HAZARDOUS WASTE MANAGEMENT FOR TAILING FROM GOLD EXTRACTION PROCESS BY CYANIDE

Ilhan Talinli & E.Gozde Ozbayram

*Istanbul Technical University (ITU), Environmental Engineering Dept., Maslak, 34469, Istanbul, TURKEY

talinli@itu.edu.tr
Hazardous Waste Management

• Every year, million tons of non-regular wastes and sludges are discharged into the environment.

• These wastes range in nature from common household trash to complex materials in industrial wastes, sewage sludge, agricultural residues, mining refuse and infectious wastes from institutions such as hospitals and laboratories.
Hazardous Waste

Among variety of waste, hazardous waste is defined as a hazardous substance that has been discarded or otherwise designated as a waste material or one that may become hazardous by interaction with other substances. Hazardous waste may either be in the form of solid, liquid, sludge-slurry or contained gaseous material (WHO, 1982).
Aim of this study

• Tailing from gold extraction processes and its storage method in tailing dam is evaluated.
• A stochastic model is applied for designation of the tailing as hazardous waste
• Appropriate treatment technology and disposal options are recommended for the designated hazardous waste instead of tailing dam.
Gold Mining

• Two basic processes including mineral processing and gold extraction by cyanide leaching is taken place in a mining area.

• Tailing from gold extraction processes and its storage method in tailing dam is evaluated.

• A stochastic model is applied for designation of the tailing as hazardous waste and appropriate treatment technology and disposal options are recommended for the designated hazardous waste instead of the tailing dam.
Gold Extraction Industry in western of Turkey
Gold Extraction Industry in western of Turkey
Gold Mining

- Slackening soil
- Taking up mineral
- Its transportation to extraction site.

Gold Extraction

Cyanide (CN) leaching process is mostly used method

4 Au + 8 NaCN + O2 + 2 H2O → 4 Na[Au(CN)2] + 4 NaOH
Gold Mining Process

Gold Mining → Grinding → Leaching and adsorption → Gold retrieval → Bullion gold → Refining → Smelting
There are two general approaches to leach gold from ore, which are tank leaching and heap leaching.

Tank leaching is the conventional method, in which gold ore is crushed and ground to a size of less than one millimetre in diameter. In most cases, the finely ground ore is directly leached in tanks to dissolve the gold in a cyanide solution.

When gold is recovered in a conventional plant with leaching in tanks, the barren solution will be collected along with the solid wastes (tailings) in a tailings impoundment system.

With heap leaching method, the ore is crushed to less than a few centimetres in diameter and placed in large piles or heaps.
Heap leaching process
# Wastes from processes of gold mining

<table>
<thead>
<tr>
<th>Waste</th>
<th>Processes</th>
<th>Pollutants, Effects</th>
<th>Form of Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater</td>
<td>All leaching processes and Carbon adsorption in pulp</td>
<td>Heavy metals, sulphide, fluoride, SS, pH, CN, As, sulphide, alkalinity</td>
<td>Liquid</td>
</tr>
<tr>
<td>Solid waste</td>
<td>Blasting, Excavation, Decoupage</td>
<td>Dust, particles</td>
<td>Solid</td>
</tr>
<tr>
<td>Air emissions</td>
<td>Blasting, Excavation, Leaching, Carbon adsorption and Carbon regeneration, Smelting</td>
<td>HCN, Particles, Dust, CO₂, SO₂</td>
<td>Gas and dust</td>
</tr>
<tr>
<td>Hazardous waste</td>
<td>Leach process, Carbon adsorption</td>
<td>CN, SCN, Heavy metals, Toxicity, Corrosivity</td>
<td>Sludge</td>
</tr>
</tbody>
</table>
Construction of the tailing dam
Tailings from gold mining
Algorithm of the rating system for determination of the hazardous waste

1. Discarded Material
   - Can it be reused, recovered and/or recycled?
     - Yes (Reuse, Recycle, Recover)
     - No (Waste)

2. Waste
   - Is it defined in your wastewater, municipal solid waste and/or air pollution control regulations?
     - Yes (Hazardous Waste Determination)
     - No (Regular Waste)

