concentration was recorded for iron (Fe), ranging from 117.3 to 123.4 mg/L, which exceeds the permissible limit (1.0 – 5.0 mg/L) by more than 20 times. Nickel (Ni) also showed a

wide variation in concentration, from 6.3 to 45.9 mg/L, significantly surpassing the global standard (0.5 – 2.0 mg/L), indicating the presence of severe metal contamination.

Lead (Pb) concentrations ranged from 12.4 to 17.7 mg/L, while the permissible limit does not exceed 0.5 mg/L. This represents a major environmental and health threat due to lead's high toxicity even at low concentrations. Copper (Cu) was detected at concentrations between 5.2 and 12.6 mg/L, also exceeding the allowed limits, though to a lesser extent. Finally, cobalt (Co) exceeded the permissible threshold, reaching up to 2.4 mg/L compared to the global limit of 1.0 mg/L.

These results highlight the urgent need for advanced water treatment before discharge, especially in cases of high contamination concentrations.

**Table IV.2:** Comparison Table of Heavy Metal Analysis in Incineration Fume Washing Water vs. International Standards for Industrial Wastewater Discharge WHO

Element	Concentration in Sample (mg/L)	Global Standard (mg/L)	Result	Note
Ni (Nickel)	6.323 – 45.93	0.5 – 2.0	Very High	Exceeds permissible limit
Pb (Lead)	12.40 – 17.73	0.1 – 0.5	Very High	Highly toxic pollutant
Fe (Iron)	117.3 – 123.4	1.0 – 5.0	Very High	Possible signal saturation
Cu (Copper)	5.234 – 12.62	0.5 – 2.0	High	Requires treatment
Co (Cobalt)	0.7178 – 2.404	0.1 – 1.0	Slightly High	Slight exceedance

#### ✓ Comparison Between XRF and AAS Results

Comparison Between XRF and AAS Results for Two Samples. The results revealed clear differences between the two techniques in terms of both the detected metallic elements and the measured concentrations.

In the XRF analysis, several elements were detected, including iron (Fe), zinc (Zn), calcium (Ca), and silicon (Si), none of which were identified in the AAS results. On the other hand, the AAS analysis revealed the presence of elements like nickel (Ni), copper (Cu), and cobalt (Co), some at higher or more accurate concentrations compared to those observed in the XRF data.

These differences can be explained by several factors:

- XRF measures the total elemental content in the sample, whether in dissolved or suspended form. It is often affected by the presence of fine particles or undissolved residues, which makes it more suitable for solid samples or liquids with suspended matter.
- Due to the absence of pre-sorting, all the hazardous and special hazardous waste received from the various institutions contracted with TRANSCO is incinerated as-is. Consequently, the composition of the incinerated wastewater varies depending on the differing nature of the incoming materials."
- AAS, in contrast, measures only the dissolved fraction of each element in the liquid, usually after sample preparation and filtration, making it more accurate for detecting soluble and bioavailable metal concentrations.
- Additionally, each technique has a different sensitivity to certain elements. AAS is generally more precise for heavy metals at low concentrations, whereas XRF is better at detecting elements at higher concentrations but is less sensitive at trace levels.

✓ **Results of chemical analysis of heavy metals for different treatments of incineration fume washing water.**

**"The analysis of heavy metal concentrations in the incineration washing water, following the selected treatment methods, is still ongoing."**

#### IV.4. Final Evaluation of Treatment Methods

✓ **Final Score Formula:**

$$\text{Final Score} = (\text{Compliance} \times 0.6) + (\text{Effectiveness} \times 0.25) + (\text{Ease \& Cost} \times 0.15)$$

**1) Integrated Multi-Stage Treatment**

- Compliance:  $12/13 = 92\%$
- Effectiveness:  $96\%$
- Ease & Cost:  $60\%$

$$\begin{aligned} \text{Final Score} &= (92 \times 0.6) + (96 \times 0.25) + (60 \times 0.15) \\ &= 55.2 + 24 + 9 \\ &= 88.2\% \rightarrow \mathbf{88\%} \text{ (rounded)} \end{aligned}$$

