Effect of temperature on the leaching of heavy metals from nickel mine tailings in the arctic area, Norway

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Abstract: The leaching of heavy metals from tailings deposit due to the oxidation of sulphidic tailings and formation of acidic leachate is considered a high risk to the surrounding environment. Temperature plays an important role in the leaching of heavy metals from tailings in changing acid-based environment, especially in the Arctic area. To investigate how the temperature variation affected metal release from tailings in the Arctic area, a series of column leaching experiments was conducted under four temperature situations (5°C, 10°C, 14°C and 18°C). Physicochemical properties, Fe, Zn, Ni and Mn concentrations of leachates at each cycle were measured, and multivariate statistical analysis was applied to research the effect of temperature on heavy metals leaching from tailings in the Arctic area. The results showed that higher temperatures encouraged tailings to oxidation and sulfuration of and promoted heavy metal release from the tailings through precipitation and erosion. Ni, Zn and Mn have similar releasing resources from tailings and positive correlation in the leaching activity. Rising temperature accelerated Fe leaching; Fe leaching promoted leaching of the other metals, especially of Mn. Appropriately increase temperature will accelerate oxidization and sulfidization of the tailings, promote acid generation and increase TDS and, finally, promote the release of heavy metals. Climate change, with rising temperatures increasing the risk of heavy metals leaching from the tailings, should be given greater attention. Keeping tailings away from the appropriate temperature and in a higher alkalinity is a good method to control the leaching of heavy metals from tailings.

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1 Introduction

Every year, almost 100 billion t of tailings were discharged all around the world[1,2]. Tailings are an important mining waste and act as a source of contaminants, which poses a serious risk to human health and have ecological implications[3]. Tailings deposit not only destroys surround ecological environment, but also poses a threat to water, soil, plants, animal and human beings by leaching[4-10]. Under the effects of temperature and precipitant, tailings released different hazards by the variation of forms and migration[11]. As the areas surrounding tailings have become more and more densely polluted in recent years, it has been established that tailings operate as an active edaphic compartment, which performs a fundamental role in the redistribution of metals to the ecosystem. Furthermore, the leaching of heavy metals from a tailings dam makes a significant contribution to surround containment. Biogeochemical activity in the tailings will change heavy metals' form and their capability to release. Besides the natural processes, such as the weathering of tailings, rainfall leaching and acid mine drainage will accelerate biogeochemical activity in the tailings and take many heavy metals and toxic substances into deep soils and groundwater[12]. The treatment of tailings' leachate, which is composed of several dissolved toxic metals, is too complex and expensive. If tailings' leachate is not managed properly, it causes considerable environmental degradation, as well as water and soil contamination, and can have a severe impact on the health of nearby communities, biodiversity loss and the aquatic ecosystem[13]. Understanding the mechanism of heavy metals' leaching from tailings is important for the control of their pollution and tailings management.

Many factors affect heavy metals release from tailings[5] , such as Chemical properties of tailings, temperature, precipitant, microorganism and O_2 content[7-10,14,15]. Changes in the form of heavy metals and acid mine drainage generation are the two main way to generate the release and transportation of heavy metals[16,17]. When the sulfide-bearing material is exposed to oxygen and water, acid mine drainage is generated and heavy metals are leached out from the tailings[18]. Although this process occurs naturally, mining and climate change can promote acid mine drainage generation and tailings' leaching, simply through increasing the quantity of sulfide exposed and the reaction rate. The tailings are of particular concern because of acid mine drainage (AMD) accompanied by environmental leaching of pollutants with potentially severe impacts on surround environment[19]. Rainfall, moistened waste generates a significant quantity of leachate, taking with it all kinds physicochemical bacteriological pollution[20]. When tailings are