3. Hazardous Waste Determination
   - Check H.W. Lists
     - Yes (Hazardous Waste)
     - No
       - Has it hazard criteria?
         - Yes (Assess CPR)
         - No (Non-Regular Waste)

4. Assess CPR
   - Yes (Hazardous Waste)
   - No (Non-Regular Waste)
Model Equations

- ORV = D + L + [Ee + (CPR) x f] x Q \hspace{3cm} (1)
- Ee = I + C + R + T \hspace{3cm} (2)
- I = i^n, \ C = c^n, \ R = r^n, \ T = t^n \hspace{3cm} (3), (4), (5), (6)
- CRP = Cr + P + In + Pe \hspace{3cm} (7)
- P = p^m \hspace{3cm} (8)
- Pe = (Bd)^{si} x (Bac)^{-1} \hspace{3cm} (9)
Where;

- ORV: overall rating value
- D: value of regular or non-regular waste
- L: value of listing
- Ee: hazard criteria as ecological effect
- CPR: combined potential risk
- f: form of the waste
- Q: quantity of the waste
- I: ignitability, flammability
- C: corrosivity
- R: reactivity
- T: toxicity
- n: correction factor of the waste
- P: poisonous effect
- Cr: carcinogenity
- In: infectious
- Pe: persistency
- I: intaken mode
- Bd: biodegradability
- Sl: solubility
- Bac: bioaccumulation

\[
\text{ORV} = D + L + [Ee + (\text{CPR}) \times f] \times Q \\
Ee = I + C + R + T \\
I = i^n, \ C = c^n, \ R = r^n, \ T = t^n \\
\text{CRP} = Cr + P + In + Pe \\
P = p^m \\
\text{Pe} = (Bd)^{Sl} \times (Bac)^{-1}
\]
## Determination of Gold Mining Tailing as Hazardous Waste

<table>
<thead>
<tr>
<th>Hazard Criteria (Ee)</th>
<th>Rating Value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0</td>
<td>Waste is not Flammable*</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>pH of the sludge is kept about 10-11 to prevent the toxic HCN gas formation</td>
</tr>
<tr>
<td>R</td>
<td>0</td>
<td>Waste is non – reactive</td>
</tr>
<tr>
<td>T</td>
<td>30</td>
<td>0,1&lt; LC$_{50}$ &lt; 10 mg/l for cyanide</td>
</tr>
<tr>
<td>p</td>
<td>30</td>
<td>Oral LD$_{50}$ for mammals range 2.1 mg/kg for coyote to 6.0-10.0 mg/kg for laboratory white rats**</td>
</tr>
<tr>
<td>Cr</td>
<td>10</td>
<td>No studies were located on the carcinogenic effects of cyanide, from inhalation or oral exposure, in humans or animals. However, because of the presence of heavy metals it can be evaluated as carcinogenic</td>
</tr>
<tr>
<td>In</td>
<td>0</td>
<td>Waste is non-infectious.</td>
</tr>
<tr>
<td>Pe</td>
<td>1.1</td>
<td>Persistency is a function of bioaccumulation, bidegradation and solubility of materials for CPR***</td>
</tr>
</tbody>
</table>

Waste is a non-regular waste → D value is 50.
Waste is not listed a/any hazardous waste list as tailings come from gold → L value is 0.

* n=1.2 Form of the waste is sludge
** m=1.3 Exposure mode: inhalation
*** Sl=0.5 Soluble, Bd=5 Slightly biodegradable, Bac=2 Bioaccumulative, f=1 Sludge, Q=1.4 >>>10 ton/month so big quantity generator
Hazardous waste determination by hour glass scale
treatment and disposal processes for tailings

- A critical question is whether phase separation is possible or not. Heterogeneous tailing sludge has two phases including 45% of solid part distributed in water.

- Since the separation of solids is possible by filtration for this kind of sludge, overall waste is segregated into two streams as wastewater and solid waste.

- The supernatant including free cyanide and heavy metals is taken to WWTP which has a cyanide oxidation tank, heavy metals, colloids and suspended solids are removed by coagulation/precipitation process.
• When sludge from the coagulation tank is directed to combine with solid cake obtaining from the filter press.