**2) Physical – Natural Treatment**

- Compliance: 10/13 = 77%
- Effectiveness: 95%
- Ease & Cost: 100%

$$\begin{aligned}\text{Final Score} &= (77 \times 0.6) + (95 \times 0.25) + (100 \times 0.15) \\ &= 46.2 + 23.75 + 15 \\ &= 84.95\% \rightarrow \mathbf{85\%} \text{ (rounded)}\end{aligned}$$

**3) Chemical Treatment (Photocatalyst)**

- Compliance: 11/13 = 85%
- Effectiveness: 90%
- Ease & Cost: 65%

$$\begin{aligned}\text{Final Score} &= (85 \times 0.6) + (90 \times 0.25) + (65 \times 0.15) \\ &= 51 + 22.5 + 9.75 \\ &= 83.25\% \rightarrow \mathbf{83\%} \text{ (rounded)}\end{aligned}$$

**4) Biological Treatment (Spirulina)**

- Compliance: 9/13 = 69%
- Effectiveness: 70%
- Ease & Cost: 75%

$$\begin{aligned}\text{Final Score} &= (69 \times 0.6) + (70 \times 0.25) + (75 \times 0.15) \\ &= 41.4 + 17.5 + 11.25 \\ &= 70.15\% \rightarrow \mathbf{70\%} \text{ (rounded)}\end{aligned}$$



# *General Conclusion*

### General Conclusion

The analysis of flue gas washing water generated from the incineration of special and hazardous waste revealed extremely harsh physicochemical characteristics. These included significantly low pH values (strong acidity), high turbidity and suspended solids, elevated concentrations of sulfates, nitrites, and nitrates, as well as high chemical and biological oxygen demand (COD and BOD<sub>5</sub>). Such parameters indicate a highly polluted effluent that necessitates the implementation of advanced and targeted treatment strategies.

X-ray fluorescence (XRF) analysis revealed notably high concentrations of zinc and sulfur, with sulfur exceeding 8000 ppm in the darker sample, underscoring the urgent need for targeted sulfate removal. While initial screening showed levels of lead, arsenic, mercury, nickel, and cadmium to be below detection limits, more sensitive analysis using Atomic Absorption Spectroscopy (AAS) revealed critical exceedances of permissible discharge thresholds. Iron reached concentrations of 123.4 mg/L—more than 20 times the allowable limit—while nickel (45.9 mg/L), lead (17.7 mg/L), copper (12.6 mg/L), and cobalt (2.4 mg/L) all exceeded accepted environmental limits. These findings highlight the necessity of adopting advanced and robust treatment technologies capable of reducing both heavy metals and sulfur levels before safe discharge.

A comprehensive evaluation of several treatment approaches, benchmarked against international environmental standards, was conducted using a dual-criteria framework, pollutant removal efficiency and operational feasibility

- ✓ The integrated multi-stage treatment system demonstrated the highest overall performance, achieving an effectiveness score of 88%, due to its balanced combination of multiple treatment phases and high pollutant removal capacity. This renders it the most suitable option for treating complex wastewater matrices.
- ✓ Natural treatment methods received a commendable score of 85%, attributed to their operational simplicity, cost-effectiveness, and efficient removal of most physical and chemical pollutants. However, they remained less effective in removing nitrogen-based compounds (NO<sub>2</sub><sup>-</sup> and NO<sub>3</sub><sup>-</sup>), which continued to pose a challenge.
- ✓ Chemical treatment via photocatalysis exhibited high pollutant removal efficiency, earning a slightly lower score of 80% due to its technical complexity and relatively high operational costs.

- ✓ Biological treatment employing *Spirulina* received a score of 70%. Although promising, its performance was constrained by filtration issues and nitrite accumulation, indicating the need for improved system design to enhance overall efficiency.

Based on these results, it is strongly recommended to prioritize multi-stage treatment systems to achieve optimal outcomes. Alternatively, the development of hybrid systems combining simplicity and efficiency is advisable to ensure both environmental and economic sustainability.

