ELSEVIER

Desalination 132 (2000) 249–253

DESALINATION

www.elsevier.com/locate/desal

Use of continuous electrodeionization to reduce ammonia concentration in steam generators blow-down of PWR nuclear power plants

Coralie Goffin[a], Jean Claude Calay[b*]

Ligne de produit "Eaux" Laborelec, rode straat,125, Linkebeek, Belgium
[a]Tel. +32 (2) 382-06-62; Fax +32 (2) 382-02-41; e-mail: coralie.goffin@laborelec.be
[b]Tel. +32 (2) 382-04-30; Fax +32 (2) 382-02-41; e-mail: jeanclaude.calay@laborelec.be

Received 7 July 2000; accepted 21 July 2000

Abstract

As to be recycled, blow-downs of the steam generators of PWR reactors must be purified on mixed beds. In order to avoid premature saturation of these mixed beds by ammonia (the conditioning agent), the normal processing includes a cation exchanger regenerated with sulphuric acid. In the Doel power plant, Laborelec has performed tests on a pilot plant for continue electrodeionization that might replace the cation exchanger. The test campaign lasted six months. It is concluded that ammonia is removed well (1000 ppb in the feed and 3–4 ppb in the dilute). Flowing over the electrodeionization the other impurities are also removed: the conductivity of the recovered wastewater amounts to nearly 0.07 µs/cm. When installing an electrodeionization, the cation exchanger of the processing chain could be removed. This would considerably relieve the mixed bed which should practically not require further regeneration. During the tests the concentration factor of ammonia ranged between 30 and 40.

Keywords: Steam generator; Blow-down; Pressurized water reactor; Ammonia; Continuos electrodeionization; Mixed bed

1. Introduction

To avoid corrosion, the secondary circuit (see Fig. 1) of units 3 and 4 of the Doel PWR nuclear power station is surrounded by ammonia solution. In each unit, the rate of flow of the fluid flushing out the steam generators is 60 m^3/h. To be used again, this water has to be purified. At the moment, this is done by filters, followed by ion exchangers. The system consists of a mixed bed preceded by a cationic ion exchange resin. The cationic ion exchange resin eliminates the ammonia in order to lengthen the cycles of the mixed bed. The resins are regenerated; sulphuric acid and sodium hydroxide are used. In one year the cationic exchangers are regenerated approximately 20 times and the mixed resin beds twice. The regeneration of a cationic ion exchange

*Corresponding author.

Presented at the Conference on Membranes in Drinking and Industrial Water Production, Paris, France, 3–6 October 2000
International Water Association, European Desalination Society, American Water Works Association, Japan Water Works Association

0011-9164/00/$– See front matter
PII: S0011-9164(00)00156-9

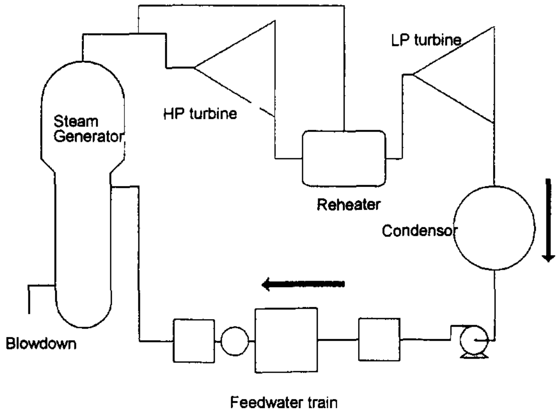

Fig. 1. Diagram of the secondary circuit of a PWR nuclear power plant.

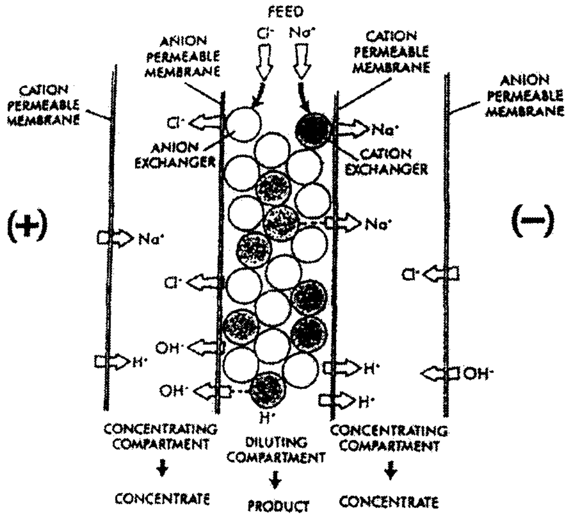

Fig. 2. Diagram illustrating the principle of continuous electrodeionization.

