Tracer Test in a Settling Pond – The Passive Mine Water Treatment Plant of the 1 B Mine Pool, Nova Scotia, Canada

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Abstract In order to verify why the design criteria of the Neville Street well field of the 1 B mine pool passive treatment plant are not met, a mine water tracer test with Na-Fluorescein (250 g) and Rhodamin B (363 g) was conducted in the settling pond. Both tracers were injected into the pond during two separate tracer tests with varying flow conditions (102 and 54 L s^{-1}). In addition, oxygen saturation and iron concentrations were measured. It could be shown that the O_2 saturation reaches 81 % after less than a second and the aeration cascade works properly. The mean residence time in the settling pond was calculated to be 10–18 hours. Consequently the reason for the expected discharge criteria not to be met is the low mean residence time in the settling pond. The plant operator therefore installed baffle plates in order to increase the mean residence time in the settling pond.

Key Words Cape Breton, Tracer Test, mine water, settling pond

Introduction

Polluted mine water can be treated with one of two methods: passive or active treatment (Younger et al. 2002). While active treatment involves the usage of electricity and chemicals and is commonly used where highly polluted mine water has to be treated, passive treatment is based on naturally occurring energy sources, such as potential energy or solar energy (ERMITE Consortium 2004). In most cases, but not exclusively, passive treatment is used for less polluted mine waters. Passive treatment is a collective term for a range of different water treatment options, thereunder constructed aerobic wetlands which usually consist of an aeration cascade, a settling pond, and a reed bed (Kleinmann 1990, Hedin et al. 1994).

In case of the 1B mine pool of the flooded Sydney Coal Mine field, with a water volume of $76 \cdot 10^6$ m^3 of mine water, the water in the passive treatment system first flows over a 2 m high, 4 step aeration cascade, then into a 11,000 m^2 and 2.6 m deep settling pond (figure 1) and finally into a 12,200 m^2 reed bed. Between 2005 and 2008 the mean flow from the pumps of the Neville Street Wellfield, which controls the mine water level in the 1 B mine pool, reached 7–9 m^3 min^{-1} at mean Fe_{tot} concentrations of 0.4–5.2 mg L^{-1} (Shea 2009). Based on that data, a mean residence time of 15–18 hours ($t = V / Q$) and a Fe_{tot} concentration of less than 1 mg L^{-1} was calculated and defined as design criteria for the settling pond (Bamforth 2008).

In 2009, the mean filtered Fe_{tot} concentration at the settling's pond inflow was 4.3 mg L^{-1} with a maximum of 10.9 mg L^{-1}, pH was 6.3, base capacity ("acidity") 1.4 mmol L^{-1}, electrical conductivity 1824 µS cm^{-1}, redox potential 307 mV, and the O_2-saturation 42.5 % (all data measured by Cape Breton University). At the outflow, the values were 2 mg L^{-1} with a maximum of 6.5 mg L^{-1}, pH was 7.2, base capacity ("acidity") 0.22 mmol L^{-1}, electrical conductivity 1894 µS cm^{-1}, redox potential 275 mV, and the O_2-saturation 94.5 %. Though the main parameters showed an improvement of the water quality after passing the settling pond, the discharged mine water still had elevated iron concentrations and consequently stained the receiving stream and natural wetland area of Cadegan's Brook.

Yet, compared to the design parameters of the settling pond, the resulting water quality was not satisfying. Therefore, the operator of the passive treatment system concluded that the mean residence time of the mine water in the settling pond and the effectiveness of the aeration cascade might not meet the design parameters. Consequently, a tracer test was initiated using the recommendations in Wolkersdorfer (2008) and in May and August 2009 two tracer tests with Na-Fluorescein and Rhodamine B were conducted. In addition, the flow over the cascade and the oxygen saturation was measured before and after the cascade as well as the settling pond's outflow.

Besides the data described in this paper, physico-chemical data of the passive system was also collected and interpreted in conjunction with the tracer test's results. Due to the space restriction, this paper will focus on the results of the tracer test only.

