Comparison of nutrient solubilisation and dewatering by freeze/thaw processing of sludge from Biological Nutrient Removal (BNR) and Non-BNR wastewater treatment plants

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INTRODUCTION

Rapid global population and economic growth contributes to environmental degradation and resource depletion. Governments have put in place stricter regulations on waste treatment and disposal in order to prevent environmental pollution. Finding alternative renewable resources to substitute for non-renewable ones is critical. Water and wastewater treatment and the processing, reuse and disposal of the consequent waste sludge have been some of the most challenging topics in this area. Finding practical, cost-effective and environmentally friendly strategies for sludge management is an important goal for those involved in waste treatment and disposal projects such as engineering consultants, facility owners, contract operators and community members.

Biosolids (sludge) are the by-products of wastewater treatment processes consisting of mostly water, microorganisms like bacteria, fungi, and viruses, organic and inorganic particles, heavy metals and micro-pollutants (such as pharmaceuticals and endocrine disrupters). The presence of carbon and nutrients in biosolids make it a valuable resource for renewable energy and fertilizer. Some sludge treatment methods are able to convert the extracellular and intracellular materials of activated sludge flocs, such as proteins, sugars and carbohydrates, into the soluble phase and allow them to be recovered. Through this recycling, the energy and nutrients in biosolids can be converted from a waste product to a potentially marketable commodity (i.e. biogas or liquid fertilizer). Typically, sludge produced in wastewater treatment processes is liquid or semisolid containing about 0.25 to 12% solids by weight (Tchobanoglous et al. 2003). The primary goal of...
Sludge thickening and dewatering is to increase solids concentration in the dewatered sludge cake in order to minimize the volume and the cost of hauling and disposal. A sludge cake concentration of 25% or more is recommended prior to disposal (Tchobanoglous et al. 2003).

Typical methods of conditioning and dewatering sludge such as gravity thickeners, filter presses, horizontal belt filters, dissolved air flotation and centrifugation are mainly used in larger treatment facilities and require skilled operators and extensive maintenance. There are also some natural dewatering methods such as sludge drying beds, sludge lagoons, and freezing beds that could be used in smaller treatment plants. These natural treatments require low energy consumption, no chemicals and less-skilled operators. For facilities located in remote and cold regions, like those in Northern Canadian communities, finding effective dewatering techniques can be difficult, since the typical dewatering methods use complex, expensive equipment, and require skilled operators. Moreover, simpler methods like drying beds and lagoons are not efficient in cold regions because of the short summer and freezing seasons (Martel 1989). One practical solution for sludge dewatering and disposal in such communities is to use a natural dewatering method such as freeze/thaw. Freeze/thaw can be performed in a constructed sludge freezing bed similar to a sludge drying bed. Sludge from wastewater treatment can be added to the freezing bed layer by layer during the cold winter months and left to freeze. The sludge freezes from the top to the bottom and pushes all particulates into larger compacted particles. During the warmer spring weather the sludge is allowed to thaw. The melted water is drained and collected, and the dewatered sludge cake remains as a residue, which can be taken off and disposed of (Wang et al. 2001). Freeze/thaw works based on the growth of ice crystals, since the structure of ice is highly organized and cannot include any other molecules. Wherever water molecules combine to form these ice crystals, impurities are rejected. The process of ice crystal growth continues until the accumulated impurities stop the water flow into the crystals. As a result, sludge transforms from a suspension of particles in water to the organized frozen ice crystals and excluded solids (Martel, 1989). The concept of a constructed unit operation for sludge dewatering by natural freezing was developed by Martel in 1986, when he conducted a pilot-scale study on a sludge freezing bed at the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire, USA. Sludge was added in layers from 25 mm to 140 mm and was left to freeze during the winter freezing period. The bed worked well for 3 years, reducing sludge volume by 95% and 83% for aerobically and anaerobically digested sludge, respectively. The average total solids content of sludge increased from 6.7% to 39.3% for anaerobically digested sludge and from 1.1% to 24.5% for aerobically digested sludge (Martel and Diener 1991). Moreover, the freezing bed could successfully dewater alum-treated sludge.