resin consumes 1770 kg of H_2SO_4 (100%) and produces 500 m^3 of effluent. The regeneration of a mixed resin bed consumes 900 kg of H_2SO_4 (100%) and 480 kg of NaOH (100%) and it produces 400 m^3 of effluent.

The objective of the studies was to determine whether continuous electrodeionization (EDI) enables ammonia to be eliminated effectively, other pollutants (salts that become concentrated in the steam generators) to be reduced and whether this can be done with a sufficient concentration factor.

2. Principle of continuous electrodeionization

A continuous EDI device is similar to an electrodialysis (ED) whose "dilute solution" compartments have been filled with mixed bed ion exchange resin beads as shown in Fig. 2. Electrodialysis is limited by a threshold of conductivity in the dilute solution below which the procedure is no longer efficient. Electrodeionization enables water to be produced that is practically pure. The mechanism of ion transfer takes place in two stages. The ions are first transported into the beads of resins by diffusion and then through the resins towards the membrane by the continuous current.

The resins of the mixed bed are regenerated by means of H^+ and OH^- ions, which appear as water splitting occurs; this takes place in some parts of the diluting compartments. The H^+ and OH^- ions formed are separated before they can recombine into water.The resins also eliminate CO_2 and silica that are found in more ionised forms.

Continuous electrodeionization is nevertheless a process used for finishing, generally used in the preparation of demineralised water after reverse osmosis.

The water supplying continuous electrodeionization equipment must reach high standards of purity: it must be free of suspended matter as the beads of resin behave like a filter and there is no backwashing mechanism; furthermore the stacks cannot be disassembled (contrary to ED).

The salinity must not be too high as in this procedure, 10–20% of the continuous current

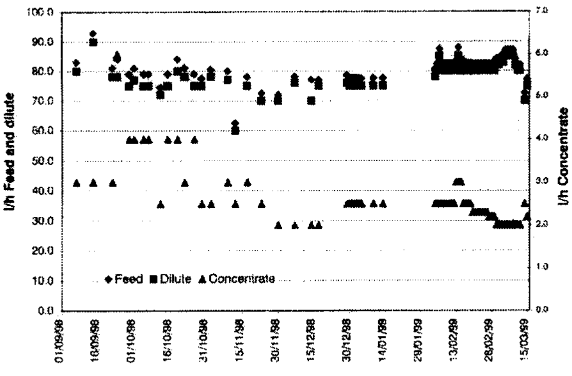

Fig. 3. Evolution of flows.

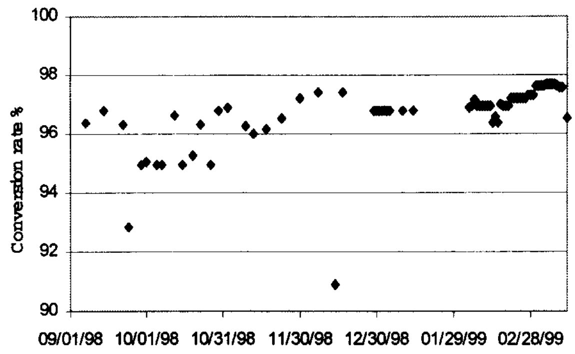

Fig. 4. Conversion rate.

applied is used to transport ionised salts, the rest of the current serves to split the water. In addition, its Ca ion content has to be as low as possible as there is a risk of precipitation within the anionic membranes.

3. Description of the pilot plant

The EDI module comprises two stacks in series, each made up of 8 pairs of cells. The voltage applied per cell is 4 V, i.e. 32 V per stack.

