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Autonomous system for the treatment of liquid and solid mining tailings

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Abstract

The extractive industry releases considerable amounts of liquid and solid residues as a result of various ore treatments. These tailings can damage the environment, including soil, groundwater and stream pollution, as toxic chemicals are used during the extraction process. As a result, they should not be dumped into the wild without treatment. This led to the establishment of an autonomous system for the treatment of liquid mine residues in the form of water for the production of electrical energy and the depollution of solid residues by the method of thermal desorption using a furnace proposed in this study. Throughout the research, various approaches have been used to determine whether the energy generated by the hydroelectric system of liquid residues would be sufficient to supply the thermal desorption for the treatment of solid residues. Consistent approximate values have been obtained but more concrete examples are needed to optimize the results.

Keywords

Thermal desorption, artificial ponds, hydroelectric, energy, slope, furnace.

1- Introduction

Mining sector is one of the economic development key bases of Madagascar. The mining industry plays a crucial role in supplying essential raw materials for modern society. But it is often accompanied by a major challenge: the responsible management of tailings. These tailings, resulting from mining and processing operations, represent a significant environmental concern because of their potential effects on ecosystems and water resources.
In 2019, the rupture of a mining tailings retention dam in Brazil contaminated about 270 hectares of land and polluted more than 300 km of rivers causing death of several people and aquatic species [1].
Also, in 2020, research carried out by Andrew Lees Trust showed that the water downstream of a Rio Tinto QIT-Madagascar Minerals mining site has an excess concentration of uranium and lead, which may contaminate nearby lakes and rivers used by the local population [2].
Faced with this reality, they cannot be poured into nature without adequate treatment. So innovative and sustainable strategies are needed to minimize the environmental impact of this waste, hence the theme**: "Autonomous system for the treatment of liquid and solid mining tailings".**
This study proposes an integrated approach that explores the potential for hydroelectric power generation from liquid residues using a low-drop micro-center, while implementing thermal desorption for depollution and recovery of solid residues.
The objective of this study is to assess whether the energy produced by the hydroelectric system of liquid residues would be able to supply the thermal desorption machine in order to treat the solid residues.
In order to achieve this, the first step will be the collection of existing data to arrive at the methods for calculating the electrical energy required by each system, hydroelectric and thermal desorption. Then the second step will establish a numerical simulation in order to provide approximate coherent values to compare the results obtained.

2- Methods

For the realization of this autonomous system, two hypotheses have been put forward:
- the first hypothesis is that the formulas for determining the electrical energy produced by the hydroelectric system and required by the thermal desorption machine are obtained from the data collected.
- the second hypothesis is that consistent values are obtained after the numerical simulation.

4.1. Data collection

4.1.1. Hydroelectric system

4.1.1.1. Characteristics of the two artificial basins [3] [4]

According to research conducted in Brazil, a mining site uses about 3 to 4 hm^3 per year for mineral processing. This quantity of water is mostly eliminated in the form of liquid residues and is treated before any form of discharge into nature. In the present research, these liquid residues have already passed the decantation and desalination stage and their storage in the basins is considered on a scale of time large enough to produce a sufficient quantity of water for the hydroelectric system.
The two basins have a fairly low altitude difference, assimilating them to a low-fall hydroelectric micro-center (Figure 1).
In terms of their dimensions, they vary according to several parameters such as the mining site, the types of ores mined, the quantity of liquid residues on the site, etc. However, it should be noted that the lower basin is larger because of the structures to be installed there: turbine and pump and also for system safety.

4.1.1.2. Flood vent **[5] [6]**

In order to prevent the maximum capacity of the basins from being exceeded due to climatic factors or in the event of excess liquid mine residues, flood evacuators shall be installed at the level of each basin in order to avoid any possible overflow. These evacuators are then connected to a water purification system to facilitate its elimination into the environment. However, the water purification system depends on several factors such as chemical composition, water radioactivity in order to adopt effective and sustainable methods. Research therefore varies according to the type of liquid tailings.