Sludge volume was reduced by about 96% in the freezing bed and the solids concentration increased from 0.5% to 13.6% (Martel and Diener 1991). In northern Sweden, a full-scale ditch was studied for sludge freezing, drying, and freeze/thawing by Hellstrom and Kvarnstorm (1997) for two consecutive winters. From early winter to spring, sludge was pumped in a thin layer of about 100 mm deep to the ditch and allowed to completely freeze before adding the next layer. Drainage pipes collected the melted water from the ditch and the water was pumped back to the treatment plant. The solids content in the freezing ditch was 30-70% and 20-40%, respectively by the end of the first year and second year. A pilot study for residual solid dewatering in the city of Winnipeg, Manitoba was done in 2008 and was completed over a ten-week period, resulting in a solids concentration increase from 0.6% by weight before freezing to about 8% by weight after the first day of thawing and about 20% after a few days of thawing (Mangat et al. 2008). The laboratory-freezing test showed that sludge with solids content from 3 to 7% can be frozen at the same rate as tap water. Moreover, the frozen samples drained very quickly during thawing and sludge cake with a solids concentration of 25% remained after one day (Reed et al. 1986). The field experiment conducted in Hanover was done in a large-scale outdoor basin with concrete walls and sandy soil. The digested primary sludge with a solids content between 6 to 8% was shipped directly from the plant and applied to the sludge bed to a depth of about 8 cm. Each layer was allowed to freeze completely before adding another layer. In total three layers of liquid sludge to a depth of 26 cm was frozen and then allowed to thaw in 14 days. The solids concentration increased to 35% and the depth of sludge cake reduced to 5 cm, indicating about 80% reduction in volume (Reed et al. 1986). Diak et al. (2011) reported 86% volume reduction following freeze/thaw processing of wastewater sludge from a rotating biological contactor. Furthermore, the total solids increased from 2.6% to 19% and volatile solids from 2.3% to 17.3%. The volume of sludge cake needed to be disposed after melting and dewatering was reduced by about 88%.

Wastewater sludge and biosolids have been considered for many years as a source of macro and micronutrients for plant growth such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) (Tchobanoglous et al. 2003). Biosolids contain approximately 3-6% organic nitrogen, 2-4 % phosphorus, 0.2-0.3% potassium, 3% calcium and 1% magnesium by dry weight (Havlin et al. 2014). Nitrogen and phosphorus are essential cell growth elements in sludge biomass. Nitrogen is an important component of amino acids, which are the building blocks of proteins. Phosphorus is the essential part of DNA (deoxyribonucleic acid), RNA (ribonucleic acid), and ATP (adenosine triphosphate) in the cell. These two components can break down and solubilize to the form of ammonia and phosphate under specific treatment processes and can be used as plant fertilizer (Tyagi and Lo 2013). Phosphorus is
a valuable product in sludge since rock phosphate ores are limited in nature. It was stated that in 150 years apatite mines could be depleted (Tyagi and Lo 2013) and P shortage would be one of the most important soil fertility problems in the world.

Developing an efficient method to recover nutrients, especially P, from other resources is important. The general method of phosphorus recovery from sludge is crystallization. This results in the production of calcium phosphate and magnesium ammonium phosphate (struvite) (Tyagi and Lo 2013). It has been shown that freeze/thaw of activated sludge can increase the concentration of proteins, carbohydrates and cations in the sludge supernatant, which indicates the release of intracellular and extracellular polymers (ECP) from sludge flocs (Ormeci and Vesilind 2001). Furthermore, a significant increase in DNA concentration in supernatant after freezing/thaw was observed and indicated the presence of intracellular materials, showing that freeze/thaw can cause cell disruption (Ormeci and Vesilind 2001). The release of ECP and intracellular materials resulted in incremental increases of soluble chemical oxygen demand (SCOD) and ammonium concentration in the freeze/thaw supernatant.

A study on the thickened waste activated sludge and the mixture of primary and secondary sludge from a treatment plant at Harbin City, China showed that keeping samples in the curing stage (the time sludge is kept below zero Celcius) could increase the solubilisation of organics significantly. The maximum Chemical Oxygen Demand (COD) solubilisation was reported as 7.5% and 10.5% of the overall COD for mixed sludge and waste activated sludge, respectively. Moreover, the maximum release in ammonia was reported to be about 45.3% and 74.5% for mixed sludge and waste activated sludge respectively (Hu et al. 2011). Other experiments examined sludge samples frozen for 24 hours at -10°C and -18°C in the freezer and then thawed at room temperature. The results indicated that freeze/thaw can increase the soluble chemical oxygen demand (SCOD) 2-8 times, as well as increase the concentration of ammonia 2-8 times and orthophosphate concentration 1.2-2.5 times (Gao 2011). The effects of freeze/thaw processing on nutrient concentration of mixed primary and waste thickened sludge were evaluated in lab experiments and resulted in increases by about 39% and 53% in ammonia nitrogen and phosphorus (as orthophosphate) in supernatant, respectively. As well, there was an increase by about 2 times in SCOD concentration (Montusiewicz et al. 2010). Wang (2001) reported an increase of 25.5, 24.6 and 18.8 times the quantity of SCOD from the sludge frozen at -10, -20 and -80°C, respectively, compared with unfrozen sludge. Furthermore, the number of viable bacteria decreased by about 96%, 93% and 84%, respectively, indicating cell damage during freeze/thaw processing (Wang et al. 2001).

