Nitrogen leaching from explosives into mine water of an underground mine.

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Abstract

Ammonium nitrate is a major reagent of mining explosives. It is relatively soluble and is leached out from undetonated explosives into mine water. The fraction and speciation of nitrogen leached into mine water are important factors controlling the chemistry of mine water discharge. This paper investigates factors affecting the fraction of leached nitrogen and nitrogen speciation in an underground mine operating in Northern Manitoba, Canada. These factors include rate of explosive use, type of explosive and dewatering flow rate. The study is based on records of explosive use and on monitoring of quantity and quality of mine water and for four years.

Results of this study shows that on average, 16.5% of the mass of nitrogen used in explosives was leached to mine water during monitoring period. The study did not show difference between ammonium nitrate/fuel oil (ANFO) and emulsion in leaching rates of nitrogen. Increase in mine inflow rates overtime does not result in higher nitrogen leaching rates, but it may be causing a declining time-trend of nitrogen concentrations in mine water. In mine water, the major nitrogen species are nitrate (55% of total N) and ammonia (42% of total N) with a minor amount of nitrite (2.1% of total N). This speciation is close to the original nitrogen distribution in the ammonium nitrate indicating a limited reactivity of nitrogen species after the blasting and dissolution of explosives.

This paper compares results of this study to literature data and provides useful quantitative data for predictions of water quality and environmental protection planning.

Keywords: nitrogen, ammonia, nitrate, mine water, underground

Introduction

Ammonium nitrate is a major reagent of mining explosives. It is relatively soluble and is leached out from explosives into mine water. The fraction and speciation of nitrogen leached into mine water are important factors controlling the chemistry of discharges and the receiving water bodies (Frandsen et al 2008). This paper presents a case study of nitrogen leaching from an underground mine operating in Northern Manitoba, Canada. The mine owners of mine prefer to keep the name of the project anonymous, replacing mine name with X in the references.

Geology and Hydrogeology

The deposit is volcanic massive sulphide (VMS) type and is located in the Precambrian metavolcanics covered with Ordovician sedimentary rocks and overburden. The Precambrian rocks underlying the Ordovician cover include a section of deeply weathered rocks which varies in thickness from 5 to 25 metres (Bailes 2010). Most of the orebody is located between 100 and 300 m below the ground. The ore is primary mined for copper with gold and silver being secondary economic metals.

Hydrogeological testing conducted indicated that there is high hydraulic conductivity of shallow rock extending up to 23 m deep from the surface. Half of hydraulic conductivity values estimated were between 10^{-5} m/s and 10^{-6} m/s (Golder 2011). This is consistent with poor consolidation of Ordovician sedimentary and weathered Precambrian metavolcanics rocks. Below 42 m, the Precambrian rock and ore have lower hydraulic conductivities, ranging between 10^{-7}m/s and 10^{-8} m/s. Grouting of mine workings has helped to reduce groundwater inflow from the shallow rock to the mine.

Methods

This study is based on records of explosive use and on monitoring of quantity and quality of mine water and for four years (2014-2017). Records of the mass and type of explosives used were available on daily basis for first 1.5 years and as monthly averages afterwards. The explosives contained 65% (by mass) of ammonium nitrate on average, which is equivalent to 24 % (by mass) of nitrogen. This information allowed for the calculation of the rate of ammonium nitrate and nitrogen used by mine (R_U, kg/day).

The leaching rates for nitrogen (RL, kg/day) were calculated by multiplying outflow rate from the mine (Q, m^3/day) by concentration of nitrogen species (C, mg of N/L) and divided by conversion volume factor (1000 liters to m^3). Outflow rates were calculated by the mine operators from flowmeter readings recorded with approximately a weekly interval. Mine water samples were taken weekly during the first year and biweekly thereafter. Samples were kept at ≈ 4°C and shipped to a certified laboratory (ALS, Winnipeg) within the required hold times and tested for ammonia, nitrite and nitrate nitrogen. Concentrations of nitrogen in these species were added to calculate the concentrations of total nitrogen in mine water for each day of sampling. For the days without flow or concentration records, the last recorded value was assumed until the next flow record or sampling event occur, respectively. Daily values were averaged for each month and the percentage of nitrogen lost (NLOST, %) in a given month was calculated as $N_{LOST} = R_L/R_U \times 100\%$.

