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Spray freezing decontamination of tailings water at the Colomac Mine

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Abstract

A field pilot scale experiment was conducted to evaluate the efficiency of spray freezing to remove dissolved chemicals from the tailings lake water at the Colomac Mine, NWT. Cores of the spray ice were then taken to the University of Alberta. The distribution of chemicals in the ice cores were determined, then a 1 m long core sample was thawed in a controlled manner to simulate thawing in the field to examine the concentrations of chemicals in the melt water as the columns thawed.

For the pilot scale project approximately 30% of the water pumped was frozen, with the remaining water returned to the tailings pond as runoff. Analysis of the water collected from an ice core melted under controlled laboratory conditions showed dissolved chemical removal of 87–99% (depending on the chemical species) after 39% of the spray ice column had melted. Arsenic concentrations were reduced from approximately 19 μg/L to 5 μg/l. Cyanide had 99.2% removal but still remained at a concentration of approximately 350 μg/L. Approximately 60% of the treated water released at the end of the melt contained only 1–17% of the dissolved species. This melt water at the end of thaw would only require minor further treatment, which may significantly reduce overall treatment costs.

Keywords: Tailings water; Spray freezing; Contaminated water treatment; Arctic mine wastes

1. Introduction

The storage of large volumes of tailings water in abandoned tailings facilities can pose management and environmental concerns. This tailings water often contains significant concentrations of numerous dissolved constituents, which may preclude direct release into the environment. Treatment of these large volumes of fluids to facilitate release, thereby reducing storage requirements can be very costly, so inexpensive treatment alternatives are of considerable interest. Spray freezing has been shown to be a very inexpensive way to remove significant amounts of dissolved constituents from very large volumes of

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water where environmental conditions facilitate freezing in the winter months and thawing in the summer months (Gao, 1998). Depending on the waste stream, spray freezing may be used alone to treat the water, or as a pre-treatment stage to significantly reduce dissolved concentrations thereby reducing the costs of subsequent chemical or physical treatment prior to release.

To examine the effectiveness of spray freezing for gold mine tailings water treatment, a field trial was conducted by the University of Alberta (U of A) from March 25 to 29, 2002, at the Colomac Mine Tailings Lake, North West Territories. This paper initially describes the execution of the spray freezing test, then goes on to describe the laboratory testing conducted on the ice cores obtained from the spray ice mound. The results and discussion of the field and laboratory testing are then presented and discussed.

2. Background

The technique of spray freezing relies on the physics of a freezing droplet of water and ice crystal formation concentrating contaminants in unfrozen liquid. Done properly, spray freezing can be an economical, efficient and environmentally friendly component of a larger water treatment system (Gao et al., 1996a, 2000).

Generally, as a droplet of impure water freezes, the impurities are pushed away from the ice crystallization front, resulting in a liquid with a higher contaminant concentration and nearly pure ice. The freezing point of the remaining impure water decreases as this process continues, and as time passes, more ice is formed and the contaminants become more concentrated in the remaining unfrozen liquid. This unfrozen liquid drains from a spray ice deposit resulting in removal of contaminants immediately following spraying. The droplet may freeze completely if it is too small, the surrounding air is too cold, and the droplet remains exposed to the air for long enough, negating much of the benefit of the spray freezing technique. Additionally, as the ice melts during spring thaw, the dissolved contaminants are preferentially flushed with the initial melt water increasing the purity of the remaining water (Johannessen et al., 1975; Cragin et al., 1993).

The field application of this technique involves pumping contaminated water through a nozzle and spraying it into cold air. Adjustments are made to the trajectory of the water jet, the rate of pumping and the size of the droplets using nozzle adjustments, to control how completely the water freezes for a given air temperature and wind speed (Instanes, 1993; Gao, 1998).

3. Site description

Colomac Mine is an abandoned gold mine located 220 km north of Yellowknife, near the border dividing

Fig. 1. Photo of site layout with pump and tarp.

the Northwest Territories from Nunavut. The mine is accessible year-round by aircraft, and for a short period each year via an ice road originating at Rae–Edzo. The spray freezing test site was on the upstream beach of one of the tailings dams. The pump was placed at the edge of the lake, and drew lake water through a 25 m length of suction line. Adjacent to the lake, a plastic tarp covering a 25 m×25 m area served as containment for the spray of water. At the end of the tarp an area of the lake was cleared of snow, and a hole was augured through the ice to allow the runoff from the spray-ice pile to flow back into the lake. Fig. 1 shows the site layout.

4. Methodology

4.1. Field work program

Prior to establishing the spray ice mound location it was necessary to resolve the distance from shore to a suitable water source (and thus the length of suction line required), due to uncertainty about the ice thickness and the slope of the beach below water. Several holes were augured initially, however a pre-existing hole through the ice was ultimately used. This hole, and others like it nearby, appeared to be kept open despite the cold temperatures by a constant bubbling of gas from the lake. The composition of this gas was not determined because no collection equipment was available because this was not part of the planned study. The large diameter (~0.75 m) of the open hole permitted shallow placement of the water intake line, whereas had an augured hole been used, the intake would have been located immediately below the ice cover increasing the potential for undesirable drawing of tailings solids into the spray water. Prior to placing the pumping equipment and tarp, an area of beach approximately 60 m×60 m was cleared of snow just uphill from the ice edge. A plastic tarp was then placed and snow berms were constructed along its edges to control runoff from the spraying operation.