The present study examined the freeze/thaw process as a potentially practical and cost-effective sludge management method in Northern Canadian communities. Northern Canadian communities have extremely cold winters and short summers. Sludge that is produced in these communities is generally stored in sludge lagoons, shipped to the local landfill or transported to the nearest equipped treatment plant for further treatment. Developing an efficient dewatering and conditioning method has advantages in terms of reducing the cost and lowering the risk of distributing untreated sludge into the environment during shipping or disposal into the landfill. Freeze/thaw experiments were designed to evaluate the extent of dewatering for BNR (biological nutrient removal) and non-BNR (conventional biological treatment plant) activated sludge. The potential of nutrient solubilisation from the organic content of these two sludges (BNR and non-BNR) through freeze/thaw processing was assessed.

**MATERIALS AND METHOD**

**Source and collection**

Return activated sludge (RAS) was used in the experiment and accessed from the South End Water Pollution Control Centre (SEWPCC) and West End Water Pollution Control Centre (WEWPCC) in Winnipeg, Canada. Treatment processes in SEWPCC include primary sewage treatment and secondary biological treatment (Biological Oxygen Demand (BOD) removal, non-BNR) and ultraviolet disinfection. The WEWPCC treatment process includes primary treatment and secondary biological treatment including nutrient removal (BNR, both nitrogen and phosphorus removal) and natural-light disinfection in polishing ponds. The sand and pea gravel used as a drainage bed was sourced from a local garden store (Lacoste Garden Centre, Winnipeg, Manitoba).

The experiments were done as batch tests and were conducted in a laboratory under controlled conditions. Three plastic boxes (0.46 × 0.65 × 0.18 m) were used as beds during the freezing period. The aim was to freeze the fresh sludge in thin layers in the freezer and then thaw and drain the water to separate the solid and liquid fractions for further examination. A freeze period of three weeks was chosen. Every week approximately 20 L of fresh sludge was collected from the wastewater treatment plant and shipped to the university laboratory on the same day of the experiment. The sludge was mixed and 3 L of fresh sludge was collected and added to each box. The presence of three boxes represents triplicate tests. The boxes were covered with lids and were placed inside a chest freezer for one week to freeze. The freezer temperature was set at -12°C. After one week a second layer composed of 3 L of fresh sludge was added on top of the initial frozen layer and left in the freezer for another week. At the end of second week, the third and last layer of 3 L of fresh sludge was added the same way and left in the freezer for one week. In summary, each box contained three layers of 3 L for a total of 9 L of sludge. Total nitrogen (TN), total phosphorus (TP), total chemical oxygen demand (TCOD), ammonia-nitrogen (NH₄-N), phosphate-phosphorus (PO₄-P), soluble COD (SCOD), total solid (TS), and volatile solid (VS) were measured for each fresh sludge layer.
The focus of this experiment was done under lab temperature and moisture conditions, and it cannot be compared with the results of other studies reporting more than 20% solids content of sludge cake post freeze/thaw treatment (p = 0.0002, comparing non-BNR and BNR sludge). However, the thawing phase for this experiment was done under lab temperature and moisture conditions, and it cannot be compared with the results of other studies reporting more than 20% solids content of sludge cake post freeze/thaw treatment (p = 0.0002, comparing non-BNR and BNR sludge). However, the thawing phase for this experiment was done under lab temperature and moisture conditions, and it cannot be compared with the results of other studies reporting more than 20% solids content of sludge cake post freeze/thaw treatment (p = 0.0002, comparing non-BNR and BNR sludge).