### Study Perspectives

Given the physicochemical properties of the incineration fume washing water from special and hazardous waste, it is evident that this effluent represents a substantial source of environmental pollution, particularly due to its high content of heavy metals and organic contaminants. These findings open several research and development avenues, notably:

- Development of effective, locally adapted treatment technologies capable of addressing the specific composition of incineration wastewater.
- Design of innovative hybrid systems that combine the operational simplicity of natural treatments with the efficacy of chemical and biological methods.
- Investigation into the long-term environmental impacts of improperly treated effluent, particularly on soil and groundwater systems.
- Enhancement of monitoring and control tools to enable real-time and accurate assessment of treated water quality.

### Recommendations for Transco Company

Based on the results of the analysis and comparative evaluation of different treatment technologies, the study recommends the following measures for Transco:

- Adopt the integrated multi-stage treatment system as a primary solution, owing to its high efficiency and comprehensive pollutant removal capacity.
- Provide technical training and certification for personnel operating and maintaining the treatment units, with emphasis on industrial safety and proper handling of hazardous materials.
- Ensure full compliance with international discharge standards such as WHO guidelines and the ISO 14001 environmental management system.

- Integrate real-time monitoring and automated control systems to ensure continuous quality assurance and prevent regulatory violations.
- Promote internal research and collaboration with academic institutions to improve the performance of physical and biological treatment methods and to develop locally sustainable solutions.
- Work proactively to reduce the environmental footprint by ensuring the treatment of contaminated water before discharge and maintaining a safe working environment for technical and operational staff.



# *Appendices*

# Appendices

## Technical Data Sheet: Clay (الطين)

Natural earthy material composed of fine minerals, widely used for its plasticity and filtration properties.

- ✓ **Scientific Name:** Clay minerals (Kaolinite, Illite, Montmorillonite)
- ✓ **Type:** Natural sedimentary material
- ✓ **Form:** Fine powder, sticky when wet
- ✓ **Color:** Gray, brown, red, white (varies)
- ✓ **Main Components:** Silica ( $\text{SiO}_2$ ), Alumina ( $\text{Al}_2\text{O}_3$ )
- ✓ **Properties:** Fine-grained, plastic when wet, hard when dry



## Technical Data Sheet: Lime (الجير)

A reactive mineral binder used in construction and water treatment, available in quicklime and slaked lime forms.

- ✓ **Chemical Names:**

**Quicklime:** Calcium Oxide ( $\text{CaO}$ )

**Slaked Lime:** Calcium Hydroxide ( $\text{Ca(OH)}_2$ )

- ✓ **Type:** Inorganic binder
- ✓ **Form:** White powder or lumps
- ✓ **Solubility:** Slightly soluble, reactive in water
- ✓ **Use:** pH adjustment, coagulation in water treatment



## Technical Data Sheet: Chelabo (الكلايو)

A common natural rock composed mainly of calcium carbonate, used in water treatment and agriculture.

- ✓ **Common Names:** Chelabo, Agricultural Lime, Calcareous Stone, Agricultural Lime, Calcium Carbonate Stone
- ✓ **Chemical Formula:**  $\text{CaCO}_3$
- ✓ **Type:** Natural sedimentary rock
- ✓ **Appearance:** White to light gray stone or powder
- ✓ **Properties:** Alkaline, low solubility in water



## Technical Data Sheet: Spirulina

(سپيروئينا)

A nutrient-rich cyanobacterium (microalga) used for its adsorption capacity in bioremediation.

- ✓ **Scientific Name:** *Arthrospira platensis* / *maxima*
- ✓ **Type:** Blue-green microalga (Cyanobacteria)
- ✓ **Form:** Powder, flakes, capsules
- ✓ **Color:** Deep green to blue-green
- ✓ **Use:** Bio-remediation, nutrient adsorption
- ✓ **Taste:** Mild earthy flavor



## Technical Data Sheet: Activated Charcoal

(الفحم النشط)

Highly porous form of carbon used for its strong adsorption capacity to remove contaminants.

- ✓ **Scientific Name:** Activated Carbon (C)
- ✓ **Type:** Adsorbent material
- ✓ **Form:** Fine black powder or granules
- ✓ **Odor/Taste:** Odorless, tasteless
- ✓ **Use:** Adsorption of pollutants and heavy metals



## Technical Data Sheet: Titanium Dioxide

(ثاني أكسيد التيتانيوم)

A white pigment with photocatalytic properties, used in advanced water purification systems.