Pumping commenced at approximately 9:30 a.m., March 28, and the trajectory of the water jet and the droplet size were adjusted to keep the spray landing near the center of the tarp, and in a state wherein water droplets were not completely frozen when deposited. The air temperature during the test remained at approximately −23 °C until 6:00 p.m., then dropped steadily to −33 °C at 02:00 a.m.. Starting at 10:00 a.m., samples of runoff water were collected hourly and electrical conductivity (EC) was measured. The value of the EC is proportional to the amount of dissolved chemicals, so provides a measure of the efficiency of the freeze-separation process. Samples of the supply water were collected at the water intake several times during the day with EC measured as well. Table 1 provides a detailed listing of these data.

As the ice mound grew, the difference between the clean ice and the concentrated runoff became visually apparent. Two distinct colour regions were observed in the spray ice mound during placement: a white zone above that corresponds to clean ice, and a brownish-yellow band around the base of the ice mound approximately 20–30 cm thick where the concentrated downward draining fluid exited the mound. After the spraying operation was completed and all the fluid had drained, this darker band of ice was no longer visible.

The pump continued to operate until approximately 2:00 a.m., March 29 (16.5 h after startup), when the diesel engine quit for unknown reasons. It was speculated that the combination of very cold temperatures, wind chill, and possibly poor quality fuel combined to restrict the fuel supply to the engine. By this time the top spray ice mound was at more than 5 m high, meeting the minimum target height for the field test, so no further spraying was conducted. Fig. 2 shows the spray ice mound upon completion of spraying. The two objects protruding from the mound are wooden posts, placed with their tops 2 m and 4 m above the tarp (as gauges of the mound height.) Fig. 3 plots a survey after the ice mound was constructed. Runoff sampling continued until 5:00 a.m., 29 March.

4.2. Spray ice sampling

On the afternoon of March 29 the mound had frozen and hardened enough to support the weight of a person. After a survey of the ice mound was performed for volume calculations, core samples were obtained by hand auguring using a 100 mm inside diameter, 1 m long CRREL core barrel. Two holes were cored vertically from the peak of the ice mound, approximately 5 m and 2.5 m deep, respectively. The

Table 1
Spray freezing data and water sample inventory from tailings lake area, Colomac mine, NWT

Sample no.	Date	Time	Sample type	Air temp. (°C)	Conductivity (mS/cm)	Conductivity Temp. (°C)	Nozzle pressure (kPa)	Flow rate setting (m^3/hr)
1	3/28/02	10:00	Supply	−23	1.79	8.4	n/a	79.2
2		10:00	Runoff	−23	1.95	7.3	n/a	79.2
3		11:10	Supply	−22	1.85	2.6	n/a	79.2
4		11:10	Runoff	−22	2.04	n/a	n/a	79.2
5		14:00	Runoff	−22	2.32	0.2	724	79.2
6		14:20	Supply	−22	1.82	−0.4	724	79.2
7		12:00	Runoff	−22	2.20	2.5	724	79.2
8		15:00	Runoff	−22	2.42	0	724	79.2
9		16:00	Runoff	−22	2.39	0	931	79.2
10		17:00	Runoff	−23	2.30	−0.2	931	79.2
11		18:00	Runoff	−24	2.35	−0.2	931	79.2
12		19:00	Runoff	−25	2.37	−0.1	931	79.2
13		20:15	Runoff	−25	2.34	1.2	931	79.2
14		21:00	Runoff	−27	2.35	0.1	931	79.2
15		22:00	Runoff	−29	2.35	−0.2	931	79.2
16		22:00	Supply	−29	1.78	−0.2	896	79.2
17		23:00	Runoff	−29	2.29	−0.3	896	79.2
18	3/29/02	0:00	Runoff	−29	2.40	−0.5	896	79.2
19		0:15	Supply	−29	1.64	−0.3	n/a	79.2
20		2:00	Runoff	−33	2.31	−0.3	896	79.2

Sample 19 was supply sample taken at the nozzle. The rest of the supply sample were taken at the lake surface.
Sample 20 was taken at the North Runoff.
Virtually no runoff after 03:30.

cores were extruded and carefully bagged for later analysis, then packed in coolers with snow for transport to Edmonton, Alberta. The cores had a consistency similar to densely packed dry snow. At the U of A the cores were stored in a chest freezer located in a cold room at −15 °C until required for testing. The samples were surrounded by crushed ice during storage to minimize any sublimation losses.

Fig. 2. Spray ice mound after completion.

4.3. Spray ice core thawing

Fig. 4 illustrates the experimental set-up for thawing. It consisted of an ice core approximately 1 m long that was melted from the top down using a 40-Watt incandescent light bulb suspended above the core as a heat source. A distance of 100 mm above the top of the ice was determined to be optimal for reasonable thaw rates. The ice core was enclosed in a PVC pipe for support, and was also tightly encased in an impermeable latex rubber membrane so that melt water would flow down through the ice core rather than down the void between the core and the PVC pipe. This better simulated field conditions of melt water migration down through the ice pile to leach the dissolved species from the ice mass as it melted. The high porosity (low density) of the ice core (approximately 0.5 Mg/m^3) necessitated that care be taken to avoid crushing the fragile core when the membrane was installed. The ice core segments were pieced together so the membranes overlapped from the bottom, up to prevent water leakage where the membranes overlapped. Water samples were collected twice daily to reduce the potential for geochemical changes prior to sample collection.