Results and Discussion

Between 2014 and 2018, the powder factor ranged between 0.64 kg and 0.66 kg of explosive per tonne of material blasted, with approximately 600 kilo tonnes mined each year. Average monthly leaching rates ranged between 13.7 kg N/day and 65.4 kg N/day with a mean value of 39.7 kg of N/day (fig. 1a). Average monthly leaching rates do not show a statistically significant correlation with monthly use of explosives indicating that there are other factors affecting nitrogen leaching to mine water.

The monthly percentage of leached nitrogen (NLOST) ranged from 4.7% to 32.2%, averaging at 16.5% of mass nitrogen used in explosives. Similar range of nitrogen loss (12%-28%) was estimated for the development of the underground mine (Moring and Hutt 2008). The case studies of open pit coal mines in British Columbia, show lower average percentages of leached nitrogen (up to 5%) than in this study (Ferguson and Leask 1988).

The major explosive type was emulsion (82%), with small amounts of ammonium nitrate/fuel oil–(ANFO) (18%). A limited percentage of ANFO (≈3%) was used in the first 1.5 years and increased thereafter (to ≈29%, fig. 1a). Revey's (1996) laboratory tests showed that ANFO has higher dissolution rates than emulsion. The data from our field study do not support this observation because there is no statistically significant correlation between use of ANFO and nitrogen leaching rates. Also, mean nitrogen leaching rates in first 1.5 years (40 kg N/day) and in the remaining monitoring period (39 kg N/day) are similar.

The major groundwater inflow to the mine is expected from shallow bedrock showing high hydraulic conductivity values. Mine outflow ranged from 341 to 957 m^3/day on monthly basis, averaging at 632 m^3/day. The mean annual outflow increased from ≈510 m^3/day in 2014 to 760 m^3/day in 2017. Pronounced increase in outflow was observed in spring months, between March and June followed by stabilization or slight decline (fig. 1b). The linear regression for outflow show long-term increasing trend, while the trend for nitrogen leaching rate show no significant change. The disagreement between these long-term trends indicate that increase in mine inflow/outflows does not seem to affect leaching rates.

Average monthly nitrogen concentrations in mine water range from 26.7 mg N/L to 114.8 mg N/L with mean value of 64.4 mg N/L. Long-term regression for nitrogen concentrations show a declining trend, which can be attributed to an increase in outflow volume resulting in dilution mine water (fig. 1c).