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discharged, the activity of heavy metals was low. After contacted with water and air, the activity of heavy metals increased, and many heavy metals released and migrated to surround soils and water[18]. Temperature has been found to result in rapid heavy metals releasing from tailings. Higher temperature is not only increase the solubility of the leachate, but also accelerated the biochemical reaction in the tailings. There are many factors that has effect on acid mine drainage generation and the leaching of heavy metals from tailings, such as temperature, precipitation, pH, salinity, conductivity, and so on[21]. The degree of environmental pollution by tailings' leaching is very dependent on its composition, climate change, biochemical reaction and surrounding environment. Temperature plays an important role in heavy metals' leaching from tailings, especially in the Arctic area, as it has undergone a more dramatic change in the past decade[22]. According to the IPCC V (Intergovernmental Panel on Climate Change) report, changes in temperature in the Arctic area are more than twice those of the inland area[23]. That has led to a difference between the Arctic area and the inland area in the oxidation and sulfuration of tailings. High temperature will accelerate the oxidization and sulfidation of tailings, which promotes acid mine drainage generation and enhances the release of heavy metals[15,24-26]. So, climate change may have different effect on the level of heavy metals' leached from tailings between Arctic and inland areas.

The aim of this study is to identify the characteristics of leaching of heavy metals from tailings under climate change in the Arctic area; to understand the influence of temperature on heavy metal leaching; and to identify the control factor of heavy metal leaching under climate change. Understanding the mechanism of heavy metals' leaching from tailings under climate change is beneficial for establishing a tailings risk assessment system and providing proper strategies for the management of tailings.

2 Materials and methods

2.1 Study site and experiments

As an important mining area in northern Norway and large amount of tailings deposits via open pit and underground mine, Ballangen faced the risk of heavy metal release from tailings[27]. Seven million tons of tailings have been deposited in Ballangen, covering an area of 500 000 m^2[28]. The deposit took place in the years 1988-2002. In total, 8 537 468 t of nickel ore, with an average content of 0.52% nickel, were deposited. On top of the masses, a thin layer of soil, approx. 20cm is applied. This layer is too thin to prevent air and water from coming into contact with the exhaust masses. There is a high content of many heavy metals in the tailings, such as iron, copper, zinc, cadmium and nickel[29]. All surface drainage, with a high level of heavy metal content from the tailings area, flows into the fjord; the surrounding plants, soil and water were noticeably affected by leaching water, and this caused a serious environmental problem[28]. The average temperature of Ballangen municipality is between –12°C and 17.1°C. The mean annual temperature and precipitation of Ballangen were 4.1°C and 1420 mm in 2016 (Ballangen meteorological station, located at 68°25'20"N, 17°27'28"E, Norway).

In laboratory experiments, leaching activity cannot occur when the temperature is below 0°C. Therefore, a temperature range of 5°C-8°C was chosen in this experiment. The highest temperature was chosen as 18°C, as the average temperature is expected to increase in the future as a consequence of climate change. A column experiment was conducted to investigate the impacts of temperature on heavy metals' leaching from mine tailings. Four temperatures were set in the experiment: 5°C, 10°C, 14°C and 18°C. Each treatment was established with a repetition. Eight columns were filled with mine tailings (Table 1 reference) from Ballangen and put into four wine fridge and keep each at a steady temperature; 600 mL of water (80 mm/month precipitation) were added to each column every two weeks to leach. Leachate was collected 24 h after the water addition, and the pH, Pe, TDS, salinity and conductivity of the leachates were measured at once by HI98193.

Table 1 Heavy metals content in mine tailings

Elements	Units	Tailings
CaO	% TS	3.18
MgO	% TS	27
SiO_4	% TS	39.5
Al_2O_3	% TS	4.47
Fe_2O_3	% TS	17.3
MnO	% TS	0.165
Co	mg/kg TS	38
Ni	mg/kg TS	77.8
Zn	mg/kg TS	48.6

In order to determine the total concentrations of five heavy metals (Fe, Zn, Ni and Mn), tailings samples were subjected to microwave-assisted digestion with concentrated HNO_3, in accordance with ASTM 3682. Reference materials (CRMs) (GSS-16) as a control sample added in the digestion experiment to analysis. Leachate was treated following EPA 200.8. Heavy metals in the leachate were determined by an inductively coupled plasma atomic emission spectrometry (ICP-AES).

2.2 Statistical analysis

The differences in tailings and leachate properties including Fe, Mn, Zn, Ni, TDS, $SO4^{2-}$, PH and salinity were examined using oneway analysis of variance (ANOVA), followed by the least significant difference (LSD) test. Linear regression was applied to the relationship between leaching and time of different heavy metals at different temperatures in tailings, obtain cumulative equation of heavy metal leaching from tailings at different temperatures by SPSS. Principal component analysis (PCA) and cluster analysis (CA) were applied to the data set to identify associations (common origin) between the metals. PCA was performed with Varimax rotation, and CA was developed according to the Ward method. All the statistical analyses were performed using SPSS software, version 24.0 (SPSS Inc., USA). Figures were drawn using OriginPro software, version 8.5 (Originlab Inc., USA).