Collection and analysis of the runoff proceeded as follows. The runoff volume was recorded (which varied from 250–700 mL), then a 20 mL aliquot was removed and two drops of sodium hydroxide were added as a preservative for the cyanide analysis. Another 150 mL subsample was taken and both sample containers were sent to a certified commercial laboratory for analytical testing. Electrical Conductivity (EC) and pH were measured on the rest of the sample, and the remaining liquid was immediately frozen and kept for future testing if needed. After each collection the reservoir was rinsed with deionized water, and wiped dry. Thawing of the 1 m long ice core took 7 days.

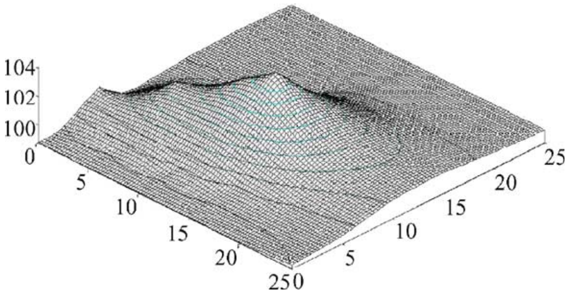

Fig. 3. Contour plot of survey data after spray freezing (dimension in metres).

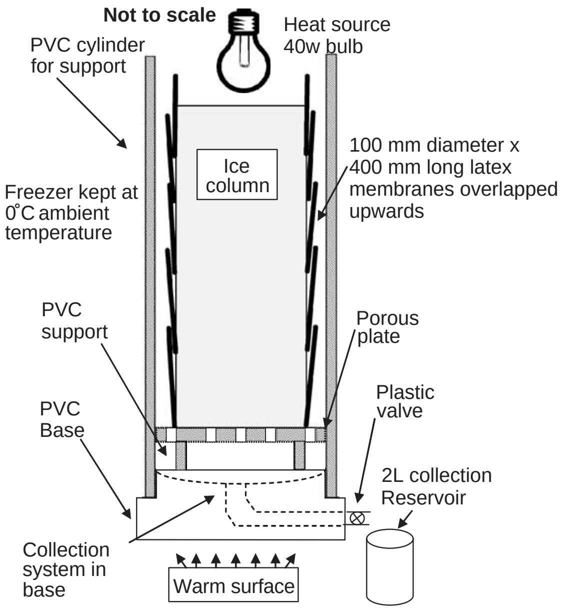

Fig. 4. Spray ice core thawing apparatus.

5. Results

5.1. Spraying operation

The pump was run at an average flow rate of 79.2 m^3/hr, from 10:00 a.m., March 28, 2002 until 2:30 a.m. on the 29th, for a total of 16.5 h. Thus a total of approximately 1310 m^3 of water was pumped. Detailed data gathered during the experiment are contained in Biggar et al. (2003).

Based on the survey data, Surfer® software was used (Fig. 3) to determine that approximately 760 m^3 of ice was produced. Based on measurements of sections of the ice core to depths of 3.5 m, the ice was found to have an average density of 0.55 Mg/m^3 (range=0.51–0.64 Mg/m^3, n=8) for a total of approximately 420,000 kg of produced ice, or 420 m^3 of the pumped water was frozen. The observed rate of runoff showed that very little ice was accumulating at the commencement of pumping. However, gradually more ice began to form and consistently accumulate. After 4 h of operation the runoff rate appeared to remain constant until shutdown.

The calculated mass of ice formed compared to the mass of water pumped indicates that approximately 32% of the water that was pumped was frozen into spray ice. Because it took approximately 4 h to reach peak freezing efficiency, during approximately 75% of the pumping the process was at peak ice production.

The electrical conductivity readings taken in the field suggest that the conductivity of the supply water remained nearly constant at approximately 1.82 mS/cm. While the runoff EC started near that value, it rose to approximately 2.32 mS/cm by the fourth hour of operation and remained there for the duration of the pumping (Table 1). This suggests that the process was concentrating dissolved ions in the runoff water, as expected. The chemical analytical results from the supply samples compared to those of the runoff samples (Fig. 5 and Table 2) confirm that the process behaved as expected and concentrated the dissolved ions in the runoff.

Table 2
Comparison of average chemical concentrations (±1Standard Deviation) of supply and runoff water samples from the tailings lake

Species	Supply water (*n*=4) mg/L	Runoff (*n*=5) mg/L	Difference (%)
Cyanide, total	47±8	72±11	31
Thiocyanate	254±10	321±25	16
Arsenic	0.039±0.004	0.068±0.006	56
Calcium	27.9±2.3	35.4±4	16
Magnesium	6.1±0.6	9.3±1.4	32
Sodium	272±19	417±63	32
Potassium	7.3±0.9	10.6±1.8	27
Chloride	120±15	171±29	23
Sulphate-S	217±17	296±44	17

n=number of samples.

5.2. Ice core analysis

The ice density varied between 0.51 and 0.64 Mg/m^3 with an average of 0.55 Mg/m^3. This is slightly more than one half the density of solid ice at approximately 0.91 Mg/m^3. The cores had voids and zones of loose ice crystals. As seen in Fig. 6, the density variations were independent of depth and appear to be random. Core samples sent for chemical analysis showed that concentrations appeared to have no relation with depth or density (Fig. 7).

