AZNALCÓLLAR TAILINGS DAM ACCIDENT. PURIFICATION OF WATERS RETAINED IN ENTREMUROS (GUADIAMAR RIVER, SPAIN)

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The Aznalcóllar tailings dam breakdown took place the 25th of April 1998 early in the morning and its flood dragged solids and acid waters along. The acid water flowed during two days the Guadiamar and Entremuros river-bed, and finally arrived at the Guadalquivir river.

The 27th of April the Junta de Andalucía (Andalusian Government) (JA) built a wall in transverse direction that kept the water from flowing in Entremuros and retained the flood's wave. Later the Confederación Hidrográfica del Guadalquivir (CHG) built a new wall parallel to the other, and safer.

The pouring out licence of the waters retained in Entremuros was given by the JA and was regulated by Resolution of its Consejo de Gobierno (Governmental Council) the 2nd June 1998. This Resolution established the limits of the pouring out of waters according to the Regulation of Littoral Waters Quality (Annexe I of Decree 14/1996, 16 January 1996), and it was pointed out that the sulphate concentration should be lower than 2000 mg/l.

The licence given by the JA didn't point out which one of the established limits in Annexe I: Monthly Mean, Daily Mean or Exact Value, should be required.

The Ministry of Environment, through its Secretary of State of Waters and Costs, asked to several Institutions some preliminary laboratory studies in order to design different possibilities of treatment:

- Institute Jaume Almera and Polytechnic University of Cataluña;
- Inerco - Sevilla Technical High School of Engineers; Department of Chemical and Environmental Engineering;
- Spanish Geological and Mining Technological Institute.

The main conclusions obtained by these institutions were the following:

	Monthly Mean	Daily Mean	Exact Value
pH		5,5 – 9,5	
Total suspended solids (mg/l)	300	400	500
Turbidity (UNT)	150	250	400
Al (mg/l)	3	6	10
Cd (mg/l)	0,2	0,4	1
Hg (mg/l)	0,05	0,1	0,1
Zn (mg/l)	3	6	10
Cu (mg/l)	0,5	2,5	4
Ni (mg/l)	3	6	10
Cr (mg/l)	0,5	2	4
Pb (mg/l)	0,5	1	2
Se (mg/l)	0,05	0,1	0,2
As (mg/l)	1	3	5
CN^- (mg/l)	0,5	1	2
F (mg/l)	10	15	20
NH_4^+ (mg/l)	60	80	100
P (mg/l)	40	50	60

Table 1.

- Zn content in water decreases quickly when pH increases to 9, reaching a value lower than 1 mg/l;
- Co, Cd, Cu, As and Pb precipitation is very effective when pH value increases;
- Mn concentration in water decreases noticeably when pH is greater or equal than 9.5;
- Water turbidity decreases considerably when aluminium sulphate is added;

Figure 1. Sedimentation pond. On the bottom emergency plant.

Figure 2. Precipitated muds before its transport to the old Aznalcóllar openpit.

- Calcium hydroxide, sodium carbonate and sodium hydroxide, as pH controller reagents, generate similar results with regard to metals precipitation. Each one has proved to have advantages and disadvantages:
  * Calcium hydroxide is the cheapest;
  * The most expensive and having the greatest consumption is sodium carbonate;
  * The most difficult to prepare and dosificate is the calcium hydroxide;
  * Sodium hydroxide is the most dangerous to use and has the greatest reactivity.
  * Sodium hydroxide requires the lesser consumption to reach a certain pH.

The precipitate muds volume is quite related with the type of used reagent and with the metal's content in the water to be treated.

Different institutions and firms proposed several alternatives for the water purification which can be systematically summed up in the next techniques:

- "In situ" treatment with calcium hydroxide.
- Treatment in an emergency plant with sodium carbonate and/or sodium hydroxide.
- Treatment in a conventional purifier plant with calcium hydroxide and/or sodium hydroxide.

The direct treatment of the affected zone was rejected for technical reasons, the great flooded area (1,500 hectare), and because of the bottom irregularity what implies several water depths that makes difficult to estimate the treatment conditions.

