Natural wastewater polishing treatment, cold crystallisation and wetlands

Jarmo Sallanko  
Lab. manager, Dr,  
Docent  
University of Oulu  
Department of process and environmental engineering  
Finland  
jarmo.sallanko@oulu.fi

Esko Lakso  
Prof. emer.  
Lakson Vesi Ltd  
Finland  
jaakko.lakso@gmail.com

Mikko Martikainen, managing director, Snow Secure Ltd, Finland, mikko.martikainen@snowsecure

Summary

Modern biochemical wastewater plants produce high quality treated wastewater. To further improve end-product quality, natural processes such as wetland passage or snowmaking can be used as a low-cost polishing treatment. These two treatment methods have different annual optimum working periods and thus combining them could be an effective solution at high latitudes.

Keywords: Wastewater, wetlands, cold crystallisation, snowmaking, polishing treatment, wastewater treatment, municipal wastewater, BOD-removal, phosphorus, nitrogen

1 Introduction

With the current tightening of environmental regulations, there is a need for improved wastewater treatment. The final stages of wastewater purification to make the last percentage reductions in contaminants are costly in terms of Euros/kg impurities removed. The conventional method for enhancement of wastewater treatment is by making process changes or by adding a finishing treatment after the process, e.g. flotation or filtration. An alternative way to improve the effectiveness of municipal or industrial wastewater treatment is to use natural processes for polishing the water leaving the wastewater plant. Potential natural polishing treatments include e.g. passage through wetlands and snowmaking from treated wastewater [1,2].

In northern areas of the world the population density is usually low and there is often sufficient land available for using wetlands for polishing treated wastewater. Wetlands are used for wastewater polishing at four sites in northern Finland. In cold climates, the winter cold can also be exploited in wastewater purification, by producing artificial snow from treated wastewater. This cold crystallisation or freeze crystallisation method is based on the fact that when water freezes, ice crystals of pure water grow, while impurities are concentrated in the remaining phase. The impurities trapped in the snow evaporate when the snow ages (nitrogen in the form of ammonia gas) and the flocs of impurities formed in the snow ageing process are adsorbed in the soil when the snow melts. This system is used at some sites in the USA and Canada and has been tested in Kuusamo, Finland [3].

2 Finnish experiences of wetlands

The soil layer has long been used for wastewater purification all over the world. For example, infiltration of municipal wastewater to marshland (seepage trench technique) was applied in many places in northern and eastern Finland in the early 1970s. Overland flow or wetland treatment is
now used in Finland as a polishing treatment after municipal wastewater treatment, or as a treatment for mining effluent and for water leaving agriculture, forestry and peat harvesting areas.

The Finnish experiences of using wetlands for polishing treated municipal wastewater are mainly from natural wetlands, of which four are currently in use in northern Finland. The number of population equivalents (PE) served by the associated municipal wastewater plants varies from 4 500 (Mellanaavaa) to 36 000 (Lakeus). The Ruka wastewater plant serves 15 000 PE and the Siikalatva plant 9 300 PE. The first three of those wetlands were built in 1990 and that at Siikalatva in 2007. The older wetlands are generally very basic and simply use an existing wetland area without additional earthworks or plantings apart from water-conducting ditches and isolation ditches and dams around the area (Figure 1).

Fig. 1. The multi-element Siikalatva wetland, Rantsila, Finland (left) and the very basic natural Ruka wetland, Kuusamo, Finland (right).

The four wetlands are quite different in nature. The Ruka wetland was originally a pine swamp, the thickness of the peat layer is 0.5-1.5 m, there is no open water and the wetland area is 0.6 ha (Figure 1) [4]. The new Siikalatva wetland, in which production in the whole area started in 2010, consists of three parts, a 3 ha natural wetland, 4.5 ha reed canary grass and 17 ha of old peat harvesting area (Figure 1). However, the latter does not yet have a satisfactory vegetation cover and slightly weakens the wetland’s purification efficiency in terms of BOD and COD.

The Mellanaavaa wetland is 5.4 ha and the vegetation is sparse (Figure 2). The thickness of the peat layer is 0.7-1.0 m [5]. The Lakeus wetland has a water depth of 0-1.1 m and the amount of open area is 30%. The soil is a dense glacial till and the vegetation consists of cane-grass and willow. The original area of the wetland was 4.4 ha, but in 2011 it was enlarged to 17 ha (Figure 2).
The purification effect of all four wetlands is quite good (Table 1). There has been no deterioration over the years, although adaptation of the vegetation might further improve the purifying effect slightly over time.

Table 1. Purification effects of four Finnish wetlands used for polishing water leaving municipal biochemical wastewater plants. $\text{BOD}_7=\text{biological oxygen demand, } P_{\text{tot}}=\text{total } P, N_{\text{tot}}=\text{total } N$ [6].