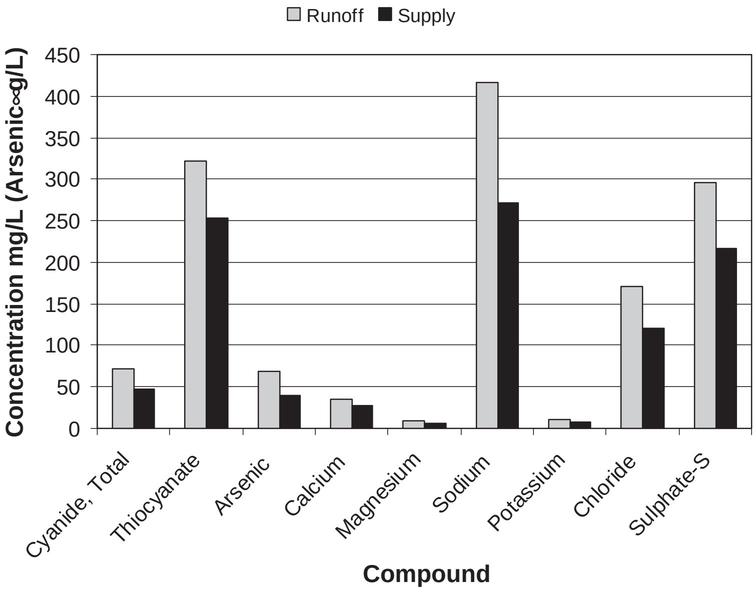

Fig. 5. Comparison of chemical concentrations of supply and runoff water samples from tailings lake.

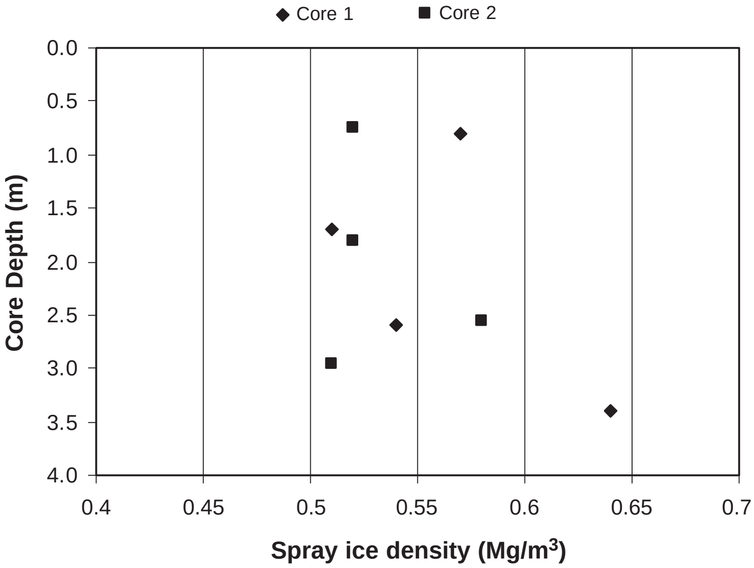

Fig. 6. Spray ice core density. (Note: Core 1 was near the center of the ice mound and Core 2 slightly off center.)