The pilot plant was designed to achieve the following performances:

Production	72 l/h
Degree of conversion	>90%
Temperature at which it was designed to operate	25°C
Elimination of conductivity	99.5%

The water used to supply it must comply with the following specifications:

Pressure	20–50 psi
Conductivity	<20 μS/cm
Hardness	<0.025°F
TOC	<0.5 mg/l
Temperature	10–35°C
pH	4–10
Free chlorine	<0.1 ppm
CO_2	<8 ppm
Suspended matter	none

4. Description of the tests

The pilot plant operated continuously on the steam generator blowdown, from the end of August 98 to the beginning of March 99, i.e. a period of 6 months.

The flow of dilute remained stable (about 75 l/h) and that of the concentrate ranged between 2 and 4 l/h (Fig. 3), reaching a conversion rate of 96% (Fig. 4).

5. Monitoring of the tests

During the tests, several factors were monitored (see Table 1). On-line measurements of cations and anions were made twice a day on the feed and the dilute solution. Regarding the concentrate, the cations were analysed once a week and the anions twice a week. The silica content was measured once a week in the feedwater, the dilute and the concentrate.

6. Results

Fig. 5 shows that the ammonia was indeed eliminated throughout the test period. Average

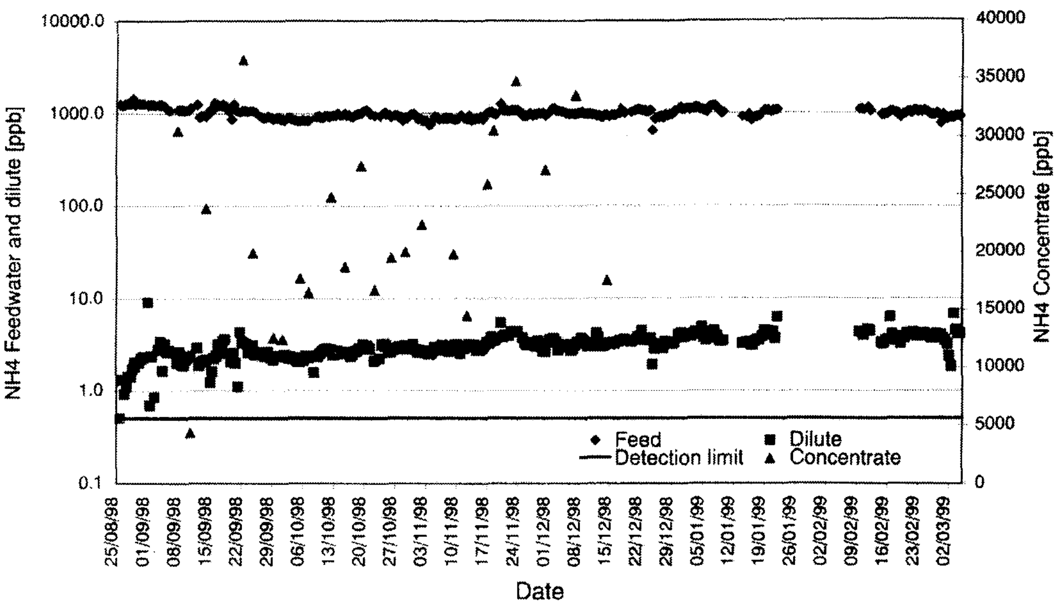

Fig. 5. Measurement of ammonia.

Table 1
Methods of analysis and limits of detection

Element	Method		Detection limit
	Feed-dilute	Concentrate	on-line, ppb
Na^+	IC-on line	Specific electrode	0.05
NH_4^+	IC-on line	IC-off line	0.5
Mg^{++}	IC-on line	IC-off line	0.1
Ca^{++}	IC-on line	IC-off line	0.3
F	IC-on line	Specific electrode	0.2
Cl^-	IC-on line	Specific electrode	0.1
SO_4^{2-}	IC-on line	IC-off line	0.1
SiO_2	Colorimetric	Colorimetric	1

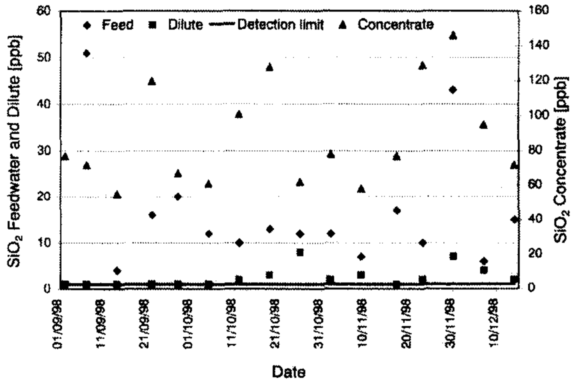

Fig. 6. Measurement of silica.

values at the intake to the EDI (i.e. steam generators blowdown) were in the region of 1,000 ppb and at the outlet they were 3 ppb. Elimination was always in excess of 99%.