4.1.1.3. Submerged rotor pump **[7] [8] [9]**

The two tanks are equipped with two forced pipes, one of which pumps water from the lower tank to the upper tank and the other transports water from the upper tank to the turbine to the lower tank (Figure 1).
For the pumping mode, a submerged rotor hydraulic pump is installed in the lower basin connected to the corresponding pipe to raise the water towards the upper basin to give a closed hydraulic cycle.
The submerged rotor pump makes it possible to raise water faster and more strongly and differs from other pumps by ensuring no leakage due to its design, which sucks water in by being submerged (Figure 2).
It has a maximum discharge rate of up to 500 m^3/h and a maximum discharge height of 2200 m for the CAM/T/K/H model.
Its efficiency or pump performance depends on its design. Table 1 shows an overview of engine power efficiency.

4.1.1.4. Kaplan turbine with vertical axis **[10] [11] [12] [13] [14] [15] [16]**

The turbine receives the gravitational energy caused by the fall of water and transforms this kinetic energy into electrical energy. It is considered the centerpiece of the hydroelectric system.
Since there are different types of turbines, whether it is an action turbine or a reaction turbine, the Kaplan reaction turbine with a vertical axis (Figure 3) is chosen for the system because it is designed for low-fall micro-centers (Figure 4) and also the one most suited to the forced pipe constituting the two basins.
It has a low to high flow range, i.e. up to 600 m^3/s or more and a high efficiency of 90 to 95%.

4.1.1.5. Electrical energy produced **[17] [18] [19]**

- *Flow rate obtained from the hydroelectric system* $\mathbf{Q_t}$

It is the amount of water that actually passes through the turbine per unit of time, generally measured in cubic meters per second (m^3/s). This is the amount of water available to generate mechanical and electrical energy in the hydroelectric system. The formula is:

$$\mathbf{Q_t = Q_p \times (\eta_t / \eta_p)\ [m^3/s]}$$

Q_p: pump flow in m^3/s
η_t: turbine efficiency in %
η_p: pump efficiency in %

- *Hydraulic power* **P**

This is the mechanical power produced by the hydroelectric system by converting the kinetic energy of water into mechanical energy. Its general formula is:

$$\mathbf{P = Q_t \times h \times \rho \times g\ [kW]}$$

Q_t: turbined water flow in m^3/s
h: net height of fall in m

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ρ: water density in kg/m^3
g: acceleration of gravity in m/s^2

- *Electrical power* $\mathbf{P_e}$

This is the power generated in the form of electrical energy by the generator in the hydroelectric system. It depends on the efficiency of the turbine, the efficiency of the generator and other possible losses. Its general formula is as follows:

$$\mathbf{P_e = P \times \eta_b \ [kW]}$$

P: hydraulic power in kW
η_b: efficiency of the system which is the efficiency of the generator to convert kinetic energy into electrical energy

- *Electrical energy produced by the two artificial basins* $\mathbf{E_b}$

This is the total amount of energy in electrical form produced by the system in an hour of time. It is calculated as follows:

$$\mathbf{E_b = P_e \times t \ [kWh]}$$

P_e: electric power produced in kW
t: time = 1h = 3600 s

4.1.2. Ex-situ thermal desorption for sustainable depollution of solid mine residues [20] [21] [22] [23] [24] [25] [26] [27]

4.1.2.1. Characteristics

Ex-situ thermal desorption involves raising the temperature of the soils to be treated, solid mining residues in this case, in a furnace to promote the vapor release of the present volatile and semi-volatile contaminants.
The temperature range most suitable for this type of thermal desorption is between 100 and 400°C. This medium temperature technique tends to heat the residues treated by conduction and not by convection.

4.1.2.2. Functioning

The purpose of the ex-situ thermal desorption principle is to transmit contaminated soils to a desorption unit (furnace). This process allows adsorbed contaminants and residue particles to detach from them and promotes the volatilization of compounds that will subsequently be recovered in gaseous form.
There are three categories of thermal desorption units: rotary unit, screw unit and belt unit.

- The rotary unit (Figure 5) composed of a cylindrical reactor in which the contaminated residues are disposed. The reactor makes a circular movement, which allows the floors to advance in the cylinder. A burner gradually increases the temperature to the required level. This system, in one hour, can treat about 25 tons of residues, regardless of contamination and residue characteristics.
- The screw unit also consists of a cylindrical reactor, but the residues advance due to an endless screw. The temperature in this system can reach 260°C and treat from 3 to 15 tons per hour. The screw unit produces less gas than the rotary unit since the treated residues are heated indirectly. This limits the risk of the system exploding.
- The belt unit comprises a flexible belt transporting the residues through the reactor. The temperature reaches the 430°C in this system, allowing to treat about 5 to 10 tons per hour.