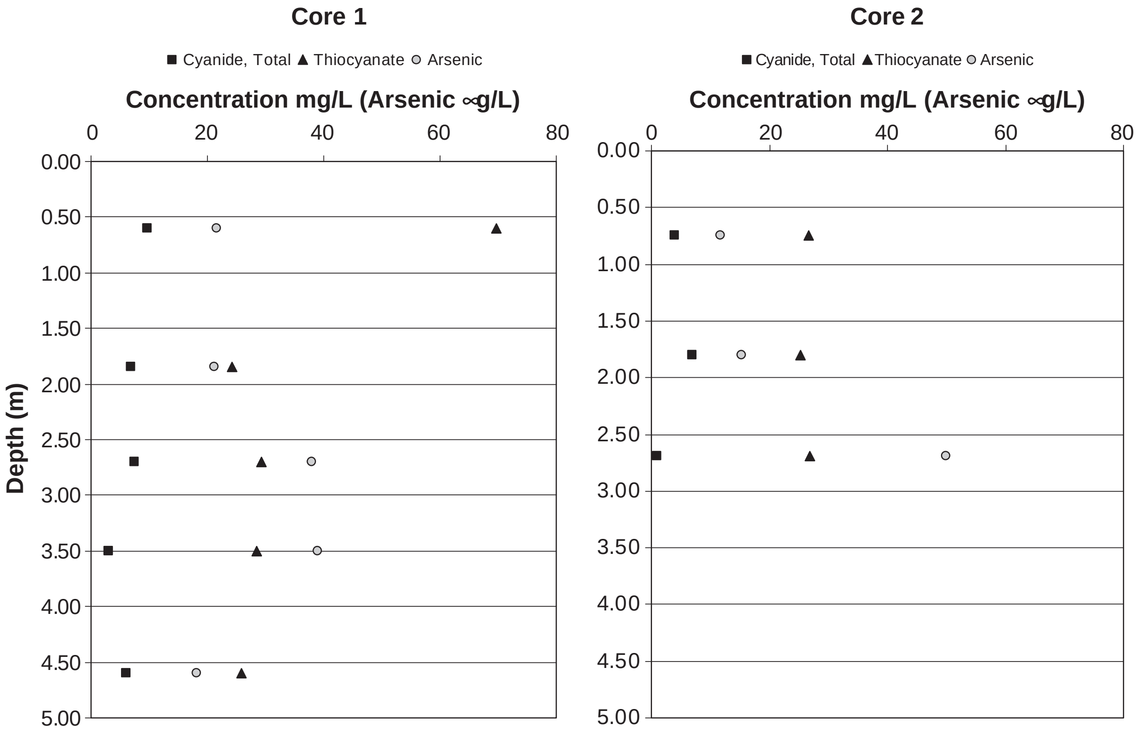

Fig. 7. Chemical concentrations versus depth in ice cores. (Note: Core 1 was near the center of the ice mound and Core 2 slightly off center.)

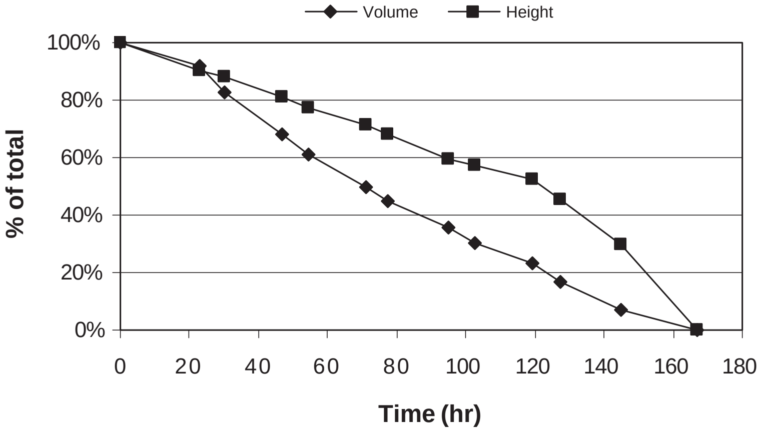

Fig. 8. Decrease in ice core volume and height versus time during thawing.

5.3. Core thawing experiment

Fig. 8 shows the rate at which the column thawed with respect to sample height and melt water volume. The rate of melt water evolution generally decreased for the entire experiment, while the height, measured by ruler along the spray ice test column, decreased linearly to approximately 120 h then decreased more rapidly there after. This implies that the ice core became less dense during the melting process. The rate at which the core melted varied through the experiment and was shown to be very dependent on the placement of the bulb used as a heat source (see Fig. 4). Fig. 9 shows that the thaw rate started at less than 20 mL/h on the first day, peaked at 64 mL/h on the second day then generally decreased with time. The saw tooth effect seen in the plot is a result of the movement of the ice surface with respect to the heat source. During working hours the bulb could be kept close to 100 mm from the column top, however during the night as the column melted the surface would move farther away from the bulb, slowing the melt. However, the trend of a general decreasing melt rate is well illustrated.

Fig. 10 shows the electrical conductivity versus time for the melt water. The electrical conductivity of the melt water started at 1800 μS/cm and fell sharply until 55 h, or until 39% of the ice had melted, then continued to decrease but at a much smaller rate.

Fig. 11, shows the calculated mass of the various ionic species remaining in the ice column versus time, and illustrates that the behaviour of the EC versus time is representative of the behaviour of most of the ionic species in the ice, in that the mass quickly

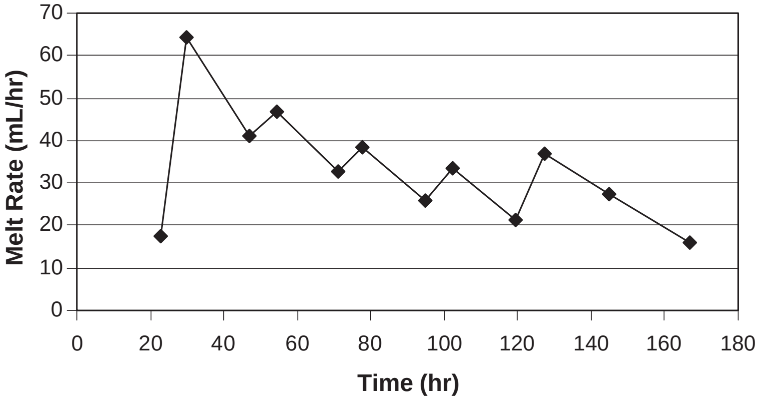

Fig. 9. Spray ice melt rate.

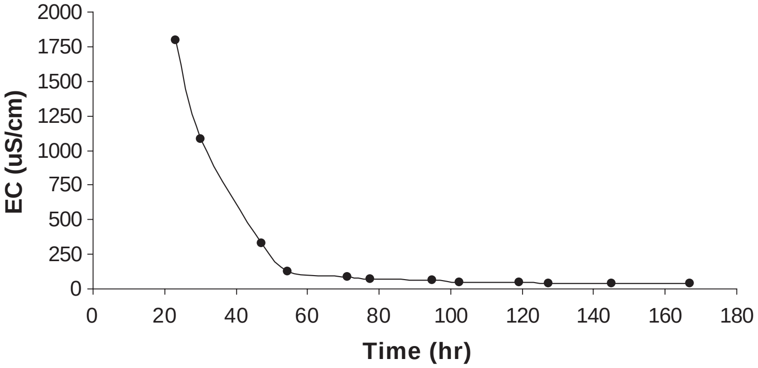

Fig. 10. Spray ice core meltwater electrical conductivity versus time.

decreased until the 55 h mark, after which mass loss was much slower, with the exception of Arsenic. The mass loss of Arsenic was slower and nearly constant, indicative of a nearly constant concentration over the duration of the melting process.