From Fig. 7, it appears that impurities were eliminated. The concentration in the dilute solution remained stable, even during periods when there were higher concentrations in the feeding solution.

By and large, the elimination of silica was good, since the concentration in the dilute often dropped as low as about 1–2 ppb (see Fig. 6). In general Ionics estimates that an elimination rate lying between 90 and 99% could be expected.

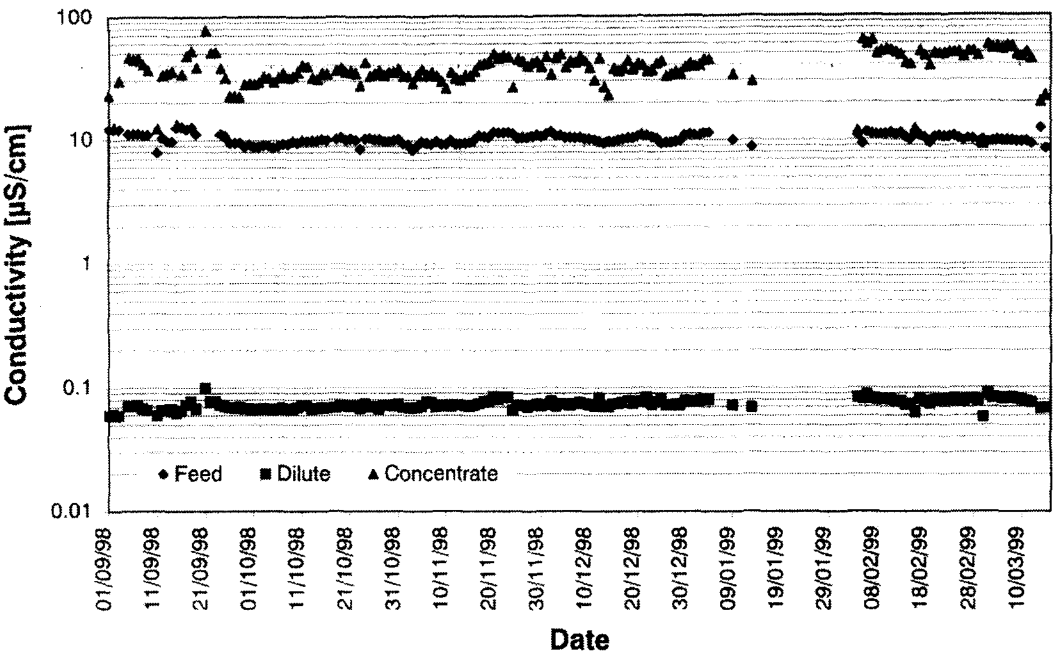

Fig. 7. Evolution of conductivity.

The silica levels in the concentrate were often too low, which we could not explain.

7. Evaluation of the treatment cost

The investment required for the installation of a continuous electrodeionization plant is estimated at around 7 MBEF. The operating costs are low: no chemicals are consumed, very little maintenance is required and the consumption of energy is estimated to be 0.5 kWh/m^3.

The operating costs of the ion exchange purification installation reach approximately 850 kBEF/y (cost of the effluent not included).

8. Conclusions

The results of the tests demonstrate that continuous electrodeionization is a technique that might with advantage replace ion exchange for purifying steam generators blowdown. On the one hand, more than 99% of the ammonia is eliminated (2 to 4 ppb in the treated water), so the use of a cationic ion exchange resin is no longer required. On the other hand, the flushing solution is also cleared of chemical contaminants (λ purified water <0.1 µS/cm). This enables us to affirm that if a mixed resin bed were kept safely downstream of an electrodeionization unit, it would practically never have to be regenerated.

The concentration factor achieved during the trial was limited to 40 since the pilot plant available was not able to adjust the flow of concentrate below 2 l/m.