Figure 1 View of the Neville Street settling pond with the mine water inflow and cascade on the right and the outflow in the upper left corner. Length of the settling pond 150 m, width 60 m

Methods

250 g of Na-fluorescein (C.I. 45350) and 383 g of Rhodamin B (C.I. 45170) were injected at the discharge pipe of the Neville Street Wellfield pumps (inflow of the settling pond) in May and August 2009, respectively. In all cases a Dirac-injection was used with a total injection time of 5–10 minutes including washing the canisters several times with fresh mine water. Na-Fluorescein (Sigma Aldrich F6377—500G) and Rhodamine B (Sigma Aldrich R6626—100G) were dissolved in 10 L of tap water (previous tests showed that the fluorescent intensity of Na-Fluorescein decreases unpredictably when diluted in distilled water) and in the lab were thoroughly shaken for 10 hours on an orbital shaker. At the outflow of the settling pond, an autosampler (SIGMA 900 MAX Portable Sampler) collected one 20-minute mixed sample every hour. Immediately after the autosampler bottles were brought to the lab, the tracer was analysed with a spectro-flourimeter (Varian Cary Eclipse Fluorescence spectrophotometer). Every sample was measured 5 times and the mean used as the real tracer concentration. Calibration was conducted with known amounts of the tracer using 5 – 10 dilution steps.

pH, temperature, redox, and electrical conductivity were measured with a Myron L Ultrameter II P6, base capacity ($k_{B8.2}$) with a Hach Digital Titrator using a Hach SensIon pH-probe, and oxygen with a Hach LDO101 Rugged LDO Probe attached to a Hach HQ40d. Iron was analysed on site using a Hach DR/890 portable colorimeter or a Hach DR/5000 UV-Vis spectrophotometer in the lab.

Flow was measured using the bucket and stopwatch method and a Grayline Ultrasonic flow measuring instrument (the latter used by the operator of the passive treatment scheme). Only the bucket and stopwatch measurements were taken as accurate for the evaluation of the tracer tests.

Results and Discussion

Recovery rates based on the Grayline Ultrasonic flow measurement were 115 % in May and 102 % in August 2009, while those based on the bucket and stopwatch method were 100 ± 2 %. Between the May and the August tracer tests the ultrasonic flow measurement system was re-calibrated and therefore the August tracer test matches the recovery rate of the bucket and stopwatch method. During the May tracer test the first tracer arrived 2.5 hours (figure 2) and in the August tracer test 4 hours after injecting the tracer (figure 3). The mean residence times were 10 ± 0.5 hours and 18 ± 1 hours with a maximum residence time of 31.5 ± 0.5 and 28.5 ± 1 hours. This difference is due to the dissimilar flow conditions with a mean flow of ≈ 102 L s^{-1} in May and ≈ 54 L s^{-1} in August. Both tracer tests show 3 peaks (breakthrough 1 to 3), which are due to two facts: the flow condition within the settling pond itself and potential seepage of the mine water back into the flooded mine workings. The first breakthrough after 3–32 hours belongs to fast flowing near surface water and slower flowing water in the deeper parts of the settling pond. Organoleptic inspections clearly proved that the first tracer arrival is related to fast flowing near surface water ($v \approx 1 \pm 0.2$ m min^{-1}). In both tracer tests the first breakthrough summed up to a recovery rate of 100 %. The second and third peaks are less obvious. Yet, the time difference between the first tracer arrival for each breakthrough in both tracer tests is, independent from the flow rate, 27 ± 2 hours. In addition, they show a low pass filtered curve progression. Consequently, the hypothesis that the second and third peaks result from re-circulated mine water was tested. As described in the introduction, the settling pond discharges into a natural wetland of Cadegan's Brook. From previous studies and from statistical investigations of the mine water chemistry it is known that Cadegan's Brook infiltrates into the mine workings. Therefore, those two peaks are related to water seeping back into the mine workings and being repumped by the mine water pumps. Using the data of the May tracer test it can be calculated that ≈ 3 ± 5 % of the water is infiltrating through the natural wetland back into the mine workings.