Fig. 11 illustrates that with 61% of water volume remaining less than 10% of the Cyanide, Magnesium, Sodium, Potassium, Chlorine, and Sulphate remained in the ice, as well as less than 20% of the Calcium, less than 22% of the Thiocyanate, and less than 40% of the Arsenic. Note that the 61% volume remaining mark corresponds to 55 h.

This leads to Fig. 12, which shows the concentrations of ions in the melt water behaving similarly, with the concentration dropping rapidly until the 61% (55 h) mark and then decreasing more slowly at threshold concentrations of 2–4 mg/L. Exceptions to this behaviour were Arsenic and Thiocyanate; Thiocyanate had a threshold concentration of approximately 10 mg/L, and the Arsenic concentration was nearly constant over the thaw duration at 0.005–0.006 mg/L. Note that the y-axis of Fig. 12 has been truncated for better resolution. Initial concentrations in the ice for all species are summarized in Table 3.

5.4. Mass balance of chemical species

To check that the concentrations of dissolved ions, and the mass of water pumped and ice formed were accurate, a mass balance was performed for the

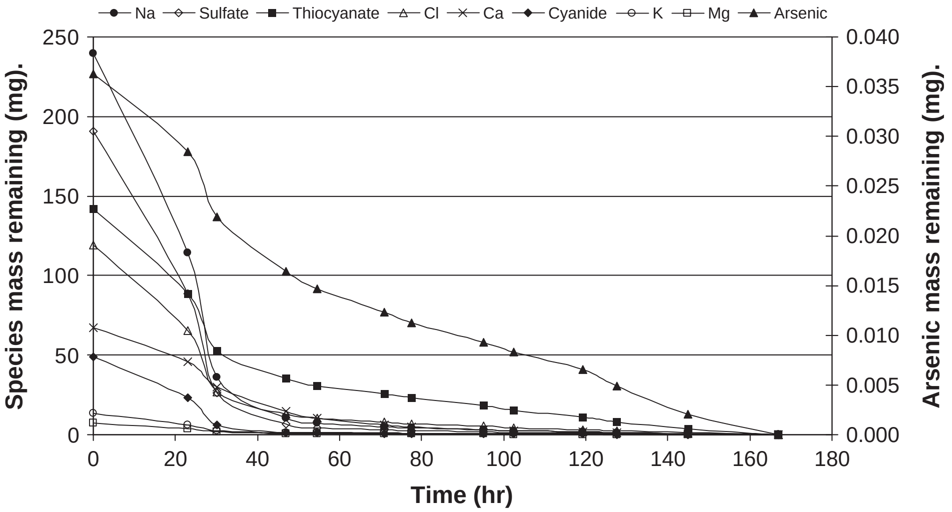

Fig. 11. Mass of dissolved species remaining in the ice core versus time.

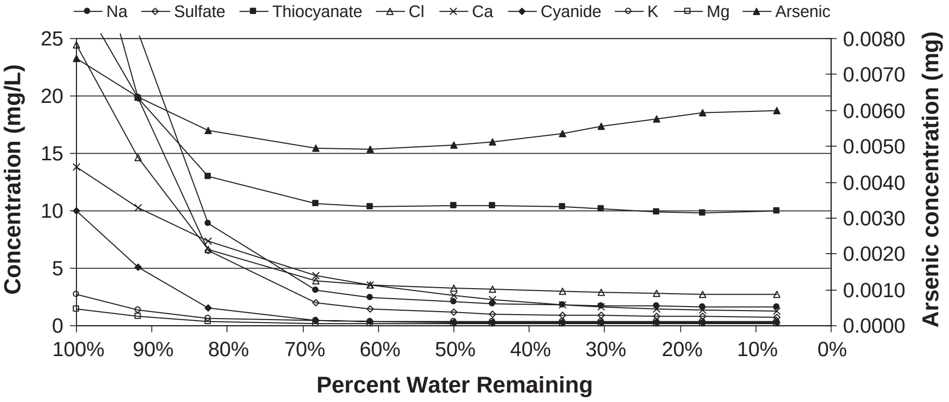

Fig. 12. Species concentration versus percent volume remaining. (Note: the Y-axis has been truncated for better resolution.)

various ionic species tested. The concentration of ions was converted to a mass by multiplying by the volume of water in the spray ice, the runoff, and supply water. If the calculations were reasonable then the calculated mass of contaminants in the ice plus runoff should be approximately equal to the calculated mass of contaminants in the supply water. Fig. 13 and Table 4 show the results of this analysis. It may be seen that in most cases the mass balance was within 10%. Arsenic had the greatest discrepancy, but the Arsenic concentrations were much lower (>2 orders of magnitude) than the other species, so small errors in the measured concentrations would lead to greater errors in the mass balance. Thus it may be concluded that the calculated values of water pumped, ice formed, and runoff are reasonably accurate.