The choice of the appropriate unit depends on the type and extent of contamination and the type of residue. The contaminants treated are hydrocarbons, chlorinated contaminants, pesticides, etc. And the unpolluted soils obtained from this method can be used for construction purposes.

4.1.2.3. Efficiency of the furnace method

The thermal desorption method in general has an enormous potential for efficiency since the purification yields are high (more than 95 to 98% for petroleum hydrocarbons) and the final concentrations of pollutants are low (less than 5 mg/kg or even 100 ppb in most cases). However, this yield depends on the operating conditions, the pollutant concentrations and the properties of the soils and residues to be treated (heterogeneity of the environment, presence of organic material and very low volatile pollutants).

4.1.2.4. Electrical energy required for the operation of the machine

- *Required heat* **Q**

The required heat refers to the amount of thermal energy required to increase the temperature of a given material over a certain temperature range. In the context of thermal desorption, this is the amount of energy necessary to heat the solid mining residues to the desired desorption temperature, taking into account the mass of the residues, their thermal capacity and the temperature variation.
Its formula is:

$$\mathbf{Q = m \times C \times \Delta T\ [J]}$$

m: mass of residues in kg
C: thermal capacity of wastes in J/g·K
ΔT: target desorption temperature in K
The thermal capacity of the residues refers to the amount of energy required to increase the temperature of one unit of mass of these residues by one unit of temperature. It is expressed in units of energy per unit of mass per degree Celsius (J/kg·°C) or per Kelvin (J/kg·K). The higher the thermal capacity, the more energy it takes to heat the residues.

- *Conversion of heat into electrical energy*

This term refers to the process of converting thermal energy (heat) into electrical energy. In the context of energy calculations, this involves taking the amount of thermal energy required to heat the residues and converting it into the required electrical energy. This implies taking into account the efficiency of the conversion process and calculating the amount of electrical energy actually required from the heat. In general, it is expressed as follows:

$$\mathbf{E = Q / \eta\ [J]}$$

Q: heat required by the machine in J
η: energy conversion efficiency in %

- *Convert E to kWh*

Just do the conversion with the reference:
3.60 x 106 J = 1 kWh

4.2. Numerical simulation

According to the data collected in the previous section, a numerical simulation is carried out in order to obtain approximate electrical energy results by each of the liquid and solid tailings treatments.

4.2.1. Hydroelectric system

- Consistent values considered from acquired data:

Optimal amount of water to operate the system:

- $100\ m^3$ of water for the upper basin
- $200\ m^3$ of water for the lower basin

Net drop height $h = 4$ m (low fall [18])
Water density $\rho = 1000\ kg/m^3$
Acceleration of gravity $g = 9.81\ m/s^2$
Pump flow $Q_p = 100\ m^3/h = 0.027\ m^3/s$ (considering the quantity of water in the lower basin and optimal pump flow in paragraph 4.1.1.3)
Pump efficiency $\eta_p = 60\%$ (most optimal from Table 1)
Turbine efficiency $\eta_t = 95\%$ (most optimal according to paragraph 4.1.1.4.)
System efficiency $\eta_b = 80\%$ (standard value [7])

4.2.2. Thermal desorption machine

- Consistent values considered from acquired data:

<u>Example</u>: Uranium and thorium mining site where the enclosing rock of the ores is granite. The ores are extracted from the enclosing rock using various acids. The crushed sterile granite rocks are to be treated by thermal desorption.

- Mass of granite to be treated in one hour: m = 25 tons = 25000 kg (with a rotary unit furnace [24])
- Target temperature for thermal desorption: $\Delta T = 300\ °C + 273 = 573$ K (optimum operating temperature [24])
- Thermal capacity by mass of granite: $C = 837$ J/kg·K [26]
- Conversion efficiency: $\eta = 0.85$ or 85%.

3- Results

According to the numerical simulation carried out on the basis of the acquired data, the electrical energy produced by the pools and the electrical energy required by the thermal desorption machine are obtained with coherent values. Table 2 shows the calculations and approaches leading to the results.