**Tables 1** shows the fresh activated sludge characteristics collected from both non-BNR and BNR plants.

Three plastic boxes (0.73 x 0.45 x 0.15 m) were used for thawing and drainage. The boxes were covered with insulation material to replicate natural soil conditions found in sludge freezing beds. Each box was prepared by making two holes and placing tubes to collect the melted water into effluent buckets. Approximately 2 kg of pea gravel and 1 kg of sand were placed at the bottom of each box as a drainage bed and the melted water drained through the sand and gravel bed. The sludge cake was left inside the box. The frozen samples were placed into the boxes and left at room temperature to melt (21 ± 1 °C). A fabric screen was used to separate the sand and gravel from the sludge. The weights of the boxes were measured before and after placing the frozen sludge, and again after thawing and dewatering. Melt-water was analyzed for TN, TP, TCOD, NH₄-N, PO₄-P, and SCOD (in triplicate). The sludge cake was analyzed for TN, TP, TCOD, TS and VS (in triplicate).

**Sample analysis**

Samples taken from fresh sludge were centrifuged at 10,000 rpm for 10 minutes and the supernatants were separated and passed through vacuum filter paper with a pore size of 0.45 μm. The filtrates were diluted with deionized (DI) water and NH₄-N and PO₄-P were measured using flow injection analysis (FIA) (LaChat QuikChem 8500). TCOD of mixed fresh sludge and SCOD of filtrate supernatant were determined using standard methods (APHA 1998). For the collected effluent, samples were taken from each box, filtered, diluted and analyzed as mentioned above for soluble materials. The pH, total solids and volatile solids of all samples were determined using standard methods (APHA 1998). The total N and total P within the mixed fresh sludge and collected effluent water were determined by a modified method of Kjeldahl digestion following a Hach procedure using sulphuric acid and hydrogen peroxide (Hach 1999). Statistical analysis was performed using SAS version 9.3. An independent t-test was used to compare the effect of freeze/thaw treatment on nitrogen, phosphorus and COD solubilisation of the BNR and non-BNR activated sludges. The null hypothesis was that there were no differences between the two types of sludge. It was assumed that all the environmental conditions during freeze/thaw were the same for the two different types of sludge for the purpose of analysis.

### Table 1. Activated sludge characteristic from non-BNR and BNR wastewater treatment plants.

<table>
<thead>
<tr>
<th></th>
<th>TN (mg/L)</th>
<th>TP (mg/L)</th>
<th>TCOD (mg/L)</th>
<th>NH₄-N (mg/L)</th>
<th>PO₄-P (mg/L)</th>
<th>SCOD (mg/L)</th>
<th>TS (g/L)</th>
<th>VS (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-BNR Sludge</td>
<td>713.28 ± 77.99</td>
<td>143.77 ± 44.71</td>
<td>922.69 ± 559.02</td>
<td>42.40 ± 3.48</td>
<td>9.45 ± 2.11</td>
<td>67.14 ± 12.90</td>
<td>7.82 ± 0.35</td>
<td>6.6 ± 0.30</td>
</tr>
<tr>
<td>BNR Sludge</td>
<td>718.11 ± 130.18</td>
<td>270.22 ± 31.73</td>
<td>11232.64 ± 2153.48</td>
<td>4.21 ± 0.98</td>
<td>13.84 ± 5.42</td>
<td>83.59 ± 10.99</td>
<td>9.83 ± 1.08</td>
<td>7.96 ± 0.75</td>
</tr>
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**RESULT AND DISCUSSION**

**Effects of freeze/thaw treatment on sludge dewatering**

Frozen sludge left at room temperature thawed and drained completely within 48 hours. The thawed water moved readily through the sand bed. Inside the boxes, the dense and compacted flocs were left on top of the flat screen as a sludge cake that was easily removed. The percentages of water removed by this method for the non-BNR and BNR sludge were 84.15 ± 0.5% and 75.3 ± 2.1%, respectively (p = 0.0262, comparing non-BNR and BNR sludge). The difference in water removal between the two types of sludge was mostly because of a leakage in one box during the thawing process of the BNR sludge. Overall, considering the evaporation and absorption of the water by the sand and gravel, this method was effective in reducing the sludge water by more than 85%. These results are consistent with other studies reporting about 90% of sludge moisture removal by freeze/thaw treatment under natural environment conditions (Martel and Diener, 1991; Reed et al. 1986).