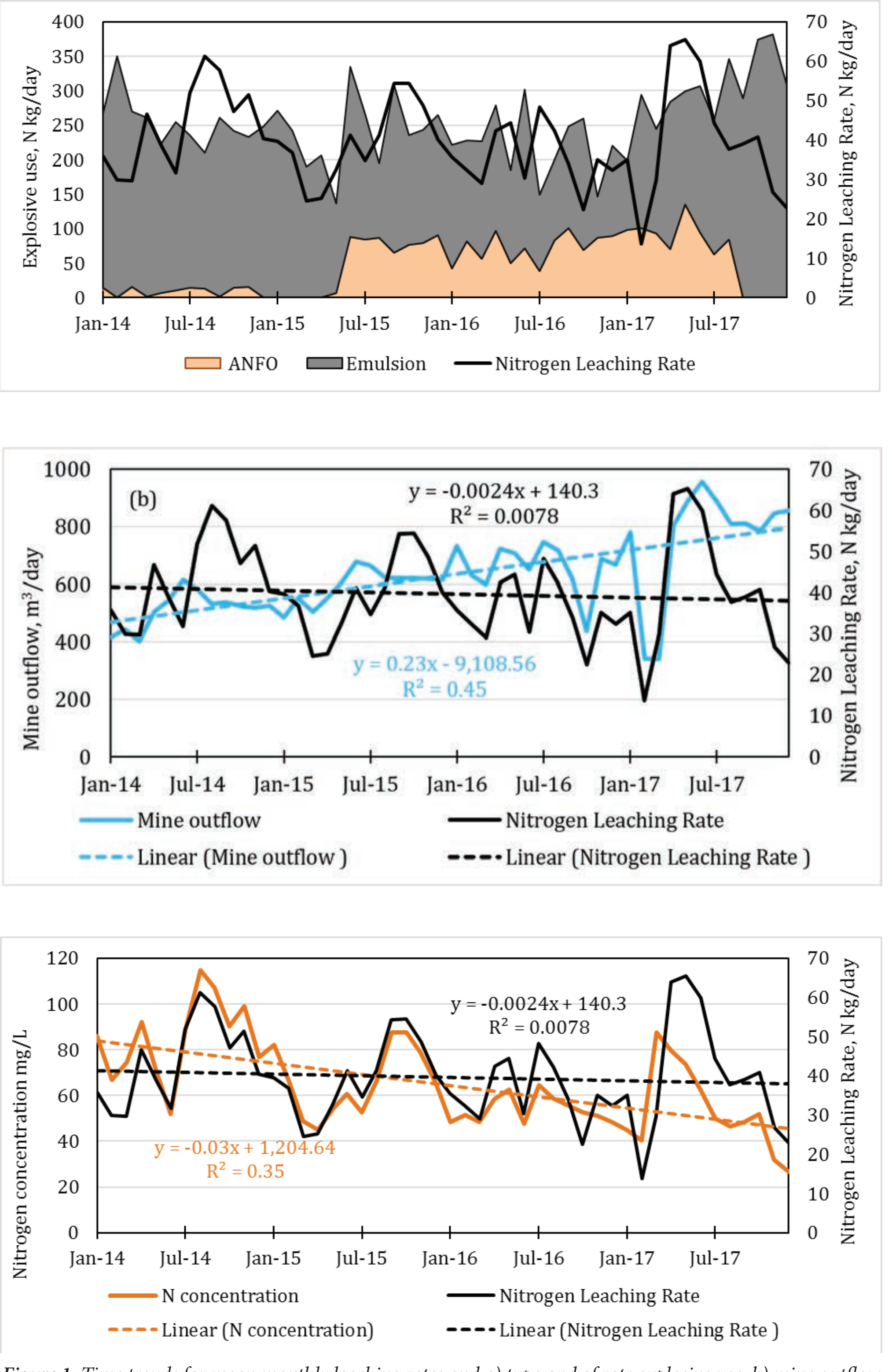

Figure 1. Time trends for mean monthly leaching rates and a) type and of rate explosive use, b) mine outflow and c) nitrogen concentration in mine water.

In mine water, the major nitrogen species are nitrate (55% of total N) and ammonia (42% of total N) with minor contribution of nitrite (2.1% of total N). This speciation is close to the original nitrogen distribution in the ammonium nitrate indicating a limited reactivity of nitrogen species after the blasting and dissolution of explosives. Similar distribution of nitrogen species was found in discharge form the underground mine by Morin and Hutt (2008).

Conclusions

The findings of this study can be summarized as follows:

- On average16.5% of mass nitrogen used in explosives was lost to mine water during monitoring period.
- The study did not show a difference in leaching rates of nitrogen between ANFO and emulsion.
- Increase in mine inflow rates overtime does not result in higher nitrogen leaching rates, but it may result in declining trend of nitrogen concentrations in mine water
- Nitrogen speciation in mine water is close to the original nitrogen distribution in the ammonium nitrate indicating a limited reactivity of nitrogen species after blasting and dissolution of explosives.

The paper also provides useful numerical data for predictions of water quality and environmental protection planning.

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