3 Results

3.1 Heavy metals in tailings

As shown in Table 1[30], which details the concentrations of heavy metals in Ballangen tailings, CaO, MgO, SiO_4, Al_2O_3, Fe_2O_3 accounted for 91.45% of the tailings, indicating that the tailings were dominated by heavy metal oxides. MnO account for 0.165% of tailings, with the content of 1650 mg/kg. Ni and Zn with low content in the tailings by 77.8 mg/kg and 48.6 mg/kg, respectively. And both Zn and Ni account for less than 0.01% of tailings. There was a low show of sulfur in the tailings, and there were fewer sulfide metals. At 39.5%, SiO_4 represented the highest content in the tailings, while the content of both Cao (3.18%) and MgO (27%) in the original tailings was high, that was easy to create buffer solution to retard the generation of acid mine drainage. High content of CaO and MgO is easy to form a strong solid shell to prevent tailings oxide and heavy metal leaching. According to the measurements, there was a high content of Co, Ni, Mn and Zn in the tailings, and all of them far exceed the background levels in Norway[31]. Although Zn and Mn are essential elements of the organism, too high a concentration level can also produce poisoning effects on the human body. Therefore, the total amount of heavy metals in the tailings carried ecological risk to the surrounding environment.

3.2 Characteristics of the leachate

The variations in the pH, TDS, salinity and SO_4^{2-} in the leachate was shown in Figure 1. It is evident that leachates' pH decreased with the rising temperature as leaching cycle goes on. The highest values of pH were above 7 and showed at 5°C, while the lowest showed at 18°C with the value of 4. There was little change between 10°C and 14°C, with the value even dropping down to 4 when the temperature increased to 18°C. The leachates' pH at 10°C was lower than that at 14°C from the 1st week to the 11th week, with the opposite being the case from the 13th to the 17th week. Both TDS and salinity had high values in the first leaching week; descending to a low value from the 1st week to the 5th week. They had the same changing trend and remained at a low value with little variance from the 5th to the 15th week. There was little change for the values of TDS and salinity at 10°C and 14°C, and their values at 18°C were apparently higher than those at 5°C. Metallic oxide takes up 91.45% percent of the tailings composition (reference). Much metallic oxide reacted with the leaching water, then Mg^{2+}, Na^{+} and Ca^{2+} dissolved in the water, which increased the leachates' salinity and TDS values. Although there was little metallic sulfide in the tailings, H^{+} and SO_4^{2-} were generated with metallic sulfide oxidation and oxide hydrolysis at the same time. So, the pH values of the leachates were lower, and the SO_4^{2-} content was higher at the beginning of the leaching cycle with higher sulfide oxidation and oxide reaction. Higher temperature is beneficial for the sulfuration and oxidation of tailings[13], which accelerated acid generation in the mine tailings. So, the highest and lowest pH values showed at 5°C and 18°C, respectively.

The results of the concentrations of Fe, Mn, Ni, Zn in the leachates from columns are shown in Figure 2. The highest and lowest leaching concentrations of Fe were at 18°C and 5°C, respectively. There was a big difference between the leaching character of Fe and that of the other heavy metals. Fe kept a low leaching concentration at 5°C with a small variation. The leaching concentration of Fe increased with the leaching cycle on at 10°C and 14°C and was shown to be higher at 10°C.