According to the previously described mechanisms of freeze/thaw treatment, sludge freezing is initiated with freezing of the free water around the sludge flocs. Then, the interstitial water, which is the water molecules inside the flocs, joins the moving ice structure. Providing sufficiently low temperature and long enough freezing time (curing time) can result in freezing of surface water and finally bound water, forcing the particles into the more compacted form (Vesilind et al 1991). The solids content of non-BNR raw sludge was 0.77 ± 0.03 %, which increased to about 9.3 ± 0.41% at the end of thawing. The solids content of the BNR raw sludge was about 0.98 ± 0.11%, which increased to 9.93 ± 0.38% in the sludge cake post freeze/thaw treatment (p = 0.0002, comparing non-BNR and BNR sludge). However, the thawing phase for this experiment was done under lab temperature and moisture conditions, and it cannot be compared with the results of other studies reporting more than 20% solids content of sludge cake under natural thawing conditions. Higher solid concentration would be expected with a drying period during the summer season as well as the presence of wind and subsequent evaporation in nature (Martel and Diener 1991; Hellstrom and Kvarnstorm 1997; Mangat et al. 2008; Reed et al. 1986).

**Effects of freeze/thaw treatment on sludge solubilisation and nutrient release**

The focus of this study was on conventional biological sludge (non-BNR
sludge) since operating wastewater treatment plants in many Northern Canadian communities are performing conventional treatment (Burnside 2011); the experiment for the non-BNR sludge was repeated three times and once for the BNR sludge. The concentrations of relevant wastewater constituents were measured, and using influent and effluent volumes, their mass was calculated. Solubilisation was determined by subtracting the mass of the constituent (N, P, or COD) in the influent supernatant from the effluent, divided by total mass of the constituent in the raw sludge. (Hu et al. 2011).

**Effects of freeze/thaw treatment on organic phosphorus release** Phosphorus is an important part of DNA, RNA, and ATP. The increase of P in the effluent liquid after freeze/thaw indicated rupture of bacterial cells through freezing and discharge of the intracellular material. Total P and soluble P before and after freeze/thaw treatment for both non-BNR and BNR sludge are displayed in Fig. 1. Results indicate the release of 33.5 ± 5.5% for non-BNR and 80 ± 12% of P for BNR through freeze/thaw treatment into the effluent. The results from this experiment are consistent with those obtained by Ormeci and Vesilind (2001), reporting a six-fold increase in DNA concentration in sludge supernatant after freeze/thaw conditioning, which indicates the presence of intracellular material as a result of cell disruption. In addition, current findings are in agreement with those by Gao (2001) who reported an increase of PO\textsubscript{4}-P concentration after freeze/thaw caused by cell disruption.

Comparing the behaviour of the two sludge types, a significant difference (p<0.0002) between non-BNR and BNR sludge in terms of organic P release with freeze/thaw treatment was observed. Considering mechanisms of P uptake in BNR processes, the difference in sludge P content can be attributed to the enhanced presence of Phosphorus Accumulating Organisms (PAOs) in the BNR system and their capacity to uptake P and store it as polyphosphate in their cells. The ratio of TP/VS (g/g) of raw sludge in the current experiment was 0.025 and 0.036 for non-BNR and BNR sludge respectively, demonstrating the higher amount of P in the biomass of BNR activated sludge.

**Effects of freeze/thaw treatment on organic nitrogen release** Nitrogen is an important component of amino acids which are the building blocks of proteins. The increase of NH\textsubscript{4}-N in the effluent can be attributed to the degradation of proteins as a consequence of cell rupture through freezing. The total organic nitrogen and ammonium nitrogen before and after F/T for both non-BNR and BNR sludge are illustrated in Fig. 2. The freeze/thaw resulted in the release of about 15.19 ± 2.4 and 6.31 ± 0.25% of the cell organic nitrogen into the collected water for non-BNR and BNR sludge, respectively. The results of nitrogen release in this study are in agreement with those from previous studies, which showed an increase of NH\textsubscript{4}-N concentration in the sludge supernatant after freeze/thaw treatment (Hu et al. 2011; Gao 2011; Montusiewicz et al. 2010; Ormeci & Vesilind 2001). Ormeci and Vesilind (2001) reported increases of proteins and carbohydrates by freeze/thaw treatment of activated sludge indicating the effectiveness of this method for releasing the extracellular materials of sludge flocs and intracellular materials of cells to the supernatant. However, different release rates were reported depending on the freezing temperature and curing time. Hu et al. (2011)}
Hu (2011) observed an increase in COD solubilisation with increasing curing time (1.6 and 10.5% after 3 h and 72 h), similar to what was observed for nitrogen release, and reported the release of these two parameters mainly depended on the curing time. Further investigation is needed in order to find the ideal conditions for organics release.