• Treated wastewater is either reused or discharged to receiving water.

• An alternative management of overall waste is disposal to landfill after encapsulation by SS method using a binder such as cement, fly ash etc.

• Because pollutants are stabilized and solidified in concrete matrices, hazardous waste is directed to landfill in which it meets Land Disposal Restrictions (LDR) (EPA, 1990b; Blackman, 2001).
Flow chart of the treatment and disposal processes for tailings

Gold Mining Tailings

Is it possible to separate water and solid phase?

Yes

Physical Separation (Filter Press)

Supernatant ww

WWTP

Detoxification by Cyanide Oxidation

Coagulation/Floculation

Treated wastewater Discharge/Reuse

Solid cake

Drying Beds

Solidification/Stabilization Process

Landfill

No

Directly Disposal

Solidification/Stabilization Process

Landfill
Cyanide Removal Methods

**Chemical Oxidation by chlorin**e

**Oxidation of cyanide to isocyanate**

\[
\text{Cl}_2 + \text{NaOH} \rightarrow \text{NaOCl} + \text{NaCl} + \text{H}_2\text{O} \quad \text{(pH=11)}
\]

\[
\text{NaOCl} + \text{NaCN} + \text{H}_2\text{O} \rightarrow \text{CNCl} + \text{NaOH}
\]

\[
\text{CNCl} + 2\text{NaOH} \rightarrow \text{NaCNO} + \text{NaCl} + \text{H}_2
\]

**Oxidation of isocyanate to end products (CO}_2, \text{H}_2\text{O, and N}_2)\)

\[
\text{NaOCl} + \text{NaCNO} \rightarrow \text{NaHCO}_3 + \text{NaCl} + \text{N}_2 + \text{H}_2\text{O} \quad \text{(pH = 8)}
\]
Cyanide Removal Methods

**Oxidation, UV/O₃**

Ozone has been started to be commonly used in cyanide oxidation due to developments in ozone generation technologies.

\[
CN + O_3 \rightarrow CNO + O_2 \quad \text{fast}
\]

\[
2CNO + H_2O + 3O_3 \rightarrow 2HCO_3^- + N_2 + 3O_2
\]

\[
CN^- + O_3 \rightarrow CNO^- + O_2 \quad \text{fast}
\]

\[
CNO^- + OH^- + H_2O \rightarrow CO_3^- + NH_3
\]

\[
NH_3 + CNO^- \rightarrow NH_2-CO-NH_2
\]
Cyanide Removal Methods

**INCO Process**

\[
\text{CN}^- + \text{SO}_2 + \text{O}_2 + \text{Cu}^{+2} + \text{H}_2\text{O} \rightarrow \text{CNO}^- + \text{Cu} + \text{H}_2\text{SO}_4
\]

The oxidation of thiocyanide and the hydrolysis of cyanide occur according to following reactions:

\[
\text{SCN}^- + 4\text{SO}_2 + 4\text{O}_2 + 5\text{H}_2\text{O} \rightarrow \text{CNO}^- + 5\text{H}_2\text{SO}_4
\]

\[
\text{CNO}^- + 2\text{H}_2\text{O} \rightarrow \text{OH}^- + \text{NH}_3 + \text{CO}_2
\]
A cyanidation characteristic in leaching process (from EIA report)

- Specific Cyanide utilization may be 0.35-1.70 kg NaCN/ton mineral (used 1.5 kg NaCN/ton).

- Water content of tailing sludge is 52% by weight.

- Specific gravity of the sludge is 1.43 ton/m³.

- Applied cyanide concentration is 1.5 kg NaCN/1.46 m³ = 1030 g CN⁻/m³.

- Utilized cyanide by gold and heavy metals is estimated as 500-700 mg/l.

- Sludge cyanide concentration is assumed that 300-500 mg/l.
A cyanidation characteristic which is used in leaching process.

