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# Separation of nutrients from mine water by reverse osmosis for subsequent biological treatment

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**Abstract**

Nutrients such as ammonium and nitrate from different sources in mining and mineral processing are often discharged during mining operation to surrounding aquatic environment. The aim of this study was to evaluate the applicability of reverse osmosis (RO) to concentrate ammonium and nitrate from three different mine waters for subsequent removal of nutrients from the concentrate in bioreactors. In initial membrane selection tests, reverse osmosis retained the nutrients and the most suitable membrane was studied for subsequent concentrating tests. The volume reduction factor was up to 20. Ammonium and nitrate were enriched by reverse osmosis 3.6 and 5.7 times, respectively. Total salinity increased about 1.5 times in the RO-concentrate. Iron, copper, zinc, lead and cadmium, potential inhibitors of bacteria, were enriched to the brine of mine water 2. In general, the permeate pH decreased slightly during the reverse osmosis concentration. The produced RO-concentrate was suitable for biological removal of total nitrogen. Prevention of membrane fouling due to suspended solids requires prefiltration of feed prior to reverse osmosis. It was estimated that the total costs for reverse osmosis with prefiltration of feed is about 0.34 €/m$^3$.

*Keywords:* Mine waters; Environment; Concentration; Reverse osmosis; Ammonium; Nitrate; Economical analysis

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## 1. Introduction

The major source of ammonium and nitrate in mining and mineral processing is the use of explosives that contain ammonium nitrate. Part of the used explosives remain undetonated and will be transported up from the mine together with extracted rock (Forsberg and Åkerlund, 1999, p. 50). Most of the explosives that are transported from the mine are dissolved in water in wet processes or remain in the barren rock that is separated in dry processes (Forsberg and Åkerlund, 1999, p. 35). Other nutrient sources in mine effluents can be flotation chemicals, cyanide destruction and pH regulation reagents (Langwaldt et al., 2006). The generated wastewaters generally contain also suspended solids, heavy metals, oxidants, reducing agents and salts (Awadalla and Kumar, 1994).

Contamination of mine water with nitrogenous compounds causes environmental problems such as undesirable algal growths in the receiving water bodies (Jørgensen and Halling-Sørensen, 1993, p. 12) and ammonia can be detrimental to fish (Revey, 1996). The promotion of corrosion is an economical issue (Jørgensen and Halling-Sørensen, 1993, p. 12). At the present in the European Union, there are no limits for the discharge of nutrients from mines to receiving waters. The European Union Water Framework

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Directive 2000/60/EC demands that member states should aim to achieve the objective at least good water status which means that nutrient concentrations do not exceed the levels established so as to ensure the functioning of the ecosystem.

One option for the total nitrogen removal from wastewater is to convert ammonium, nitrite and nitrate into dinitrogen gas by biological nitrification–denitrification. Since the amount of formed mine effluents is extensive, a volume reduction step prior to biological treatment could be economically feasible. For this purpose, membrane filtration is a promising option, since it simultaneously can remove also other pollutants in addition to nitrogenous compounds (Shrimali and Singh, 2001) and requires less energy than many other concentrating processes (Chang, 1996). The molecular weight of ammonium and nitrate is approximately 500 g/mol and, therefore, viable membrane processes for their removal are reverse osmosis and electrodialysis (Shrimali and Singh, 2001). Membrane separation processes are quite simple, the equipments are compact and modular and capable for continuous operation. (Awadalla et al., 1994) In addition, the efficiency and performance of membrane treatment are stable, and predictable with proper feed treatment (Lee and Lueptow, 2001). For this reason, the use of reverse osmosis (RO) was tested to produce a permeate that could be discharged directly to the nature and a concentrated brine including nitrogenous compounds for subsequent treatment in bioreactors (Zaitsev et al., accepted for publication).

Although studies on removal of nitrogenous compounds from wastewater by RO have been published, very few studies have been conducted on separation of nutrients from mine water. Malaiyandi and Sastri (1981 as referred by Awadalla et al. (1994)) reported less than 30% retention of ammonium and nitrate by RO with a cellulose acetate membrane. The Du Pont company (1972 as referred by Awadalla et al. (1994)) reported 80% rejection of ammonium and 85% rejection of nitrate ions from ammonium nitrate and sodium nitrate solutions, respectively, by a hollow fine fiber B-9, polyamide RO membrane. Awadalla et al. (1994) tested four different RO membranes for the removal of ammonium and nitrate from mining effluents with a 99% separation of ammonium and 97% separation of nitrates ions with a crosslinked thin-film composite RO membrane (Toray Ind. Japan). The aim of this study was thus to evaluate the applicability of RO in concentrating ammonium and nitrate from mine waters before the removal of nutrients from the concentrate in bioreactors.

## 2. Experimental

In this study, water from three different mines was tested for nutrient separation by reverse osmosis. The mines produced gold, chromite and phosphate and samples were entitled mine water 1, 2 and 3, respectively.

For the membrane selection and concentration experiments, a DSS Labstak M20 laboratory equipment was used, manufactured by Danish Separation Systems AS. It can be equipped with flat sheet membranes. The effective membrane area is 0.036 $m^2$ and it can be increased up to 0.72 $m^2$ by placing 20 membranes to the packing. Four thin film composite membranes were applied in the bench-scale reverse osmosis equipment (Table 1).

The feed temperature was kept at about 15 °C using a cooler inside the feed tank, to simulate the conditions in the mines. For the pilot scale concentrations, a spiral wound module equipment constructed by Lappeenranta University of Technology was used. The active membrane area depends on the type of membrane used.

Firstly, the feed effluent was filtered through four different commercial membranes. The experiment was carried out in a batch mode, both permeate and concentrate were returned to the feed tank. The operating pressure was raised stepwise from 6 bar to 35 bar and the permeate was sampled. The optimum pressure to be used in the concentrations was chosen based on the measured permeate fluxes and calculated retention based on electric conductivity. The samples from the optimum pressure were further analysed, and based on the analysis results, the most suitable membrane for each mining effluent was selected.

After the most suitable membrane and pressure values were selected, the mine effluents were concentrated by using an effective membrane area of 0.144 $m^2$. The concentrate was returned to the feed tank and the permeate was gathered in a separate tank. The concentration, to reduce the amount of water, was carried out with five different volumetric reduction factors (VRF).

The volumetric reduction factor was calculated according to the following equation:

$$\mathrm{VRF} = \frac{\text{Total feedwater amount}}{\text{Total feedwater amount} - \text{Amount of permeate}} \tag{1}$$

If the samples from the concentrate could not be returned, the amount of those samples was subtracted from the total feed water amount. A sample from every volumetric reduction factor concentrate was subjected to nitrification and denitrification tests (results not shown).

When the feed is concentrated with high volumetric reduction factors, the osmotic pressure of the effluent

Table 1
Technical data of the studied thin film composite RO membranes as provided by manufacturers

| Membrane identification | Supplier manufacturer | Retention (%) | Operating pH range |
|---|---|---|---|
| SW 30 HR | Filmtec Corp. | 99.6[a] | 2–11 |
| Espa 2 | Hydranautics | 99.5[b] | 3–10 |
| TFC ULP | KOCH membrane systems | 98.0[c] | 4–11 |
| RO1 | Sepro | 98.0[d] | 3–10 |

[a] Tested with 32000 mg/l NaCl, 55 bar and at 25 °C.
[b] Tested with 1500 ppm NaCl feed water solution.
[c] Nominal rejection conductivity percent.
[d] Tested with 2000 ppm NaCl feed water, with 8.6 bar pressure at 25 °C.