The results of COD solubilisation in the current study are comparable with the thermal treatment of activated sludge in an oven set at 121°C for 30 min that resulted in 17.6% COD solubilisation (Jeongsik et al. 2003). In addition, Bougrier et al. (2008) reported the COD release of about 20% by thermal treatment of activated sludge at a temperature of 100°C. In fact, this suggests that freezing/thawing has the same effect as thermal treatment in terms of solubilizing of COD. Gao (2010) has shown that the effect of one freeze/thaw cycle of activated sludge was the same as the thermal treatment in an oven set at 103°C for 30 min in solubilizing COD. Comparing two different types of sludge from BNR and non-BNR plants, it was demonstrated that F/T affected both sludge types similarly (p = 0.1258). The amounts of organics in BNR and non-BNR sludge were 1.5 ± 0.12 and 1.4 ± 0.07 (TCOD/VS g/g) respectively.

There is a potential for using the collected water from F/T treatment directly for agricultural purposes since the released soluble nitrogen and phosphorus in the effluent are mostly in the form of NH₄-N and PO₄-P, respectively, which are ready for uptake by plants, comparable to mineral fertilizers. However, the overall concentrations of N and P in the effluent are low (less than 0.1%), and would need to be amended with additional mineral nutrients to be used as a fertilizer in agriculture or gardening applications. Overall, the effluent from F/T has the potential to be used for irrigation or for nutrient recovery. Designing a pilot scale freezing bed will be beneficial in order to validate results of this research study and also develop a specific design model applicable for Northern Communities, taking into consideration their natural environmental conditions and community infrastructure. Moreover, measuring and monitoring microbial activity, in particular fecal coliform density for both post freeze/thaw sludge cake and effluent water will be beneficial in order to find the most efficient end use of both the solid cake and filtrate. This will be a function of specific local environmental regulations, and fertilizer use guidelines.

**CONCLUSION**

Freeze/thaw treatment was carried out as a sludge dewatering and conditioning method to explore a practical, low-cost, natural sludge treatment for remote and cold regions. The main objective of the study was to dewater the sludge using natural freezing winter conditions in Northern communities. This was done successfully through a lab-scale freezing bed. Freeze/thaw treatment experiments showed that freezing can reduce the sludge moisture by more than 85%. In addition, the method effectively agglomerated small particles and improved
sludge dewaterability. Sludge solid concentration was increased by approximately 10 times and the compacted form of the remaining sludge cake after dewatering was removed easily from the bed. Advantages of sludge volume reduction include lowering transportation and disposal costs and energy consumption. Furthermore, the compacted and concentrated sludge cake is easier to remove, transport and dispose than untreated waste sludge. The study showed that freeze/thaw is solubilizing complex insoluble organic compounds of activated sludge into soluble ones. Freezing can cause disruption in microorganisms in activated sludge and result in the release of intracellular and extracellular materials of cells to the supernatant. Solubilisation of about 15.2% of organic nitrogen, 33.5% of organic phosphorus and 21.5% of total COD were achieved, respectively, for the activated sludge from a non-BNR treatment plant. For the sludge from a BNR treatment plant 6.31%, 80% and 16.5% were observed for nitrogen, phosphorus and COD solubilisation. The effluent water collected after thawing has the potential to be used for agriculture purposes, primarily in irrigation systems for northern food production (greenhouse, growth chambers, etc.)

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LIST OF SYMBOLS

AANDC  Aboriginal Affairs and Northern Development Canada
ATP  Adenosine triphosphate
BNR  Biological nutrient removal
BOD  Biochemical oxygen demand
COD  Chemical oxygen demand
DI Water  Deionized water
DNA  Deoxyribonucleic acid
ECP  Extracellular polymers
FIA  Flaw injection analysis
F/T  Freeze/thaw
INAC  Indigenous and Northern Affairs Canada
NH₄-N  Ammonium nitrogen
PAOs  Polyphosphate-accumulating organisms
PO₄-P  Orthophosphate
RAS  Return activated sludge
RBC  Rotatory biological contactor
RNA  Ribonucleic acid
SCOD  Soluble chemical oxygen demand
SEWPCC  South End Water Pollution Control Centre
TCOD  Total chemical oxygen demand
TN  Total nitrogen
TP  Total phosphorus
TS  Total solids
VS  Volatile solids
WAS  Waste activated sludge
WEWPCC  West End Water Pollution Control Centre

REFERENCES