- ✓ **Common Names:** Titania, Titanium White
- ✓ **Chemical Formula:**  $TiO_2$
- ✓ **Form:** Fine white powder
- ✓ **Density:**  $\sim 4.23 \text{ g/cm}^3$
- ✓ **Melting Point:**  $1843 \text{ }^\circ\text{C}$
- ✓ **Use:** Photocatalysis, advanced water treatment



## Technical Data Sheet: Alum (الشيْب)

A chemical coagulant is widely used in water treatment to aggregate suspended particles and improve clarity.

- ✓ **Chemical Name:** Potassium Aluminum Sulfate (KAl(SO<sub>4</sub>)<sub>2</sub>·12H<sub>2</sub>O)
- ✓ **Type:** Inorganic coagulant
- ✓ **Form:** White crystalline solid or powder
- ✓ **Solubility:** Soluble in water
- ✓ **Properties:** Acidic pH, strong coagulating effect
- ✓ **Use:** Coagulation in water and wastewater treatment



## Technical Data Sheet: Sand (الرمل)

A granular material mainly composed of quartz (SiO<sub>2</sub>), commonly used as a filtration medium.

- ✓ **Chemical Formula:** Silicon Dioxide (SiO<sub>2</sub>)
- ✓ **Type:** Natural granular material
- ✓ **Color:** White to brown
- ✓ **Density:** 1600–1800 kg/m<sup>3</sup>
- ✓ **Hardness:** 6–7 (Mohs scale)
- ✓ **Use:** Filtration media



## Technical Data Sheet: Wood Shavings (نشارة الخشب)

A natural, biodegradable material produced from planing or cutting wood, used as a filtration medium or absorbent.

- ✓ **Type:** Organic natural material
- ✓ **Form:** Fine to coarse fibrous shavings
- ✓ **Color:** Light to dark brown (depends on wood type)
- ✓ **Texture:** Lightweight, soft, fibrous
- ✓ **Properties:** Porous, biodegradable, good adsorptive capacity
- ✓ **Use:** Filtration, support media in biofilters, absorption of contaminants



## Technical Data Sheet: Palm Fiber (ألياف النخيل)

A natural fiber extracted from palm fronds, characterised by its coarse texture and strong fiber. It is an eco-friendly and renewable material.

- ✓ **Name:** Palm Fiber
- ✓ **Type:** Natural fiber (plant-based)
- ✓ **Origin:** Extracted from palm fronds
- ✓ **Appearance:** Light to dark brown, coarse with long fibers
- ✓ **Density:** Low
- ✓ **Flexibility:** Moderate to low
- ✓ **Moisture Resistance:** Medium
- ✓ **Biodegradability:** Fully biodegradable
- ✓ **Common Uses:** Filtration media, biofilm carrier in bioreactors, erosion control, eco-friendly composites



# Technical Data Sheet: Multi-Stage Treatment System

A compact water treatment unit inspired by advanced osmosis filtration systems. It is designed to enhance sedimentation through engineered flow and multi-layered filtration media.

- ✓ **Name:** Multi-Stage Treatment System
- ✓ **Type:** Passive filtration and sedimentation unit
- ✓ **Structure:** Plastic tank (80 liters) equipped with an internal guiding tube
- ✓ **Tank Capacity:** 80 liters
- ✓ **Internal Tube:** Length: 30 cm, Diameter: 40 cm, Material: PVC plastic

## 🌀 Purpose of the Internal Tube:

To simulate deep sedimentation zones by directing flow through vertical media layers, inspired by osmosis-based filtration systems.

## 🌀 Internal Media Configuration (from bottom to top):

1. **Pure gauze fabric (30%):** Bottom layer with an approximate length of **2.5 meters**, used for fine particle filtration.
2. **Granular activated carbon (10%):** Approximate weight of **4 kg**, for adsorption of organic matter and chemical pollutants.
3. **Clean sand (30%):** Approximate weight of **36 kg**, to settle fine suspended particles.
4. **Medium-sized gravel (30%):** Approximate weight of **43 kg**, to support upper layers and enhance flow stability.

