EVALUATION OF HYDRAULIC RESIDENCE TIME IN THE LIMESTONE DRAINS OF THE LORRAINE SITE, LATULIPPE, QUÉBEC

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1. Introduction

- Acid mine drainage (AMD) is still a major environmental concern for the mining industry.
- The AMD is produced when sulphide minerals, such as pyrite and pyrrhotite, present in the rock are exposed to water and atmospheric oxygen.
- When AMD is produced on a mine site, passive treatment techniques such as anoxic limestone drains (ALD) can be used to improve water quality.
- An ALD consists of limestone buried in a trench, underdrain, or cell. The acidic drainage is intercepted while it is anoxic (underground) and directed into the limestone placed in a drain (or ditch) which is also free of oxygen.

- Two main objectives are generally considered in designing an ALD: (1) generate sufficient alkalinity to neutralize the acidity, and (2) decrease the metals loading through oxidation/hydrolysis and precipitation mechanisms.

- The ALD technique was selected to complement the action of a specially constructed cover with capillary barrier effects (CCBE) used as oxygen barrier to rehabilitate the abandoned Lorraine mine site (near Latulippe, in Abitibi-Témiscamingue).

- The installation of the limestone drains has lead to a significant improvement of seeping water quality, but their performance is not as good as expected and the effluents do not yet meet the standards of the Québec regulation.

- Various factors can explain the relatively poor behaviour of the Lorraine limestone drains, including as:
  - ✓i) drain design and construction,
  - ✓ ii) grain-size and mineralogy of the calcareous material used,
  - ✓iii) presence of oxygen in the limestone drains,
  - ✓iv) the hydraulic residence time (HRT) inside the drains (Bernier et al. 2002).

- To evaluate the latter parameter, various artificial tracer tests were performed at the Lorraine site.

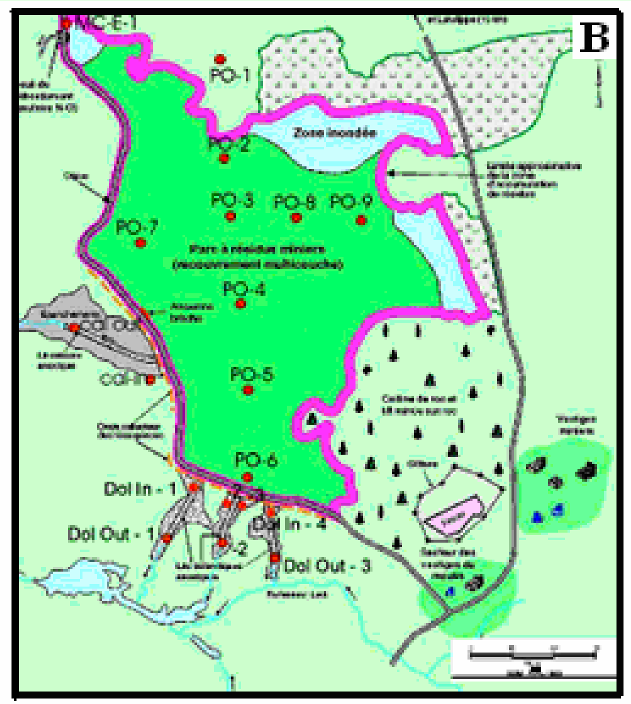
- These tests constitute the subject of this presentation

2. Lorraine site and limestone drains description

- The Lorraine mine site is located near Latulipe, in the Temiscamingue region, Québec, Canada.
- Approximately 600 000 tonnes of ore were treated at the mill, generating approximately the same amount (excluding water) of tailings (Lavergne, 1985).