So, there were two alternatives left to follow:

- The treatment in an emergency plant, proposed by the ITGE, able to work in less than 14 days. A pilot-test of 100,000 m^3 of water was done with an estimated cost of 60 million pesetas (360,600 euros). The final estimated cost was 180 million pesetas (1,081,800 euros) in the event of treating all the retained water in Entremuros.
- The treatment in a conventional purifier plant, proposed by the CHG, able to work in 40 days and with an estimated budget of 1.200 million pesetas (7,212,100 euros).

However, the Ministry of Environment decided, being aware of its greater cost but looking for the highest security, the next solution:

- The building of a coffer-dam in the Entremuros head-zone, where the water conditions allow a direct pouring out.
- The immediate carry out of the pilot-test proposed by the ITGE and, in case of a positive result, the continuation with the treatment of the remaining water.
- Authorise to build the conventional purifier, proposed by the CHG, to treat polluted waters, alone or with the ITGE plant, depending on the result of the previously pilot-test done with the ITGE plant.

In fact, a very important point was that the pilot-test treated 100,000 m^3 and stored them in a pond. For this reason the JA was forced to define the limits to perform the pouring out, i.e. to license or to refuse the pouring out of treated waters, because for example the sulphate limit was not possible to be fulfilled in any case, independently of the treatment.

The pilot-test of 100,000 m^3 water in the emergency plant of the ITGE was successful. However, 12 days of intensive negotiations were necessary for the General Co-ordinator in order to get the permission of the JA for pouring out and therefore the continuation of the plant progress.

CHG divided the Entremuros surface in three areas

Figure 3. Mobil Laboratory on the Emergency Plant.

Figure 4. ITGE Emergency Plant.

building two coffer-dams, one in the Vaqueros bridge and the other in the middle of the first one and the retention dike. The area of the down-stream was considered as polluted water and therefore an area to treat. The area of up-stream contained water with values that allow the direct pouring out. The intermediate area contained water situated in the established limit to perform a direct pouring out. Two pumps were installed, one with a piping for a direct pouring out and another to pump out water to the polluted water area.

The CHG pumped out from the intermediate area around 1,000,000 m^3 water to the polluted water area, so that this polluted water was diluted, reducing the Zn concentration from 90 mg/l to 50 mg/l. The remaining water from the intermediate area was poured out directly without purification.

The ITGE emergency plant purified in 33 days 1,639,000 m^3 water, of which 120,000 m^3 were treated with sodium carbonate and the rest with sodium hydroxide. Aluminium sulphate was added when an increase of turbidity was detected. The plant stopped working the 21st of August 1998, when there was still about 300.000 m^3 to treat, because it was decided that they will be treated with the conventional purifier of the CHG. The total cost of the operation managed by the ITGE raised up to 226,699,716 pesetas (1,362,489 euros).

The CHG conventional purifier treated in 8 days of test and starting, plus 31 days operation, nearly 350,000 m^3 polluted water, which constituted the rest stored in Entremuros when the ITGE plant was stopped. The process was stopped the 21st September 1998. The total cost of the operation of the conventional purifier raised up to 1,200 million pesetas (7,212,100 euros).

Both, precipitate muds in the emergency plant, and those precipitate muds in the conventional purifier were transferred to the old Aznalcóllar openpit.

The direct pouring out of water, retained by the coffer-dam built between the Vaqueros bridge and the first retention wall, which formed the experimental pond, was near 1,500,000 m^3.