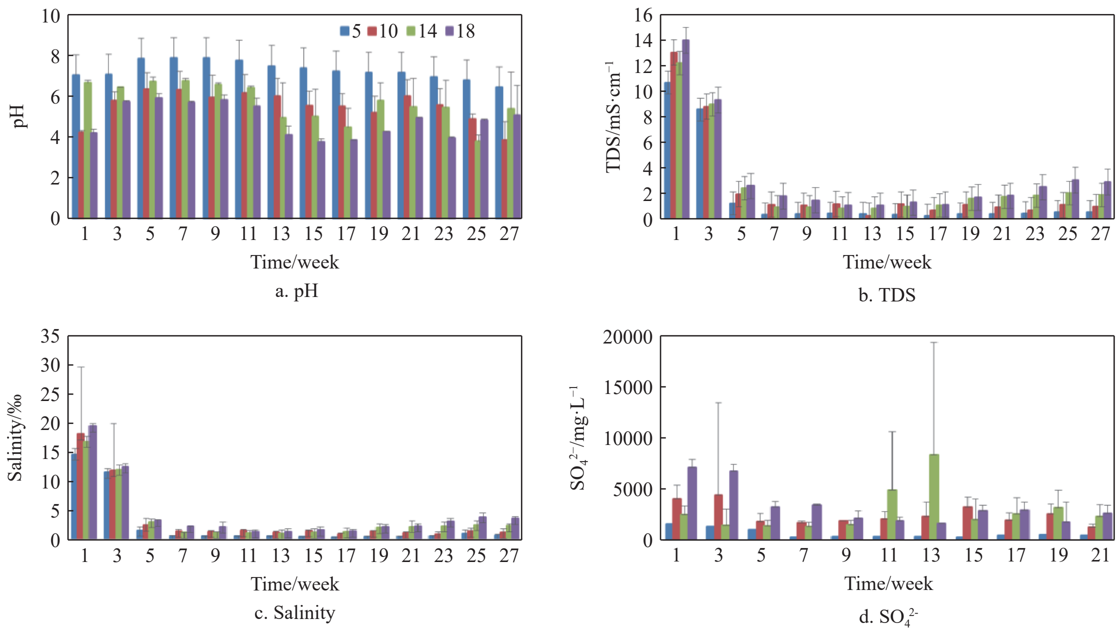
Both the leaching concentrations of Zn at 5°C and 14°C were low during the leaching experiment. They increased as the leaching cycle goes on. the leaching concentration was higher at 14°C than at 5°C. A higher leaching concentration was obtained at 10°C and 18°C; there was a decreasing trend with leaching time. The highest leaching concentrations at 10°C and 18°C were obtained in the first leaching cycle: 7347 μg/L and 7909 μg/L, respectively. After the first cycle, the leaching concentration of Zn was higher at 10°C than at 18°C.

The concentration of Ni in the leachate decreased with the leaching cycle at the four tested temperature. In each cycle, the highest and lowest concentrations were obtained at 18°C and 5°C; the leaching concentration at 10°C was higher than that at 14°C. The highest Ni in the leachate at 18°C and 5°C were 609 mg/L and 7 mg/L, respectively.

In the first cycle, the leaching concentrations of Mn were 574 μg/L, 2964 μg/L, 1470 μg/L and 7548 μg/L at 5°C, 10°C, 14°C and 18°C, respectively. The leaching concentration of Mn showed a small change from the 1st cycle to the 8th cycle at 5°C, 10°C and 14°C. At 18°C, its leaching concentration decreased with leaching time. In the leaching test, the highest and lowest leaching concentrations of Mn were at 18°C and 5°C, while that at 10°C was higher than that at 14°C.

From the leaching cycle, all the leaching heavy metals had high and low leaching concentrations at 18°C and 5°C, with the leaching concentration at 10°C being higher than that at 14°C.

There are many kinetic equations in fitting heavy metal leaching from tailings, such as the primary diffusion equation, parabolic equation and the Elovich equation[32]. As shown in Figure 3, all the heavy metals in the leachate fitted well with the first-order kinetic equation at each temperature. The cumulative concentration increased with leaching cycle, and the fastest accumulation was at 10°C for Zn and Ni, while, for Fe and Mn, the highest showed at 18°C. At the beginning of the leaching test, the highest leaching concentration of the heavy metals was at 18°C, followed by 10°C,