<table>
<thead>
<tr>
<th>Reduction (%)</th>
<th>Mellanaava</th>
<th>Ruka</th>
<th>Lakeus</th>
<th>Siikalatva</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended solids</td>
<td>45-50</td>
<td>80-86</td>
<td>64-68</td>
<td>95-99</td>
</tr>
<tr>
<td>$\text{BOD}_7$</td>
<td>16-25</td>
<td>60-65</td>
<td>60-80</td>
<td>55-60</td>
</tr>
<tr>
<td>$P_{\text{tot}}$</td>
<td>10-15</td>
<td>64-90</td>
<td>60-80</td>
<td>0*</td>
</tr>
<tr>
<td>$N_{\text{tot}}$</td>
<td>2-18</td>
<td>13-30</td>
<td>18-30</td>
<td>27-70</td>
</tr>
</tbody>
</table>

* Outflow of P from wastewater plant only 0.1 mg/L.

3 Cold crystallisation

The freezing process can be exploited in many ways for concentration and purification of fluids, for example for freeze concentration of fruit juices, desalination of sea water, sludge dewatering and wastewater purification, as described by many studies in this field [7,8,9]. Freezing requires a lot of energy, but at high latitudes the natural winter cold can be used for this purpose. The purification effect in cold crystallisation occurs during many phases: spraying and freezing, snowpack ageing and finally when the snow melts and the meltwater flows over the soil surface (Figure 3).
In the spraying phase, up to 10% of the water disappears due to the evaporative requirement of the heat transfer process [11]. Small amounts of gases such as ammonia (NH₃) and hydrogen sulphide (H₂S) are also removed. Freezing then starts from outside the sprayed droplets. There is some degree of sublimation from the surface of snow flakes, perhaps up to 20-30% [12]. A considerable amount of CO₂ is also removed from the water, raising the pH of the water by 1.5-2.5 units. When the pH rises, ammonium (NH₄⁺) is increasingly converted to ammonia gas (NH₃) [13]. The concentration of impurities in the liquid phase of snowflakes assists floc formation and precipitation. The reduction of ammonium also assists phosphate precipitation, because phosphate readily binds with ammonium ions to form highly soluble ammonium phosphate. When the amount of ammonium decreases, the phosphate reacts with calcium and precipitate [7]. The ammonium reduction starts in spraying and continues progressively as the snowpack ages. During snowpack ageing, contaminants travel downwards and there is some diffusion and gas exchange with the surrounding air. Light, UV-radiation, rain, temperature changes and microbial activities also alter the snow. When the snow melts, the flocs formed remain on the soil surface and there is also some adsorption of soluble impurities to soil on the surface and at deeper levels. After melting of the snow, growing vegetation uses those impurities and thus nutrients remain in the snowmaking area.

4. Studies on cold crystallisation at Kuusamo

The cold crystallisation method was tested at the Ruka biochemical wastewater plant in 2006. For this, 6 700 m³ of treated wastewater were made into snow using hybrid snow guns. Total snow production was 10 000 m³ (Figure 4).
The average quality figures for the treated wastewater in the snow storage area were: chemical oxygen demand (COD) 17.3 mg/L, BOD$_7$ 6.9 mg/L, P$_{tot}$ 56 µg/L, N$_{tot}$ 9.4 mg/L, pH 6.8, colour 150 mg Pt/L. Thus the reduction in nitrogen was very high but the reduction in phosphorus and organics (BOD$_7$) was somewhat lower (Figure 4). The energy consumption was 1.12 kWh/m$^3$ and the snowmaking area required was 0.37 m$^2$/m$^3$ wastewater [3].

5. Combined methods

Wetlands work somewhat less efficiently in wintertime than in spring or summer. The main vegetation in the wetlands consists of annual species and they grow in warm spring and summer conditions. They gradually extend their roots and build up new filter/substrate/adsorbent every year. Chemical reactions and biological activity are also much lower at a temperature of 2°C than 20°C. Although these affect the efficiency of wetlands in winter, wetlands still work moderately in cold weather.

In wintertime the coldness of nature can be exploited for the cold crystallisation method. The only energy needed is for pumping the snowguns, as nature supplies the rest. The greatest requirement is for a sufficient land area for storing the snow. This should not be near housing areas or other
regularly used areas, because the fog produced by the snow guns covers a wide area. Although it is possible to include for example UV-light disinfection before snowmaking, the fog is not very pleasant to breathe. One possibility to improve the quality of this fog is wetland treatment before UV-disinfection and snowmaking. Wetland pre-treatment is also a good method for lowering the temperature of the water before snowmaking.

6. Results

There is long experience in Finland of using wetlands for polishing treated municipal wastewater and good purification results have been achieved with a small capital investment. The purification effect of wetlands is greatest in spring and summer, although they work moderately well in winter. The cold crystallisation method is not as well-known as wetland treatment, but experiences to date are positive. Cold crystallisation exploits the natural cold, so is only possible in winter. However, if there is sufficient land available, these methods can be combined so that the winter load of wastewater is sprayed to form snow and the cold crystallisation method partly purifies the water. In spring and summer, when wetlands are at their most effective, the meltwater from the snow spraying area is then conducted to the wetland for further purification before release to the recipient. In wintertime, wetland treatment before snowmaking would remove some of the pollutants and lower the temperature of the water.

References

agriculture: Forest service research paper RM-90, Rocky Mountain forest and range experiment station, Fort Collins, Colorado, 1972.