## 🌀 Key Features:

- Promotes laminar flow and deep sedimentation
- Supports multi-layer treatment with various filtering media
- Innovative design allowing integration of additional filters if needed

## 🌀 Applications:

- Treatment of industrial wastewater



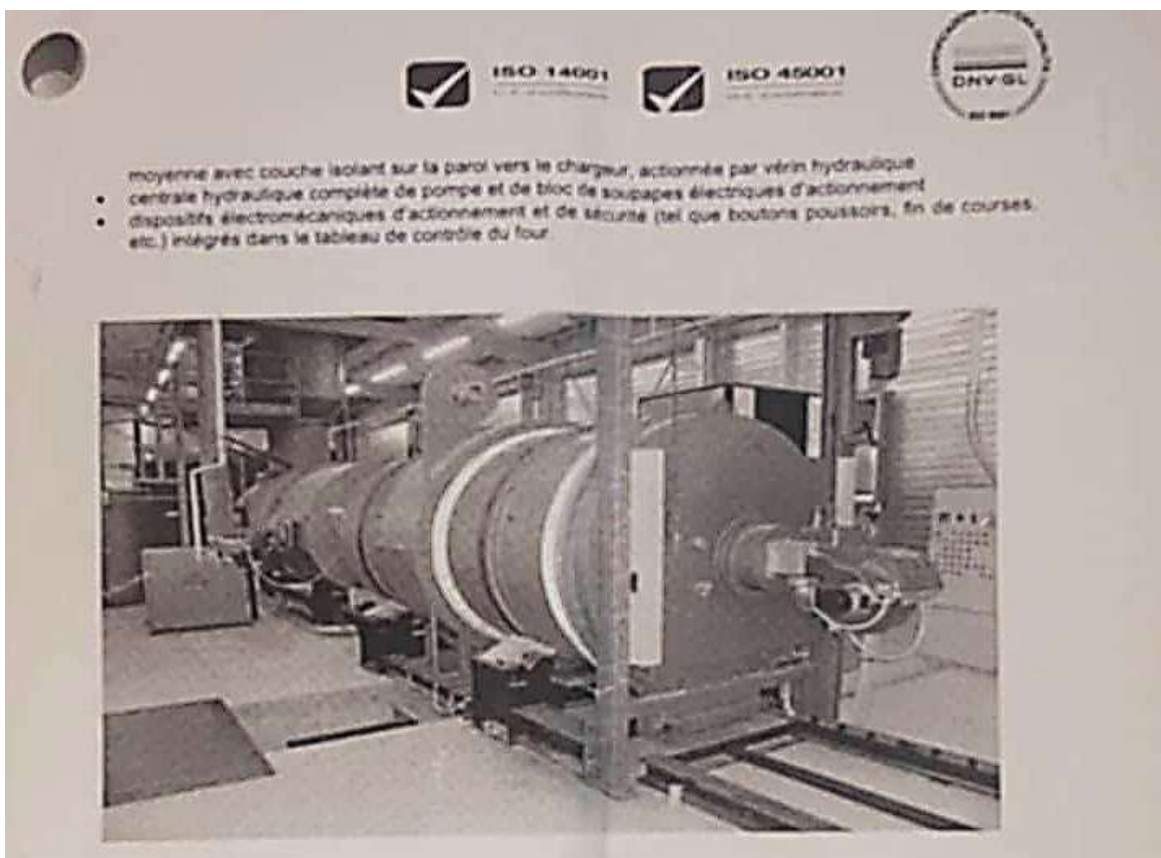
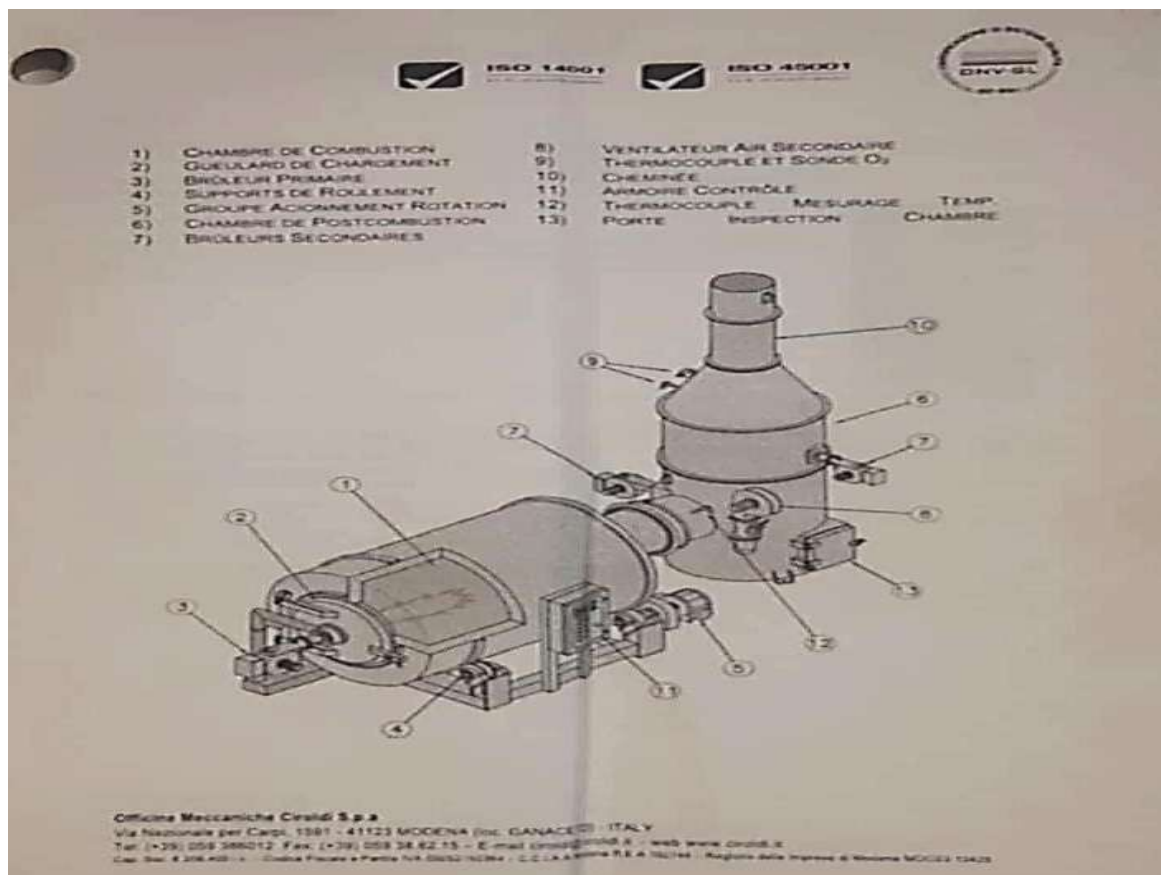
*Photos of hazardous and especially hazardous waste storage areas at Transco*