a. pH b. TDS c. Salinity d. SO_4^{2-}

Figure 1 Variations in physicochemical properties of leachates

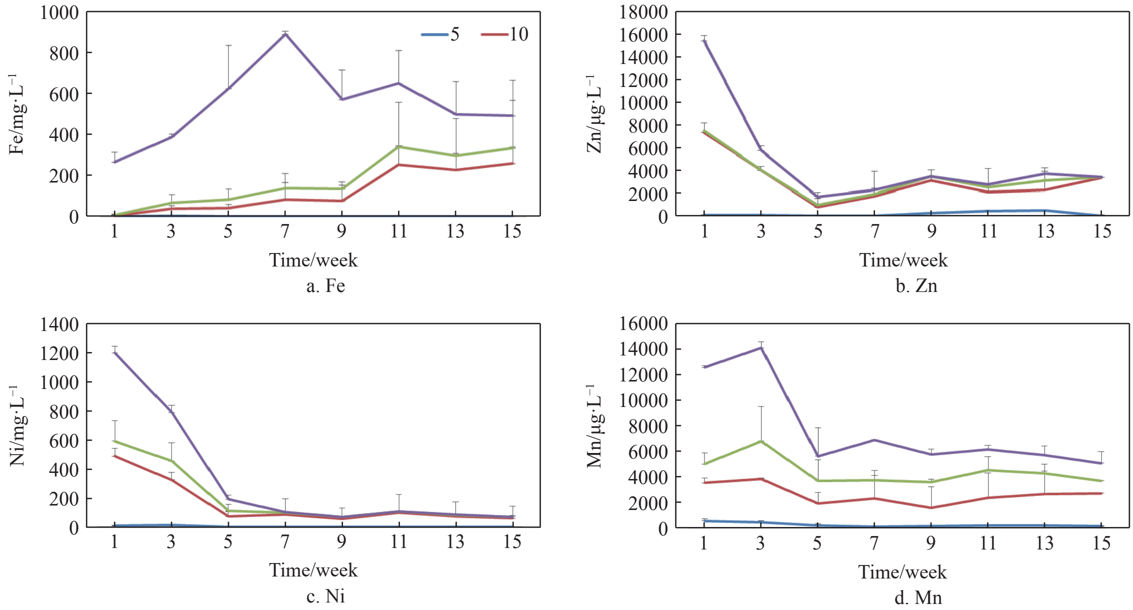


Figure 2 Leached concentrations of Fe, Zn, Ni and Mn from tailings

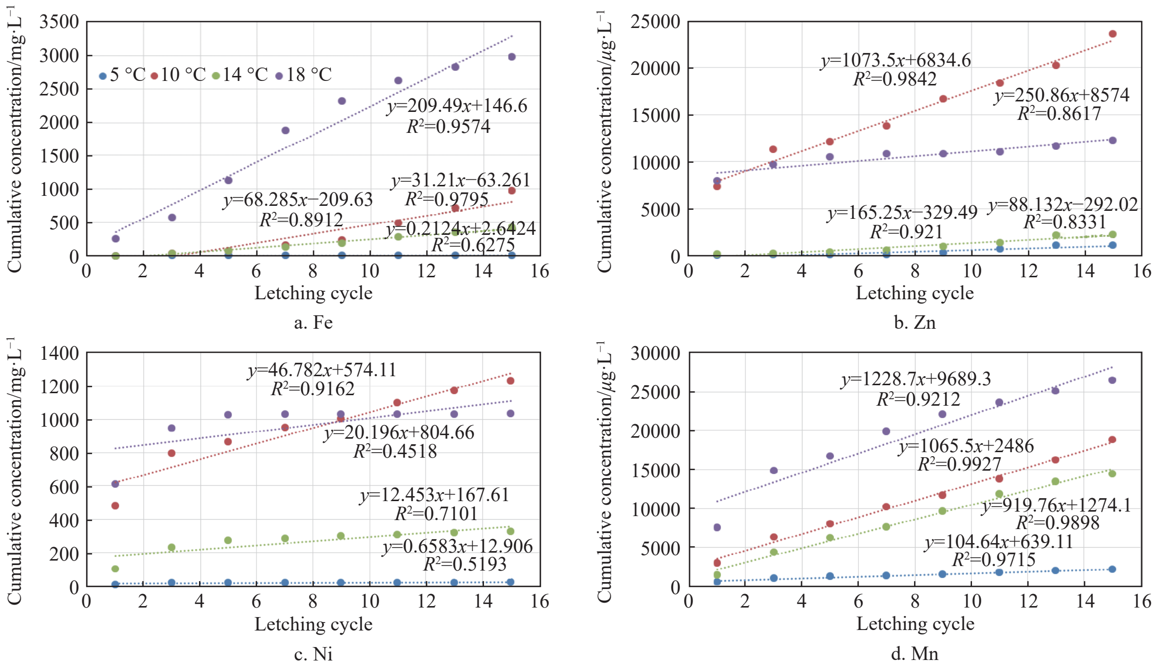


Figure 3 Cumulative equation of heavy metal leaching from tailings at different temperatures

while the lowest was obtained at 5°C.