**Designed tailing dam**

- Surface area: 15 ha
- Volume: 4 M m³
- Cyanide Accumulation: 4000-8000 kg due to 1-2 g/m³ concentration
Cost to Western European Chemical Industry for treating and disposing of waste by different methods

<table>
<thead>
<tr>
<th>Methods</th>
<th>Cost Range ($ /tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Disposal to land</td>
<td>1-20</td>
</tr>
<tr>
<td>Disposal to land in a site lined with plastic sheet</td>
<td>10-50</td>
</tr>
<tr>
<td>Underground disposal to dropping into old wells or mines</td>
<td>20-150</td>
</tr>
<tr>
<td>Land disposal after encapsulation by S/S process</td>
<td>10-100</td>
</tr>
<tr>
<td>Simple incineration (without significant heat recovery)</td>
<td>30-150</td>
</tr>
<tr>
<td>Incineration with alkaline stack scrubbing</td>
<td>100-350</td>
</tr>
<tr>
<td>All types of chemical treatment and, in particular:</td>
<td></td>
</tr>
<tr>
<td>Destruction of cyanide by hypochlorite</td>
<td>300-500</td>
</tr>
<tr>
<td>Reduction of chromic acid</td>
<td>100-300</td>
</tr>
<tr>
<td>Destruction of cyanide (catalytic)</td>
<td>200-500</td>
</tr>
</tbody>
</table>
Cost Calculations for Waste

Amount of the waste in tailing dam:
4.10^6 m^3 x 1.43 tons/ m^3 = 5.72 M tons

Total cost for treatment and disposal:
5.72 M tons x 300 $/ton = 1.7 Billion $

Calculation of the total cost for cyanide removal by oxidation methodologies:
2x10^6 kg CN (assumption 500 mg/l CN concentration in 4x10^6 m^3 tailing volume)
## Comparison of Cyanide Removal Methods’ Costs

<table>
<thead>
<tr>
<th>Treatment methods</th>
<th>Cost*</th>
<th>Total Cost (Calculated***)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkaline Chlorination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Chlorine ($Cl_2$)</td>
<td>0,45 $/kg removed CN</td>
<td>0,9 M $</td>
</tr>
<tr>
<td>• Sodium Hypochlorite (NaOCl)</td>
<td>3,11 $/kg removed CN</td>
<td>6,22 M $</td>
</tr>
<tr>
<td>• Calcium Hypochlorite (Ca(OCl)$_2$)</td>
<td>4,22 $/kg removed CN</td>
<td>8,44 M $</td>
</tr>
<tr>
<td>SO$_2$/Air Oxidation (INCO Process)</td>
<td>11,95 $/kg removed CN</td>
<td>24 M $</td>
</tr>
<tr>
<td>Ozonation</td>
<td>0,31-1,42 $/kg removed CN</td>
<td>3 M $</td>
</tr>
</tbody>
</table>

* Modified from Johannes et al. (1989).

** According to assumptions in this study.
EIA reports present an economical table for similar projects

Initial Investment Cost = 50-100 M $

Production Income per year = 40 M $

Production Outcome = 20 M $

Rant per year = (40-20) \times 10^6 = 20 M $

Rant of investment for 10 years = 10 \times 20 M = 200 M $

10\%$ of this rant remains for Turkey = 200 M \times 0.1 = 20 M $
Conclusion

- Cyanide and heavy metals are main pollutants in tailing. Overall waste is required phase separation to obtain liquid phase, because both cyanide oxidation and heavy metal precipitation can be only achieved in aqueous phase of the sludge.

- Tailing from gold extraction processes is a hazardous waste in sludge form and its main characteristic is toxicity. It should be managed by T/S/D facilities such as detoxification, solidification, deep well injection, disposal to spent mining after solidification and disposal to controlled landfill area.

- About 1-2 M $ guaranties for rehabilitation of tailing dam at the evacuation period is not even comparable to the cost of 1.7 Billion $ of treatment and disposal.
Conclusion

- Alkaline chlorine oxidation and ozonation processes are more cost effective than SO$_2$/Air oxidation and there is no public benefit even in the context of cyanide removal cost.

- Above evaluation shows that the benefit/cost ratio is very low. Whereas economically minimal hazard and impact is aimed in EIA concept, as well as environmentally.

- Tailing dam should be neither storage nor disposal method for gold extraction tailings.
THANK YOU FOR YOUR ATTENTION
talinli@itu.edu.tr