*Photos of specific areas within the Transco facility*



## Transco Incinerator



## *Transco Sterilization System 1000 kg /h*

### **AKR 500A-1000A-1500A POST-SHREDDED**

### **SYSTEMS FOR CENTRALIZED COLLECTING PLANTS**

#### **MEDICAL WASTE STERILIZATION SYSTEM WITH POST-SHREDDED AUTOCLAVE METHODS**

6log10 Microbial Inactivation.

Inspection Report as per International Standards  
(Robert Koch Institute & STAATT Level IV etc.)

International Standards including CE, ASME, EAC.

Up to 80% Volume Reduction.

Capacities from 500Kg to 1800Kg per hour.

Autoclave and Shredder are separated from each other.

Ideal for Big Plants.

Turn-key Solutions.

Multiple Safety Control Features.

Advanced Reporting and Monitoring Features.



*Some tools that assisted us in the project*



## Quality Analysis: The incoming water to Transco

Zone : Ouargla  
Unité : Ouargla

Ministre des ressources en eau  
Algérien des eaux  
Laboratoire de contrôle de la qualité des eaux

### Bulletin d'analyses

Code de l'échantillon :  
Nature de l'échantillon : EAU DE FORAGE  
Lieu de prélèvement : EAU DE FORAGE SARL TRANS CO  
Commune : OGX

Date et Heure de prélèvement : 20/03/2024  
Prélèvement effectué par : Demandeur  
Date d'analyse : 20/03/2024  
Analyse effectuée par : Laboratoire Central

Paramètre Organique	Unité	Résultat	N.A (E.I)	Minéralisation Global	Unité	Résultat	N.A (E.I)
Couleur	mg/plaine	00	15	Calcium Ca <sup>2+</sup>	mg/l	136.27	200
Odeur à 25 C°	Taux dilution	Néant	04	Magnésium Mg <sup>2+</sup>	mg/l	92.35	150
Saveur à 25 C°	Taux dilution	Néant	04	Dureté Totale (TH)	CaCO3 mg/l	720	500
Chlore résiduel libre	mg/l	BRUTE	>0.1	Sodium Na <sup>+</sup>	mg/l	205	200
Paramètre Physique-Chimique	Unité	Résultat	N.A (E.I)	Potassium K <sup>+</sup>	mg/l	16.38	12
Concentration en ions hydrogène	Unité PH	7.92	≥6.5 et ≤ 9	Chlorures Cl <sup>-</sup>	mg/l	466.56	500
Conductivité à 25C°	µs/cm	2340	2800	Sulfate SO <sub>4</sub> <sup>2-</sup>	mg/l	364	400
Température	C°	/	25	Nitrate NO <sub>3</sub> <sup>-</sup>	mg/l	12.68	50
Turbidité	NTU	2.27	5	Bicarbonate HCO <sub>3</sub> <sup>-</sup>	mg/l	167.31	-
Oxygène dissous	mg/l	/	-	Titre alcalimétrique complet (TAC)	mg/l CaCO3	137.14	-
TDS	mg/l	1167	-				
Résidu sec 105 C°	mg/l	1534	-				
Paramètres de Pollution	Unité		N.A (E.I)	Paramètre Indésirables	Unité	Résultat	N.A (E.I)
Ammonium NH <sub>4</sub> <sup>+</sup>	mg/l	0.056	0.5	Fer	mg/l	00	0.3
Nitrite NO <sub>2</sub>	mg/l	0.019	0.2	Manganèse	mg/l	/	0.05
Phosphore (p)	mg/l	<0.005	5	Aluminium	mg/l	/	0.2
Oxydabilité	mg/l		5				
Paramètre bactériologiques	Unité	Résultat	N.A (E.I)	Paramètre Ioniques	Unité	Résultat	N.A (E.I)
Coliformes totaux	/	/	/	Fluorures (F)	mg/l	/	1.5
Escherichia-coli	n/100ml	/	00	Cyanures (CN)	µg/l	/	70
Entérocoques	n/100ml	/	00	Bromes (Br)	mg/l	/	
Bactéries Sulfito-réductrices	n/20ml	/	00	Sulfure d'hydrogénée (H <sub>2</sub> S)	mg/l	/	
Observation							

N.A Norme Algérienne relative au décret exécutif N° 14-96

E.T : Eau Traitée

Siège Laboratoire :

Tél :

Fax :

Site web : [www.ade.dz](http://www.ade.dz)





**ANRH Laboratory, Ouargla – National Agency for Water Resources.**



**CRAPC, Ouargla – Centre for Research in Analytical Chemistry and Physics.**



**Entreprise de Chaudronnerie et de Ferblanterie d'Alger,**



**National Waste Agency**



**Office national de l'assainissement**

سوناطراک



sonatrach

**Sonatrach**

**Basin of Berkaoui (H.B.K.)**



**TRANSCO**

STATION D'INCINERATION DES DECHETS SPECIAUX  
ET SPECIAUX DANGEREUX ET BANALISATION DES DASRI

**SARL TRANSCO**

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DANGEREUX ET BANALISATION  
DES DASRI**



**UNEP**

**World United Nations Environment  
Programme**



**World Health Organization**