Table 3
Initial average concentrations* in spray ice test column (mg/L)

Species	Concentration
Cyanide, total	9.96
Thiocyanate	29.1
Arsenic	0.0074
Calcium	13.9
Magnesium	1.46
Sodium	49.1
Potassium	2.71
Chloride	24.4
Sulphate	39.1

* Average concentrations calculated based on the mass of contaminants removed (concentration×volume for each sample) and the total volume of melt water collected.

6. Discussion

6.1. Ice formation efficiency

The equipment setup that was used in the field for this experiment was able to freeze approximately one third of the water that was pumped, once the process reached its full freezing capacity approximately 4 h into the test. This efficiency is lower than a fully optimized system. Testing conducted at Tuktoyaktuk obtained an efficiency of approximately 60% (Instanes et al., 1994). Gao (1998) developed a theoretical framework following the work by Instanes (1993) to show that by adjusting the nozzle spray height, direction, and droplet size, the hang-time of the droplets can be adjusted to account for the cooling rate due to ambient weather conditions (temperature and wind). This can be done manually for small-scale operations, or automatically for large-scale operations.

6.2. Chemical species removal

The spray-freezing and subsequent controlled thawing process was very effective in removing most ionic species from the water. Under the conditions tested, the spray freezing resulted in an average of approximately 30% removal of the various chemical species (Table 2).

For the thawing portion of this study, most of the mass of dissolved species had been removed when 39% of the ice melted, leaving 61% of the ice volume with very low concentrations. This occurred after 55 h

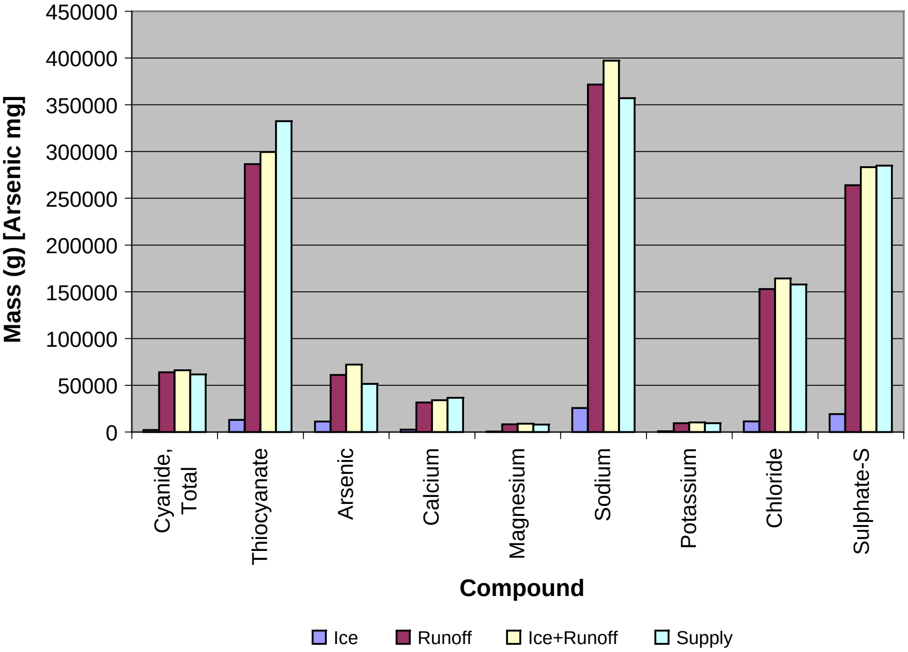

Fig. 13. Calculated mass balance of dissolved ions.

of thawing, or 33% of the total time it took to melt the entire column. Given an ice formation efficiency of 32%, and that 61% of the ice was left with very low concentrations, approximately 20% of the total amount of water that had been pumped had very low concentrations of dissolved species due to the spray freezing and thawing process.

At 39% melting of the ice core, more than 90% of the contaminant mass was removed from the ice core for all species except thiocyanate, Arsenic and calcium, which had removals of 78%, 60%, and 84%, respectively (Fig. 11). Fig. 14 shows the removal efficiencies for the different compounds, when compared to the concentrations in the supply water. These removal efficiencies are even higher because they are compared to the supply water, not the initial concentration in the ice core. Field evidence has indicated that thawing in the field is slower than generally obtained in the lab, so removal efficiencies in the field tend to be higher (Gao et al., 1996b). Thus the removal efficiencies observed in this laboratory test are expected to provide a lower bound on potential field removal efficiencies.

Table 4
Calculated mass balance of dissolved ions

	In ice (g)	In runoff (g)	Ice+runoff (g)	In supply (g)	Difference (%)
Cyanide, total	2,210	63,900	66,100	61,600	−7.2
Thiocyanate	13,000	286,000	299,000	333,000	9.9
Arsenic	11.2	61.0	72.2	51.4	−40
Calcium	2,500	31,600	34,100	36,600	6.8
Magnesium	594	8,300	8,900	8,020	−10
Sodium	25,600	372,000	398,000	357,000	−11
Potassium	748	9,470	10,200	9,510	−7.5
Chloride	11,400	153,000	164,000	158,000	−4.1
Sulphate-S	19,200	264,000	283,000	285,000	0.6