	Feed water	Poured out water
PH	7,2 - 7,6	7,2 - 8,1
Total suspended solids (mg/l)	71,6 - 77,9	53 - 150
Turbidity (UNT)	37,4 - 54,96	10 - 158,7
Al (mg/l)	<0,2	<0,2
Cd (mg/l)	0,033 - 0,082	<0,005
Hg (mg/l)	<0,0005	<0,0005
Zn (mg/l)	21,6 - 38,5	0,05 - 1,09
Cu (mg/l)	<0,05	<0,05
Ni (mg/l)	0,157 - 0,263	<0,05 - 0,18
Cr (mg/l)	<0,025	<0,025
Pb (mg/l)	<0,025	<0,025
Se (mg/l)	0,005 - 0,014	<0,005 - 0,016
As (mg/l)	<0,05	<0,05
CN^- (mg/l)	<0,1	<0,1
F (mg/l)	1,70 - 2,39	1,4 - 2,0
NH_4^+ (mg/l)	0,38	<0,05 - 0,15
P (mg/l)	<0,02	<0,02
SO_4^{2-} (mg/l)	3067 - 4083	3380 - 4240
Mn (mg/l)	70	4 - 60

Table 2.

CONCLUSIONS

Among the conclusions that can be obtained from the applied treatment to the retained water in Entremuros, we would remark the following:

- The initial estimations about metal contents in the water to be treated have significantly diverted from the reality because the samples that have been analysed for the first tests were taken in the most polluted place, that is, near the south wall or the nearest wall to the purification pilot-plant. In the farest places from the referred wall and because of simple dilution, the quality improves gradually.

Figure 5. ITGE Emergency Plant.

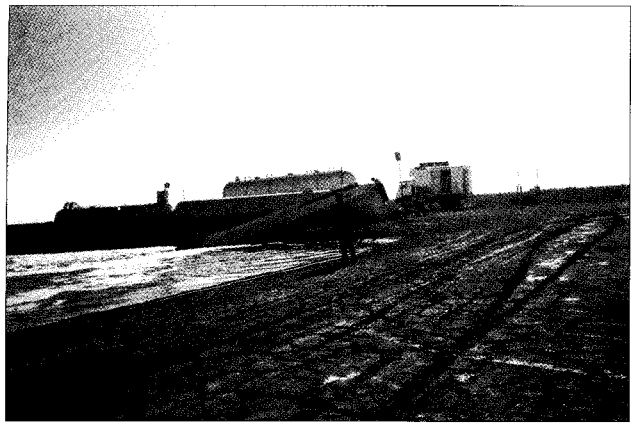

Figure 6. ITGE Emercency Plant and Mobil Laboratory.

- The estimation about the volume of retained water was more correct.
- Evaporation in the zone has played a big role in resolving the problem, specially during the months of July and August. Some days, the evaporation has reached values of the order of 0.01 m^3/m^2day (10 cm).
- The importance in the resolution of the problem that has had the direct pouring out of around 1,500,000 m^3.
- The mistake in mixing near 1,000,000 m^3 water, that may have been poured out directly, with the considered as polluted water. This forced to treat nearly the double of volume, with half dissolved metal concentration. For this reason, the cost of treatment raised and delayed the conclusion of tasks in order to solve the problem, at expense of making use of the conventional purifier.
- In equivalent or similar future situations, it is recommended to reckon better estimations of the quantity and quality of water, that will be purify, since this allows to optimize the solutions to be taken.
- The obtained results in the emergency plant proposed by the ITGE have been better than the initial estimations, both in the quality of poured out water and in the capability of treatment and also in the facility of maintaining stable the process. There is no doubt that the exposed problem of the water purification in Entremuros would have been solved with this single plant.
- The total cost of the treatment of 1,639,000 m^3 of polluted water, including the previous studies expenses, pilot-proof and removal of muds, raised up to 226,699,716 pesetas (1,362,492 euros), VAT included, what implied a unitary cost of 138.3 pesetas/m^3 (0.83 euros/m^3)
- The cost of treatment, without the previous expenses of the pilot sample, implied a unitary water's purification cost of 98.2 pesetas/m3 (0.59 euros/m^3).
- It should be recognized as a mistake not to have removed the precipitated muds in the emergency plant process with the centrifuge machine offered by the S.E. de Aguas Filtradas, S.A., since this would have cheapened the process and would have been made possible to finish the work about one month earlier.
- The conventional purifier itself would have not solved the problem in time, since 40 days after the inauguration, the 20th September 1998, the evacuation's problem of the precipitated muds at the established rhythm of its nominal capability was not solved yet.