4- Discussion

By comparing after calculations (Table 2), the electrical energy produced by the hydroelectric system is greater than what is required by the thermal desorption furnace.
In general terms then, according to these results obtained, the electrical energy produced by the two liquid residue retention tanks would be able to supply the thermal desorption machine.
The installation of a low-drop micro-hydroelectric plant minimizes the cost while being more energy efficient [18]. In addition, the use of renewable energy is a means of preventing climate change by limiting carbon emissions into the atmosphere.
Despite the consistency of the values obtained, these are only approximate values. Several variables remain to be considered, both in the hydroelectric system and the operation of the thermal desorption machine.
The amount of liquid residue present at a mining site depends on the type of mined ore deposit, i.e. the feasibility of installing the entire system depends strictly on the mined substances and their extraction methods.
A choice of specific mining site is necessary in order to optimize the results on the quantity of liquid residues stored to ensure the efficiency of the installation of the low-fall micro-hydroelectric plant.
The same applies to thermal desorption, the quantity and specificity of solid mining residues are necessary in order to optimize the obtained results and to guarantee the proper functioning of the depollution treatment as solid wastes always represent management challenges even outside mining sector [28].

5- Conclusion

The management of tailings presents a major challenge for the environment. Appropriate treatment of these residues depends on several factors and site conditions. This study showed an approach by using liquid mine residues as a source of hydroelectric energy and solid residues depolluted by thermal desorption.

Data were collected to establish a numerical simulation which gave results with consistent and considerable values for the realization of this autonomous system of treatment of liquid and solid mining tailings. It has been demonstrated that the electrical energy produced by the retention ponds of liquid tailings would be able to supply the thermal desorption machine. The research and studies carried out lead to the minimization of the impact of tailings on the ecosystem. The use of renewable energy in this autonomous system also contributes to limiting carbon emissions into the atmosphere and thus prevents climate change, which is an environmental main issue now. However, more research is needed accompanied by a choice of a specific case in order to optimize the obtained results.

6- Acknowledgements

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8- Tables

Table 1: Performance of standard submerged rotor pumps

Pump with engine power	Performance η_p
Up to 100 W 100 to 500 W 500 to 2500 W	About 5-30% About 20-50% About 30-60%

Source: [6]

Table 2: Results of the numerical simulation

Type of residue treatment	Liquid residues: Hydroelectric system	Solid residues: Thermal desorption
Calculations	▪ Flow rate obtained from Qt system $Qt = 0.027 \times (0.95/0.6)$ $Q_t = 0.04275\ m^3/s$ ▪ Hydraulic power P $P = 0.04275 \times 4 \times 1000 \times 9.81$ $P = 1677.51\ W = 1.67751\ kW$ ▪ Electrical power P_e $P_e = 1.67751 \times 0.8$ $P_e = 1.342\ kW$ ▪ Electrical energy produced by pools E_b $E_b = 1.342 \times 3600$	▪ Required heat Q $Q = 25000 \times 837 \times 573$ $Q = 11990025000\ J$ ▪ Conversion of heat into electrical energy $E = 11990025000/0.85$ $E = 14105911764.705883\ J$ ▪ Energy required by the desorption machine: Convert E to kWh $3.60 \times 10^6\ J = 1\ kWh$ $E = 14105911764.705883 / (3.60 \times 10^6)$
Results	**E_b = 4831.2 kWh**	**E = 3918.3 kWh**