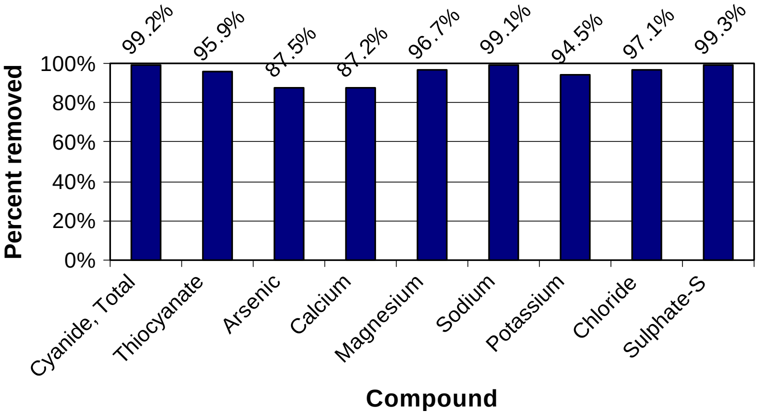

Fig. 14. Reduction in individual species concentration from supply water to melt water at 39% of core thawing.

Supply water concentrations of Arsenic ranged from 35 to 45 μg/L with an average of 39 μg/L. Melt water concentrations from the ice core decreased from 19 μg/L initially to approximately 5 μg/L, at 39% ice core melting, which was just at the maximum allowable limit of 5 μg/L for aquatic life according to the CCME, 2002 guidelines.

Supply water concentrations of total cyanide ranged from 39,000 to 58,000 μg/L with an average of approximately 47,000 μg/L. Even with 99.2% removal at the end of the ice core thawing cyanide concentrations were 357 μg/L, still well above the maximum allowable limit of 5 μg/L for aquatic life according to the CCME, 2002 guidelines. At 39% ice core melting the concentration was approximately 1300 μg/L.

The removals observed in this study for many of the ions agree with those reported in other spray freezing field studies. Krepchin (1985) reduced salt concentrations in sea water from 30,000 mg/L to approximately 10 mg/L at a Long Island pilot desalination experiment during the winter in New York. A field study by Gao et al. (1996a) on oil sands tailings pond water froze a 5 m high spray ice mound over a 15-h period. They observed chloride reductions of 91–99% for ice core and melt water samples collected. Removal of sodium ions was similar to that of chloride.

6.3. Application of spray freezing for large-scale operations

The magnitude of a full-scale operation would depend on the amount of water that needed to be treated on an annual basis. Variables that must be considered include:

- Thickness of ice that can be melted annually, because spray freezing can generally freeze more ice than can be thawed annually in Arctic climates. Typical thicknesses of ice that may be melted range from 5–8 m (Gao, 1998).
- The location of the ice mound:
  - A southern exposure is preferred because radiant energy from the sun will significantly hasten the melt rate, especially given extended daylight.
  - The slope should be gentle.
  - The area available.
- Target concentrations of individual chemical species.
- Final disposition of melt water.

The amount of pumped water that may be frozen will range from approximately 35–80%. This will determine the pumping capacity required. Spray freezing also requires that the initial runoff be properly managed, because there will be large volumes of water with chemical concentrations greater than the supply water. This water would likely be returned to the tailings lake as surface runoff, but in a large-scale operation control of this runoff is required. The continued effectiveness of the spray freezing process may be impacted if the runoff is returned close to the supply intake, because higher concentrations of chemical species will further depress the freezing point of the fluid prior to it being sprayed.

When melting begins, the water will have the highest concentrations of dissolved species. This first meltwater will likely have to be contained. Depending on the concentrations and volumes, it may be returned to the supply water, or treated separately. As melting proceeds, concentrations will drop rapidly. For the tests conducted in this study, the sharp reduction in concentrations ended at approximately 39% melting of the ice column. Determination of when this occurs in the field could be done initially by monitoring the electrical conductivity of the runoff (manually or remotely). When the EC reaches some predetermined value, samples of water may be analyzed for individual chemical species concentrations. When an acceptable standard is met, the meltwater could then be routed via pumps or valves and pipes to its next or final destination.

The meltwater which meets some predetermined criteria may be able to be released to the environment, or may require further treatment (for Cyanide in this case). The treatment system to treat this dilute runoff will likely be significantly less costly than one used to treat the original supply water.

7. Conclusions

The results of this field and laboratory study have shown removal of dissolved chemicals from the Colomac mine tailings lake water of 87–99% (depending on the chemical species) from the ice remaining after 39% of the spray ice column had melted. Arsenic concentrations were reduced from approximately 19 μg/L to approximately 5 μg/L. Cyanide had 99.2% removal but still remained at a concentration of approximately 350 μg/L.

The pilot scale freezing project had only approximately 30% of the pumped water freeze. An optimized system is expected to freeze up to 80% of the pumped water.

The technical feasibility of large-scale spray freezing operations to treat mine waste water has been well documented in Gao (1998) where costs for treating oil sands tailings water were determined to be approximately 7–10 ¢ (Cdn) per cubic meter treated for a spraying operation to treat 1,000,000 m^3 per year.

Spray freezing at the Colomac mine does not appear to be able to reach regulatory requirements for Cyanide. It does however potentially provide the ability to provide an inexpensive pre-treatment option. The ~60% of the treated water released at the end of the melt would only require polishing of low TDS water, which may significantly reduce overall costs. The concentrated initial runoff may be refrozen to further concentrate the dissolved chemicals, or treated or disposed of in another manner appropriate for the volume.

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