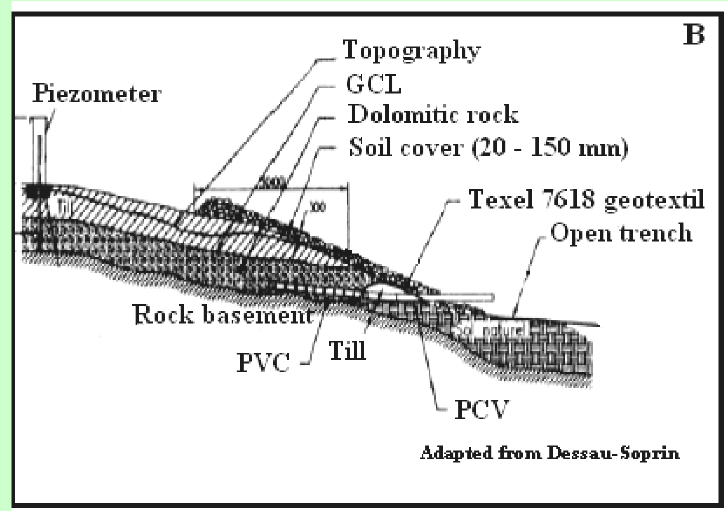
- The tailings thickness ranges from a few centimetres up to 6 meters in the impoundment area which covers approximately 15.5 hectares.

- The Lorraine tailings impoundment was rehabilitated in 1999 using a cover with capillary barrier effects (CCBE): a 0.3 m thick capillary break layer; a 0.5 m thick moisture-retaining layer; a protective layer 0.3 m thick (Nastev and Aubertin 2000; Dagenais et al., 2001, 2005).

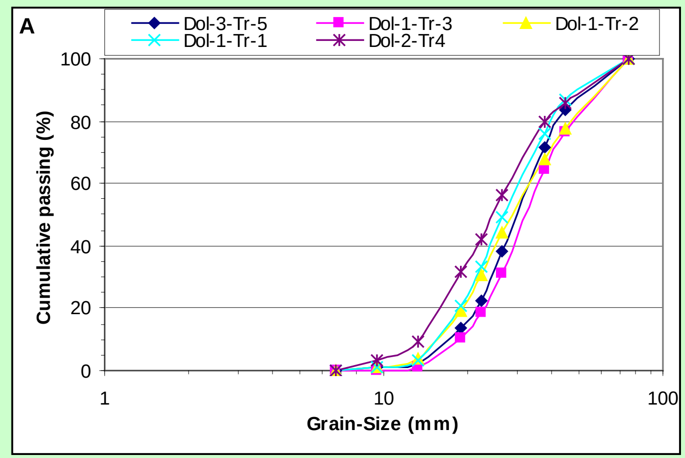


- In parallel with the construction of the CCBE, 3 limestone drains were constructed at the base of the south dike (Bernier et al. 2002). These drains (or trenches) were filled with crushed dolomite rocks (83.5 % dolomite and 2.6 % calcite).

➢ Each drain consists of an isolated trench filled by dolomitic stones; A geosynthetic clay liner (GCL) was placed on top of each trench to ensure sealing.



➢ Most of the dolomitic grains have a size between 26.5 and 37.5 mm, and the material does not contain particles finer than 7 mm.



3. Use of tracers in the context of AMD flowing through ALDs

- The basic idea of a tracer test is simple. It consists in injecting a tracer that flows with water to characterize water displacement in the medium (Sauty 1976; Parriaux et al., 1988).
- The main artificial tracers can be divided into two groups (Käss, 1998; Schudel et al., 2002): soluble and particle tracers.
- The fluorescent tracers are common choices to characterize groundwater movement in rocks (fractured and karstified) and sediments with low clay content (Field et al., 1995) because they are generally easy to handle and to detect at low concentrations.

Table 1: Main properties of fluorescent tracers
(Data taken from Charrière, 1974; Field,2002; Kola and Amatal, 2006)

	Uranine	**Rhodamine B (RB)**	**Rhodamine WT (RWT)**	**Sulfo-rhodamine G (SRG)**	**Eosin**	**Tartrazine**
Empirical formula	$C_{20}H_{10}O_5Na_2$	$C_{28}H_{31}O_3N_2Cl$	$C_{29}H_{29}O_5Na_2Cl$	$C_{25}H_{25}O_7N_2S_2Cl$	$C_{20}H_8Br_4O_52Na$	$C_{16}H_{12}N_4O_9S_2Na_3$
Water solubility	Very High	Low (15/l)	Low	Very low	High (500 g/l)	High (250 g/l)
Maximum thickness of adsorbed layer(nm)	492	554	554	530	517	425
Maximum fluorescence (nm)	514	576	572	560	NA	NA
Measurement disturbance with other tracers	Eosin	SFG Eosin, RWT	SRG, Eosine, RWT	Eosine, RB, RWT	RB, RWT, SRG, uranine	-
Photo-chemical sensibility	High	Low sensibility	Low sensibility	Moderate	Yes	No
Oxydation	sensitive	Not very sensitive	Not very sensitive	Very low	-	Yes
Retention in the medium	Very low	Important	Moderate	Moderate	Low	-
pH sensibility	Yes for pH < 5.5	Yes for pH <5	Yes for pH <5	Low effect for pH <6	No	No