9- Figures

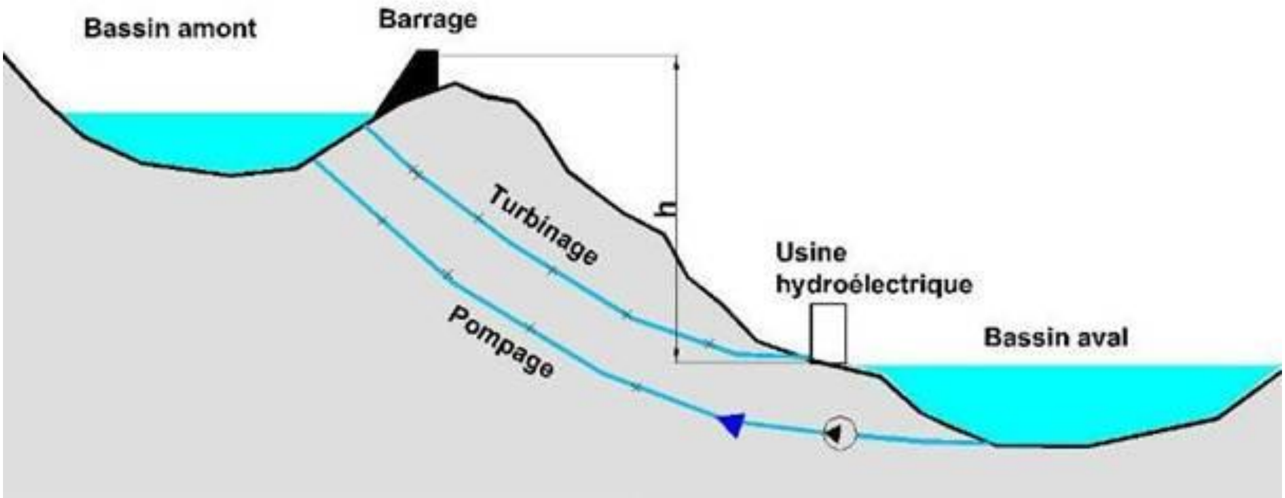

Figure 1: Illustration of the artificial tanks with the two turbines and pumping pipes
Source: http://rivieres.info/parti/grandmaison.htm

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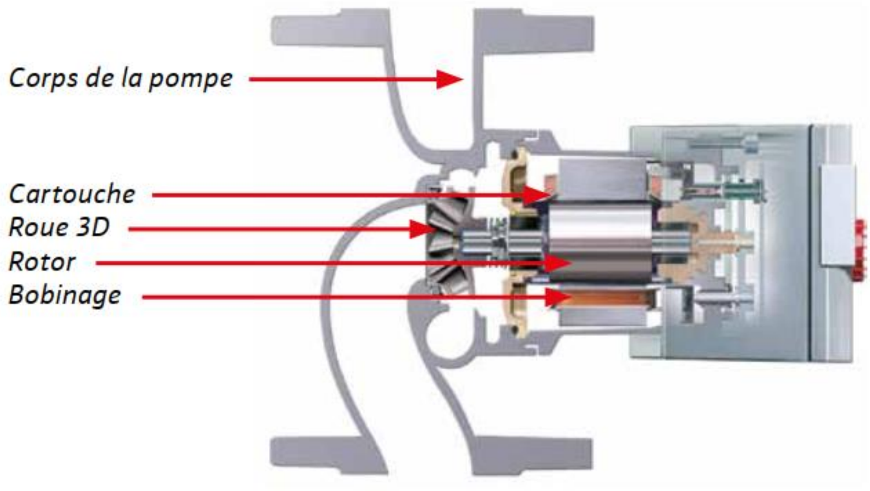

Figure 2: Submerged rotor pump
Source: [7]