Oxygen saturation was measured at three locations: before the cascade, at the bottom of the cascade and at the outflow of the settling pond. Before the cascade the saturation was 42.5 ± 5.5 % (1 σ, n = 24), at the bottom 80.9 ± 4.6 % (1 σ, n = 23), and the settling pond outflow 94.5 ± 2.5 % (1 σ,

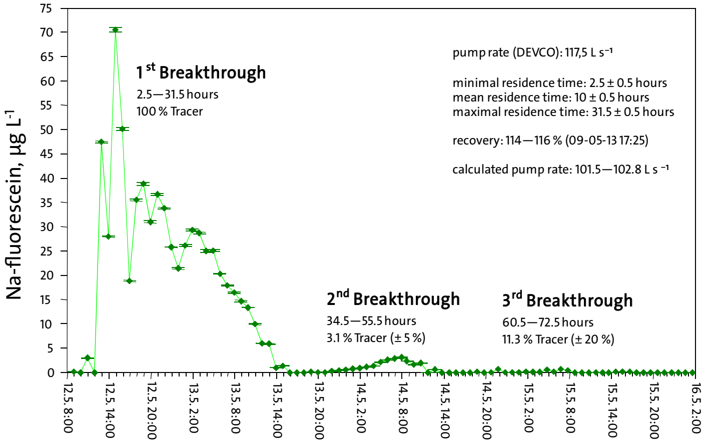

Figure 2 *Breakthrough curve of the May 2010 tracer test in the Neville Street settling pond*

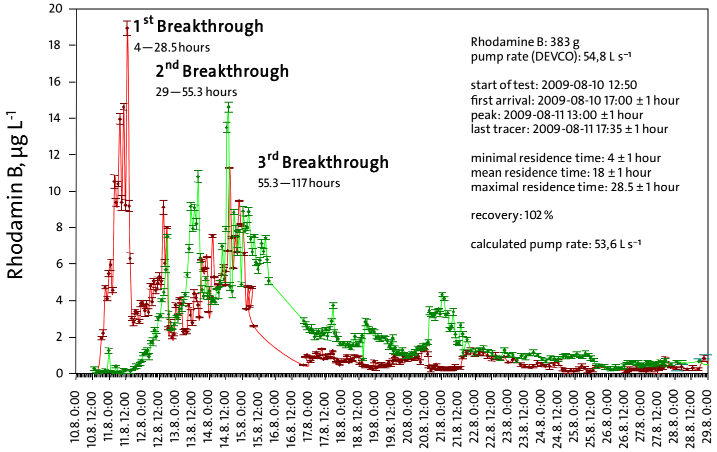

Figure 3 *Breakthrough curve of the May 2010 tracer test in the Neville Street settling pond. The 2 curves belong to the sampling locations at the settling pond outflow (higher concentrations) and the outflow wetland (lower concentrations)*

$n = 24$). Most of the oxygen in the settling pond is therefore from the first couple of seconds while the mine water flows down the cascade, whereas a smaller portion comes from the several hours residence time in the settling pond.

Iron was also measured at those three locations in order to identify the effectiveness of the cascade and the settling pond. Before the cascade the filtered Fe_{tot} mass concentration was 4.3 ± 3.3 mg L^{-1} (1 σ, $n = 30$), at the bottom 4.1 ± 3.2 mg L^{-1} (1 σ, $n = 27$), and the settling pond outflow 2.0 ± 1.7 mg L^{-1} (1 σ, $n = 26$). Ferrous iron mass concentrations were 2.6 ± 1.7 mg L^{-1} (1 σ, $n = 30$) at the inflow, at the bottom 2.2 ± 1.4 mg L^{-1} (1 σ, $n = 27$), and the settling pond outflow 0.7 ± 0.7 mg L^{-1} (1 σ, $n = 26$). Statistically, no difference before and after the cascade could be found and the Fe_{tot} concentrations do not meet the design criteria at the settling pond's outflow.

Conclusions

As has been shown, the aeration cascade of the Neville Street settling ponds functions according to the expectations and the mine water is aerated from 40 % to 80 % oxygen saturation, reaching 90 % at the settling pond's outflow. Furthermore, the tracer test clearly shows that the elevated iron mass concentrations at the settling pond's outflow are a result of the low mean residence time of the mine water in the settling pond. This mean residence time is too low to oxidyze the iron and also too low for the iron oxy-hydrate to settle in the settling pond. In addition, the tracer test's results indicate that part of the discharged mine water may re-infiltrate into the mine workings. A further tracer test will be conducted to verify this hypothesis.

In order to increase the mean residence time of the mine water in the settling pond baffle curtains were installed within the settling pond. During a storm event at the beginning of 2010, the baffle curtains were damaged and no additional tracer test could be conducted since then. Meanwhile new baffle curtains were installed, but at the time of writing no physicio-chemical results are available.

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