Summary

- Eosin and tartrazine possess all the properties needed for being used as a tracer in an AMD context.
- These tracers can resist to low pH, they are easy to detect using standard apparatus (available at UQAT), they have a large solubility, they are inoffensive for the environment, and their cost is relatively moderate; consequently, eosin and tartrazine can be considered as the most adequate tracers for assessing the AMD flow in the limestone drains at the Lorraine site.
- In addition to these fluorescent tracers, standard salt (NaCl) was also used in this study conducted at the Lorraine site.
- The objective was to evaluate if this common material can be used for tracer tests under such conditions.

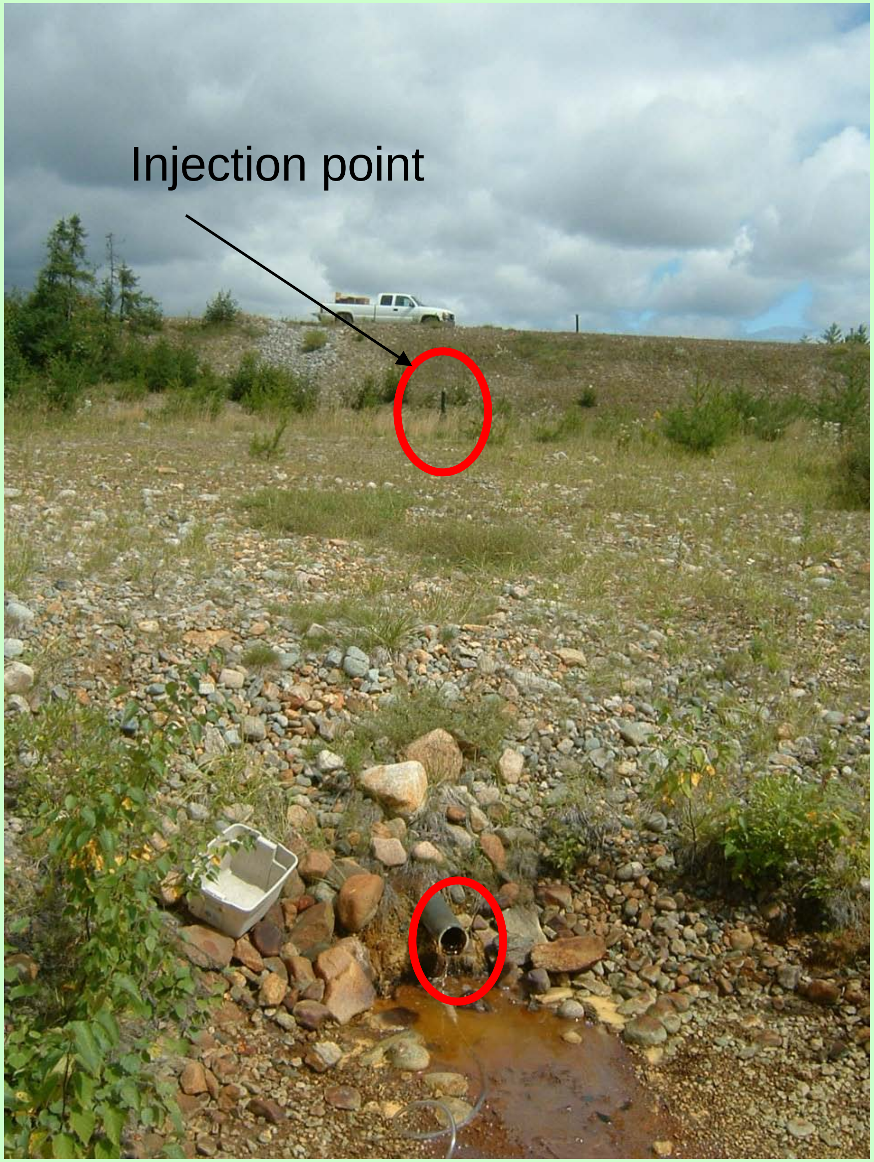
3. Experimental tests and interpretation method

3.1 Experimental tests

- Six tracer tests were conducted at the Lorraine site. Four tracer tests were performed in the Dol-1 drain (Test 1, 2, 3 and 4) and two others (Test 5 and 6) in the Dol-2 drain.
- No test was performed on Dol-3 due to clogging problems observed in this drain (Maqsoud and Bussière, 2007).