4 Discussion

4.1 Effects of temperature on tailings oxidation

Heavy metals will be activated by oxidization reaction in tailings, and the chemical forms of heavy metals will be changed[13]. Tailings' oxidization promotes the generation of acid mine drainage and the release of heavy metals. Coupled with precipitation, many heavy metals will be leached from the tailings to the surrounding environment.

Many factors affect the oxidization of tailings, such as temperature, oxygen and precipitation. So, climate change will influence the storing and transportation of heavy metals in the tailings. Surface water will scour and leach the tailings, which will accelerate the release and transportation of heavy metals from the tailings[32]. Water will take much oxygen to the tailings, accelerating the reaction of oxidized tailings. Temperature will promote or restrain oxidization reaction, to change the form of heavy metals, therefore changing their forms of storage and their ability to transport[33]. The ability of heavy metals to leach from tailings varies with temperature[24]. So, 10°C showed an evident promotion of Zn, Ni and Mn release: higher than that at 14°C.

4.2 Effects of temperature on pH, SO_4^{2-}, salinity and TDS in the column leaching

In the column leaching, because of the solubilization of heavy metals from tailings' oxidation, sulfuration and acidification, changes in the pH of tailings over time can be used to represent the level of acid mine drainage. It is obvious from Figure 1 that SO_4^{2-} had the same trend of change as H^+ (pH) due to tailings' oxidation and acid generation. From the 1st week to the 6th week, the leachate pH had an increasing trend from: 7.01 (initial pH) to 7.87, 4.21 (initial pH) to 6.3, 6.64 (initial pH) to 6.74 and 4.18 (initial pH) to 5.2 after six weeks at 5°C, 10°C, 14°C and 18°C, respectively (Figure 1); after the sixth week, the leachate pH decreased with leaching time on at the four temperatures. From 4°C to 18°C, there was an initial rise in pH, which was caused by the buffer or by the release of alkaline from tailings during the initial stage of leaching[26]. This agrees with the results of TDS and salinity. In the initial stage, high TDS and salinity were shown in the leachate, which indicated considerable generation of buffer solution. High temperature is not only beneficial for tailings' biochemical reaction; it also improves solution solubility[34], so the highest and lowest levels of salinity and TDS were obtained at 18°C and 5°C, respectively. It is agreed that high temperature will lead to high salinity and low pH drainage[25,26]. At 10°C, pH was lower than that at 14°C, while TDS and salinity were higher at 10°C than at 14°C, which indicates that the biochemical reaction at 10°C was fiercer than that at 14°C. That is the same as the Tsai's research[25]: the proper temperature improves enzymic activity and the oxidized ability of bacteria. It had a stronger sulfurization reaction at 10°C for its higher SO_4^{2-} content in the first seven weeks.

4.3 Effects of temperature on heavy metal leaching from tailings

Changes in temperature have a significant impact on changes in the leaching of heavy metals (as shown in Figure 2). Temperature affects heavy metal leaching from tailings by changing metal solubility and biochemical reaction[31]. Lower temperatures decrease the metal ions' solubility and prevent metal sulfur oxidation reaction, so there is less leaching out of heavy metals at 5°C. Metal oxides and sulfides are easier to oxidize and hydrolyze at higher temperatures, and higher temperatures will increase the water solubility of heavy metal ions; therefore, higher leaching concentration was shown at 10°C, 14°C and 18°C. Significant positive correlation showed at T (temperature)-Fe and T-Mn, and positive correlation showed at T-Ni and T-Zn. This indicates that temperature has a positive effect on the leaching of these heavy metals[35]. Although the leaching concentration of Ni decreased with leaching time on, it also had a significant positive correlation with temperature. Leaching concentrations of Fe, Zn, Ni and Mn were higher at 10°C than at 14°C, proper temperature promote heavy metals oxidize and vulcanize in the leaching, more acid generation accelerate the release of heavy metals. These results showed that the temperature had an appreciable effect on the Zn, Ni and Mn leaching out at 10°C.