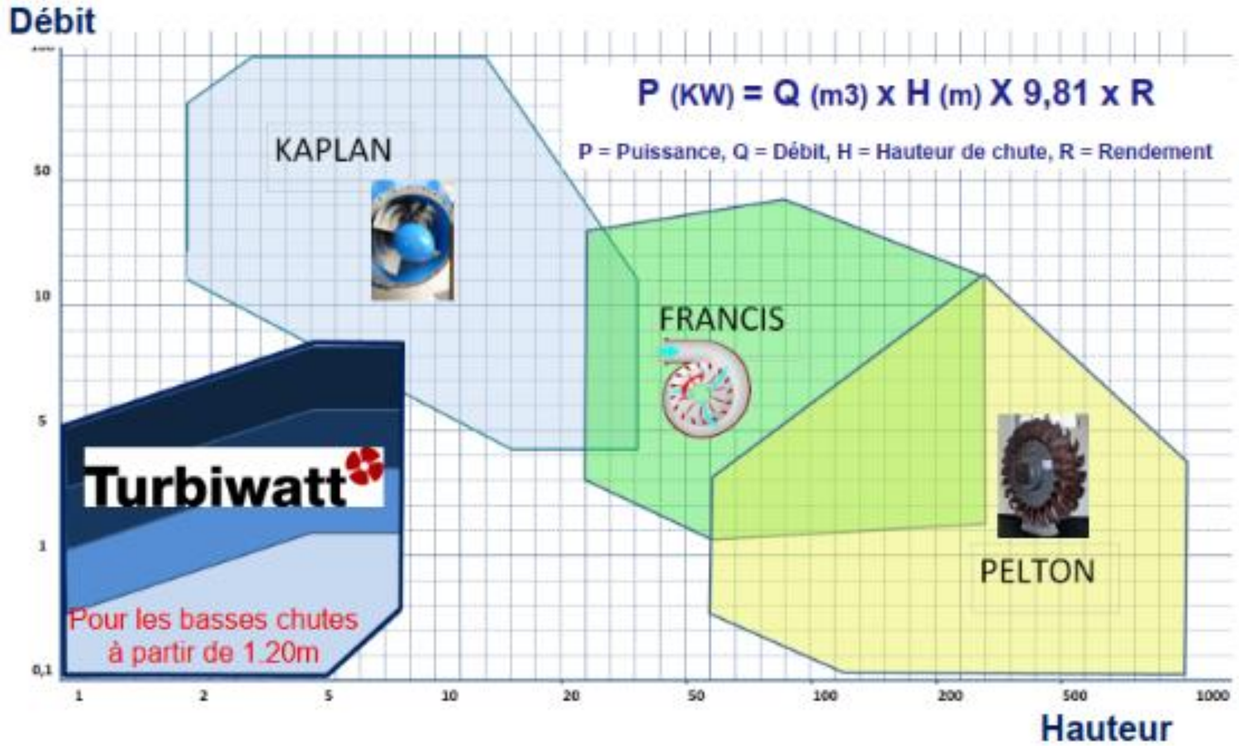

Figure 3: Different turbines as a function of flow and drop height
Source: www.turbiwatt.com