Table 2: Tracer tests performed at the Lorraine site

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Date	August 2006	September 2005	July 2007	July 2007	July 2007	July 2007
Used tracer	Eosin	Eosin	Eosin	NaCl	Eosin	Tartrazine
Tracer quantity	100 g	200 g	100 g	300 g	100 g	1400 g
Duration (min)	1733	5665	5887	2991	5896	2987
Linear distance (m)	63.3	63.3	63.3	63.3	41	41

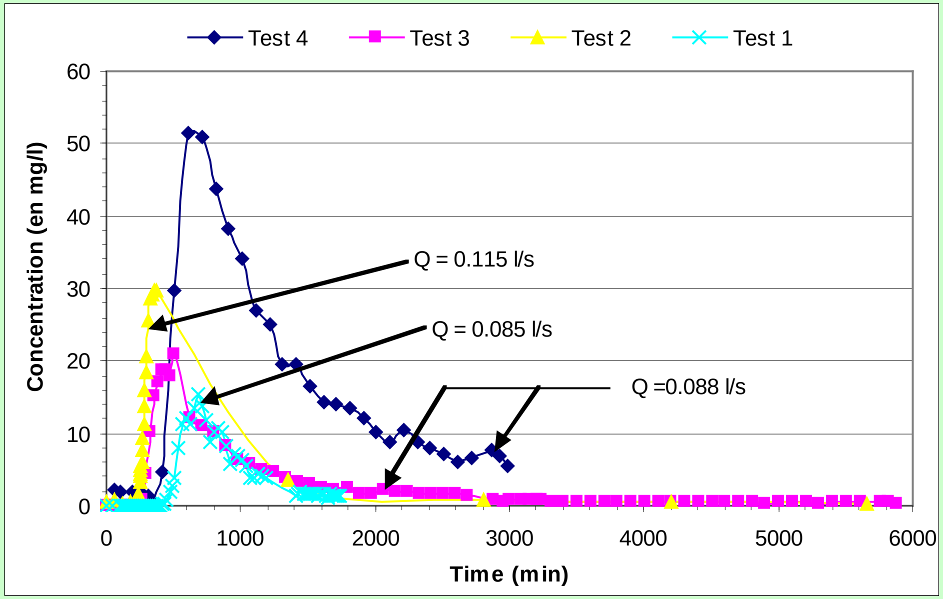

Injection point

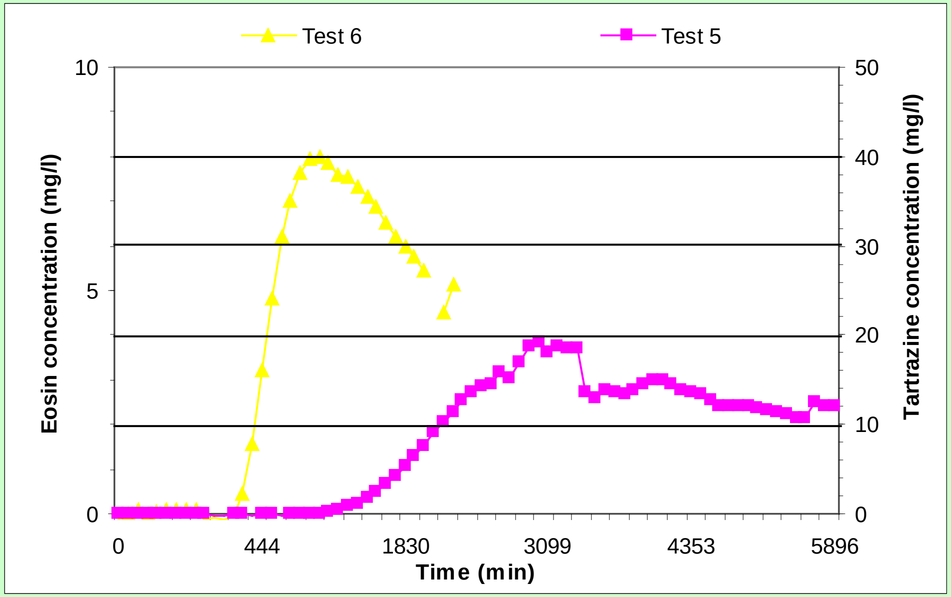
3.2 Interpretation method

- The QTRACER2 program (Field, 2002) was used to interpret the tracer test results.
- According to Field (1997) and Field and Nash (1997), the QTRACER2 program provides a reasonable assessment of the flow dynamics of various types of hydrological and hydrogeological studies including surface-water streams, granular aquifers, fractured-rock aquifers and subsurface-flow channels.
- The QTRACER2 program uses the Chatwin (1971) method, which is based on the analytical solution of the one-dimensional advective-dispersive equation, for the evaluation of the tracer residence time and the determination of the hydrodispersive parameters.
- See proceeding for details.

4. Main results of tracer tests

- Results show the impact of different parameters on the water flow into the drains such as:
  - tracer type,
  - water flux,
  - evolution of the porous medium,
  - and the configuration of the drains (Dol-1 or Dol-2).





Main results obtained using QTRACER2 program are:

Time effect

Tracer type effect

ALD Configuration

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Mean drain discharge Q (l/s)	0.085	0.115	0.088	0.088	0.04	0.04
First arrival (min)	375	180	240	412	1020	744
Time to peak tracer concentration (min)	683	355	500	612	2983	1544
Mean transit time (min)	825	432	686	835	2414	1870
Mean tracer velocity (m/s)	0.13E-02	0.24E-02	0.15E-02	0.13E-03	0.28E-03	0.37E-03
Maximum velocity (m/s)	0.28E-02	0.59E-02	0.44E-02	0.25E-02	0.67E-03	0.92E-03
Percent recovery of the tracer injected (%)	33.86	77.3	56.3	27.8	7.53	53.39

Discharge effect

Summary

- The evolution of Dol-1 properties (due to clogging, dolomite dissolution, secondary mineral precipitation, etc.) is not significant over a one year period.