4.4 Effects of pH, SO_4^{2-}, salinity and TDS on heavy metals leaching

Acidity or alkalinity has a significant impact on the leaching of heavy metals from tailings in the Arctic area. The pH values at 10°C and 18°C were lower than those at 5°C and 14°C, and the leaching concentrations of Fe, Mn and Zn were higher at lower pH than at higher temperature (Figures 1 and 2). This agrees with the present research that low pH promotes the leaching of heavy metals from tailings and that high pH restrains their leaching[36,37]. When pH is higher than 7, leaching concentration is very small. Tailings or leachate with lower pH are good for generating and releasing H^+, which is of benefit for the replacement of metal ions from tailings and then dissolved into solution[38]. As shown in Equations (1) and (2) (M: heavy metal), lower pH promotes metal dissolving, and chemical oxidation occurs, leading to high concentration in the leachate[38]. So, in the Arctic area, keeping tailings at high pH will decrease the leaching of heavy metals from tailings. SO_4^{2-} is produced in the sulfidation and oxidation of tailings (Equation 3)[39,40], it changed the same with H^+ variations. Therefore, higher SO_4^{2-} is a good indication of heavy metals dissolving and acid generation. Because there was little change in pH in the experiment (Figure 1), there was no significant correlation between pH and heavy metals (Table 2).

$$MO + 2H^+ \rightarrow M^{2+} + H_2O \quad (1)$$

$$4M^{2+} + O_2 + 4H^+ \rightarrow 4M^{3+} + 2H_2O \quad (2)$$

$$MS_2 + O_2 + H_2O \rightarrow M^{2+} + 2SO_4^{2-} + 2H^+ \quad (3)$$

Table 2 Correlations between heavy metals' leaching concentrations and physicochemical properties of leachates

	T	SO_4	pH	TDS	Salinity	Fe	Zn	Ni	Mn
T	1								
SO4	0.358*	1	*						
pH	−0.472**	−0.408*	1						
TDS	0.052	0.206	−0.021	1					
Salinity	0.045	0.200	−0.026	0.999**	1				
Fe	0.652**	0.068	−0.061	−0.048	−0.053	1			
Zn	0.127	0.097	−0.337	0.471**	0.480**	0.060	1		
Ni	0.219	0.179	−0.219	0.687**	0.691**	0.057	0.887**	1	
Mn	0.577**	0.215	−0.288	0.541**	0.542**	0.433*	0.638**	0.802**	1

Note: * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

TDS is measured by the combined content of all inorganic and organic substances contained in a different liquid form, and salinity is a similar index to reflect the water quality by some ions, constituting the definition of TDS. So, they have the same trend of change in the leaching cycle. The highest levels of TDS and salinity showed at 18°C and the lowest at 5°C. TDS and salinity sharply decreased by 1/10 in the 6th week, meaning that most of the Na^+, Ca^{2+}, Mg^{2+} and K^+ leached out in the first cycles. This indicated that most of the sulfur oxides were leached out in six weeks. Buffer solution formation, coupled with ions' release, is good at maintaining the solution's pH value and is of benefit for the releasing of Ni, Mn and Zn. Therefore, pH values decreased after the 7th leaching week for less buffer solution (Figure 1). Although high levels of TDS and salinity are good at balancing pH, they are a good indication of heavy metal leaching. Both TDS and salinity had a significant positive correlation with Ni, Zn and Mn (Table 2), so they are a good indication of heavy metal leaching, and they may have the same origin source. pH was negatively correlated with heavy metal leaching in the experiment, which means that a lower pH is beneficial for heavy metal leaching. It takes about 51 weeks to occur acidification process of stacking, indicating that acidification will take a long time. However, low sulfur tailings will not acidify in a short time[41,42]. The acidified tailings have a strong promoting effect on the dissolution of heavy metal ions and salts in the tailings, so that the dissolution concentrations of heavy metals such as Pb, Zn and Cd are increased[43,44].