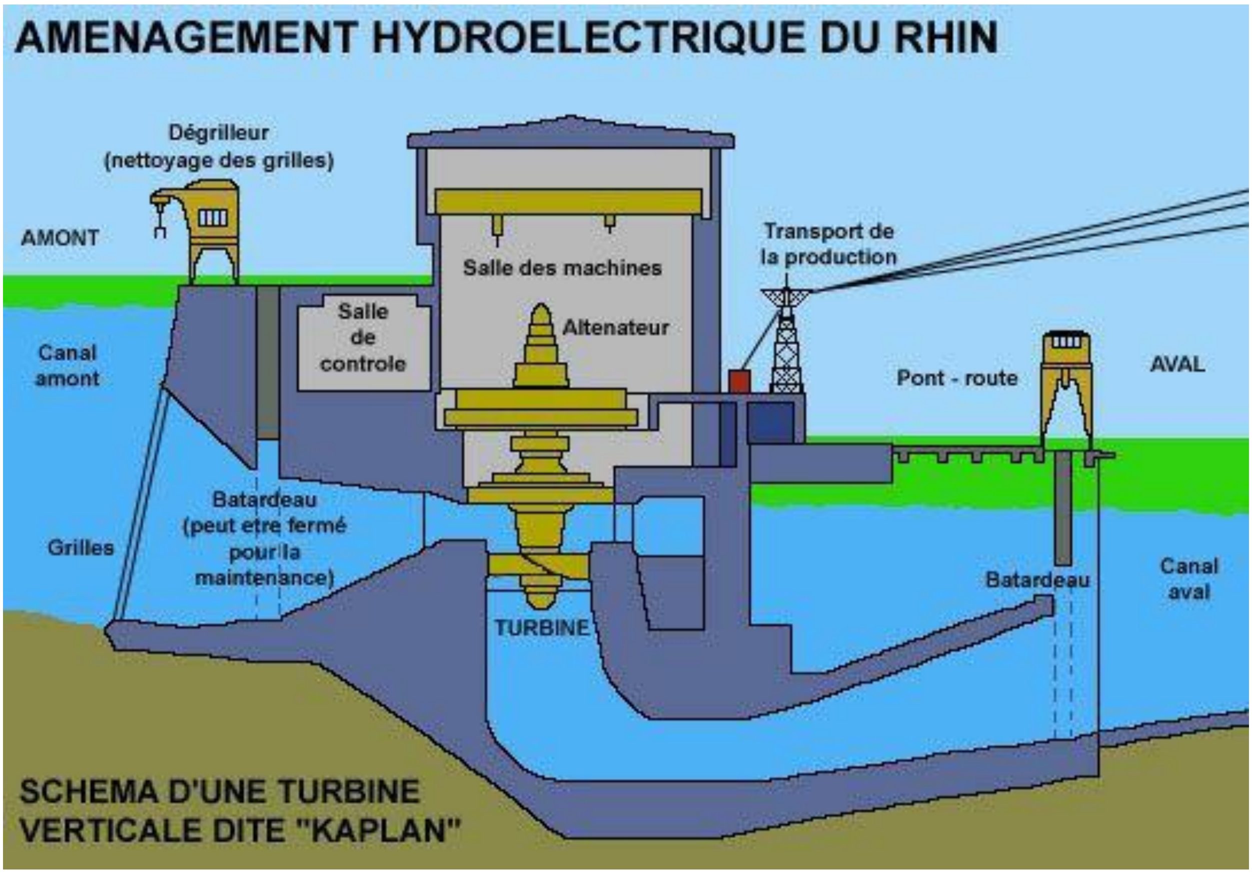

Figure 4: Illustration of a Kaplan turbine in a low-fall system - Hydroelectric development of the Rhine
Source: https://www.encyclopedie.bseditions.fr/image/article/plan/FRALPLANRHO007.jpg

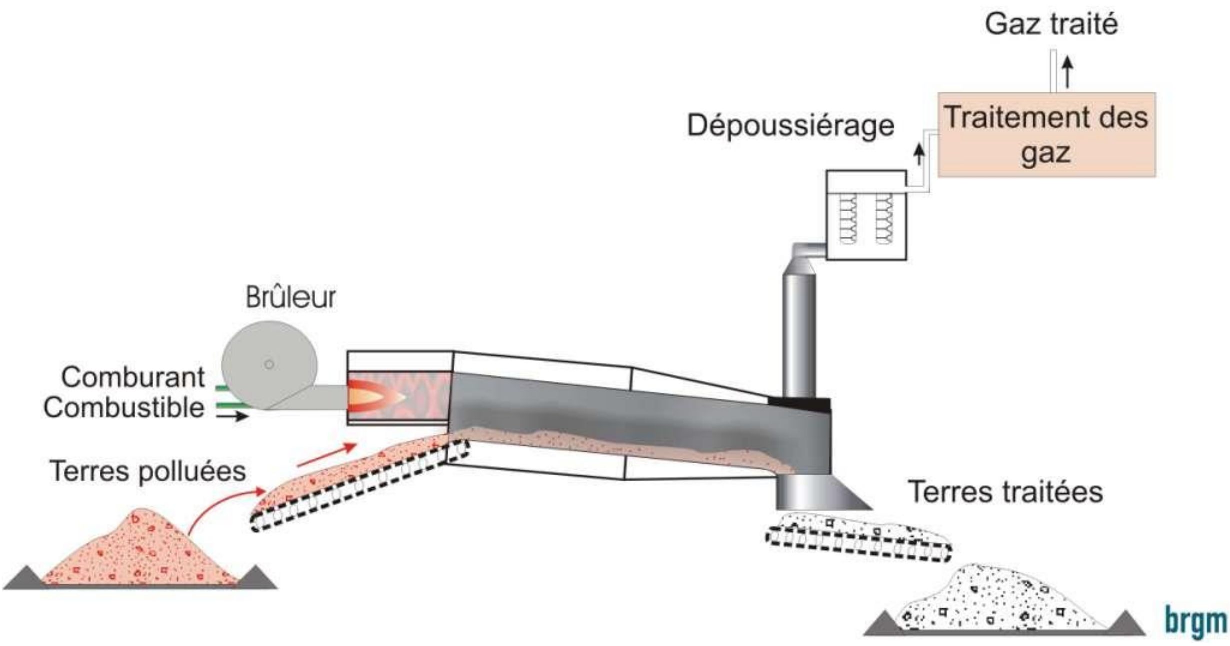

Figure 5: Principle of ex-situ thermal desorption with a rotary unit furnace
Source: [25]