- The mean transit time increases when the flow rate decreases. For instance, when the flow decreases from 0.115 (Test 2) to 0.085 (Test 1) l/s, the mean transit time increases from 432 to 825 min.
- The tracer test performed using NaCl shows a larger first arrival time, mean transit time, and time to peak tracer concentration than those obtained using the eosin tracer.
- The first arrival time is larger for eosin than for tartrazine (1020 and 744 min respectively for Test 5 and test 6).
- The different behaviour between different tracer could be due to density effect (Test 3 and 4) or to the interaction effect between eosin and the dolomitic stones (Test 5 and 6) which are coated with secondary mineral (St-Arnault et al., 2005).
- The first arrival time, mean transit time, and time to peak tracer concentration are higher in Dol-2 (even if Dol-2 is shorter than Dol-1).
- For both ALDs, the HRT is lower than expected at the design stage

5. Conclusions

- To evaluate HRT of the drains, tracer tests were performed at Lorraine mine site.
- Results of these tests showed that the average of the mean residence time inside the drains is 694 and 2142 min respectively for Dol-1 and Dol-2 and that the time to peak tracer concentration is 537 and 2263 min respectively for Dol-1 and Dol-2.
- This means that the residence times in the Lorraine ALDs are much lower than those targeted at the design stage and found in the literature.
- A short residence time inside the drains is one of the key reasons that explain the lower than expected performance of the limestone drains installed at the Lorraine site for the passive treatment of AMD.
- This study also showed that the selection of an appropriate tracer is essential to obtain representative and precise results.

- Research works are presently underway at the Lorraine site to evaluate the influence of other factors on the drains performance such as:

  - coating of the limestone particles,
  - precipitation of secondary minerals that modifies the pore structure of the medium,
  - and the influence of the unsaturated portion of the drain that affect their geochemical behaviour.