Correlation analysis was used to detect the relationship between heavy metal leaching under temperature change, and cluster analysis was used to detect the similarity groups between leaching characteristics. As shown in Table 2, temperature was a significant positive correlation with SO_4^{2-}, Fe and Mn. Temperature and pH had significant negative correlation. TDS and salinity were significantly correlated with Zn, Ni and Mn in the leaching action. In the leaching cycles, there were significant positive correlations between heavy metals, Zn-Mn, Zn-Ni and Ni-Mn, and they were in a group (Figure 4). Mn had significant positive correlation with Fe, Ni and Zn in the leachate (Table 2). The products of Mn^{2+} oxygenation occur spontaneously in an alkaline aerated solution[45], Mn-oxides precipitation increased surface is available for the adsorption and coprecipitation of other metal ions in the tailings' solution. Lower pH leads to Fe oxidizing (Equation (4)), and a higher buffered solution will keep Fe out of precipitation (Equation (5))[35,46,47]. Therefore, both low pH and high TDS promoted Fe leaching. The various trend of Fe showed opposite with Ni and Zn leaching (Figures 2 and 3), for iron precipitation played an important role in the migration and retention of trace elements[1].

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O \quad (4)$$

$$Fe^{3+} + H_2O \leftrightarrow Fe(OH)_3 + 3H^+ \quad (5)$$

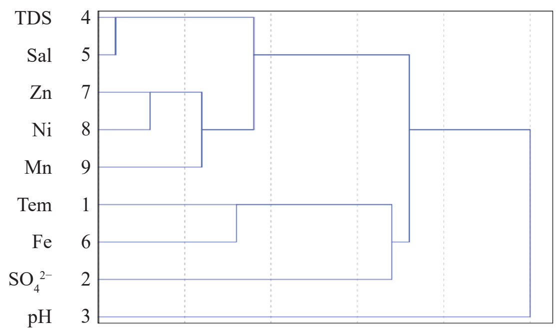


Figure 4 Dendrogram showing clustering of leachate quality characteristics of the tailings' leachate

TDS and salinity were in the same group (Figure 3), Zn, Ni and Mn were in another group, while temperature, Fe and SO_4^{2-} were in the third group. Heavy metals' adsorption and the coprecipitation of other metal ions in the tailings solution make them have a similar leaching ability, and high TDS and salinity make it easier to create alkali and to generate colloids to adsorb heavy metal[1,35]. Proper temperature will accelerate the vulcanization of tailings, change Fe activity and decrease the pH of the solution[48]. Finally, it will affect the leaching of heavy metals. Therefore, both the acid generation and sulfur oxidation reaction will change heavy metals' form and promote leaching. Change temperature appropriately will improve tailings' sulfur oxidation reaction[49] and decrease tailings' pH, in order to promote heavy metals' leaching[50].

Temperature is a main factor to affect biochemical reaction in heavy metals leaching from tailings. It improved tailings sulphur oxidation and adjusted the ion concentration, pH, and salinity in acidic drainage. Both the sulfide oxidation state and acid drainage nature of tailings determine the lymphatic release characteristics of heavy metals in tailings. In order to prevent leaching of heavy metals from tailings into the surrounding environment, it is very important that the tailings always have a neutral or near neutral pH value. Maintaining a high pH in the tailings has two effects: on the one hand, the solubility of heavy metals at high pH is greatly reduced, and the leaching of heavy metals can be effectively prevented; on the other hand, the formation of hydroxides at high pH causes sulfide. The rate of oxidation decreases over time. So, keep tailings at a proper temperature is a good way to keep tailings out of oxidization and sulfuration, and keep them in a low acidity environment.

5 Conclusions

The results definitely demonstrated that temperature change not only resulted in the release of heavy metals in the tailings but also led to variations in leachate characteristics. In addition to the heavy metal concentrations in the tailings, heavy metal leaching was strongly associated with pH, temperature, salinity and TDS. The temperature at which the fastest heavy metal accumulation was seen in the tailings' leaching was 10°C. Appropriately increase temperature will accelerate the oxidization and sulfidization of tailings, promote acid generation, increase leachate TDS, and, finally, promote the release of heavy metals. A good method for controlling the leaching of heavy metals from tailings is to keep tailings away from the appropriate temperature and in higher alkalinity. Getting the appropriate temperature and understanding the relationship between heavy metal leaching and its influences is good for tailings' management.

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