System Development Strategy for Removal of Boron Discharged from PWR NPP's

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1. Introduction

Unlike the boiling-water reactor (BWR), the PWR uses boric acid as a neutron absorber and regulates the pH with lithium hydroxide (^{7}LiOH). Accordingly, liquid waste from PWR systems contains a significant amount of boron. The World Health Organization (WHO) recommends drinking water to be below 2.4 mg/L as boron is known to inhibit the growth of plants and animals at very low concentrations, and even China is limited to 2 mg/L [1,2].

Currently in Korea, the concentration limit of boron in discharge water is not regulated in accordance with the relevant laws, but the standard for boron concentration (4.0 mg/L) in wastewater is strictly limited worldwide and there is a global trend to manage discharge [3].

1.1 Problems

Most of PWR NPP's, the liquid radioactive waste disposal system (LRS) does not have a waste evaporator. Advanced reactors (OPR1000 & APR1400) are using the ion exchange resin and reverse osmosis membrane (RO) system for purification of waste water. A lot of excess waste generated during operation of nuclear power plant are released into the sea with diluted sea water after removing radioactive materials.

In the case of boron recovery from discharge liquid waste, it is removed using anionic resin, but too much resin acquisition, replacement cost, and radioactive waste are generated.

The waste disposal system has only managed pH and radioactive concentration when discharging the waste into the sea. Due to the limited size of the plant site, a large amount of boron is released into the sea even though a small amount of boron waste is discharged into the environment. The lack of boron recovery technology makes marine pollution inevitable due to the long-term operation of power plants.

In order to reduce the cost of purchasing and replacing ion exchange resin, to decrease the generation of radioactive wastes, and to cope flexibly with the regulation of boron concentration in the plant discharge waste solution, it is urgently required to develop facilities that can effectively remove boron before it is released from the liquid waste system.

1.2 Objectives

To develop high-efficiency boron separation/recovery prototypes (treatment capacity: 0.5 ton/hr) that can remove boron more than twice the existing boron removal facility.

2. Method and Results

2.1 Technical Characteristics for Removing Boron

While the realistic boron recovery rate in the existing reverse osmosis (Reverse Osmosis, RO) and ion exchange technique is 50%, the hybrid CDI-EIX boron removal and recovery techniques, consisting of technologies of Capacitive DeIonization (CDI) and Electrochemical Ion Exchange (EIX), can selectively remove, concentrate and recover 80% boron or more.

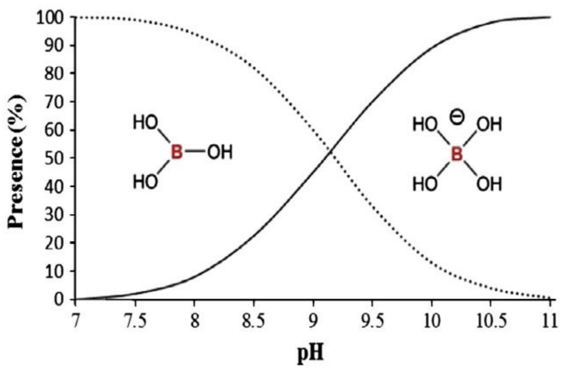

Fig. 1. Distribution of Boric Acid and Borate Ion in Solution for Various pH ranges.

Boron exists in water in the form of boric acid (weak Lewis acid) and borate ions, both of which are generally associated with pH as shown in Fig. 1.

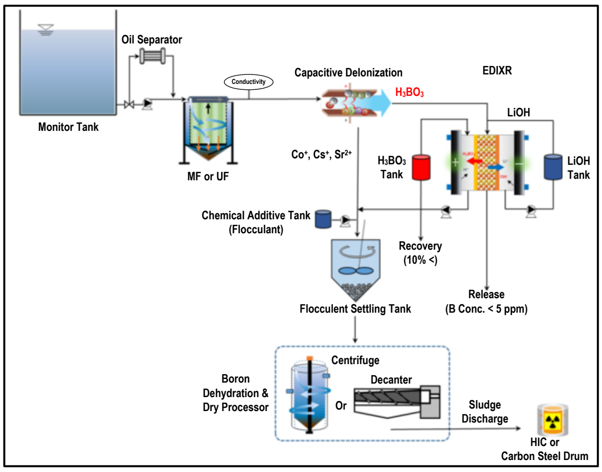

Fig. 2. CDI-EDIXR Boron Removal Process Methodology

CDI is a mechanism by which ions are absorbed into the electrical double layer formed by potential difference between the two electrodes and electromagnetic fields. As figure 2 shows, pH penetrates boron that is mostly present in molecular form (boric acid) and releases other ions, so no other ions exist in the original water entering Electric DeIonization Exchange Resin (EDIXR).

EDIXR is induced by the dichotomy of the boric acid into the DC current so that it has negative charges regardless of pH, which allows it to pass through the boron selective membrane to move towards the anode and concentrate on anolyte, thus recovering boron to a higher purity than other technologies. In addition, the ion exchange resin of the inflow water components can be regenerated by a water decomposition mechanism, so there is no concern about large amounts of radioactive waste generated by conventional ion exchange resin construction, and there is good management efficiency in that there is no need for a separate regeneration process.

The boron remover to be developed in this study is applied by applying ionizing method by electrolysis to ionize boron and apply ion electrode separation process. Since ion film and electrode can selectively remove ionizing material, the amount of waste and the amount of used resin can be greatly reduced, reducing the cost of purchasing and replacing ion exchange resin applied to remove boron.

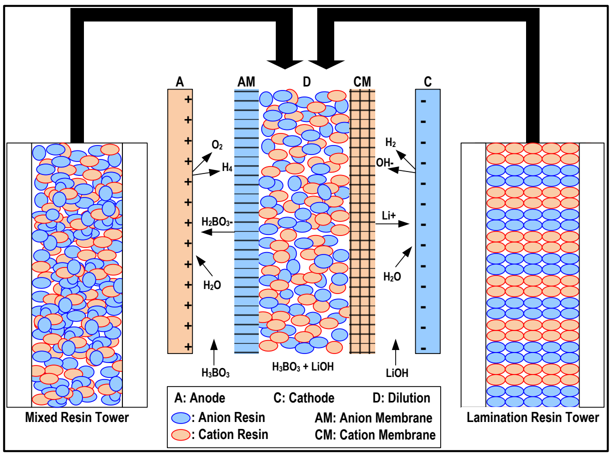

Fig. 3. Schematic Diagram of Boron Separation and Concentration Process Using Ionic Membrane and Cation/Anion Resin Layer

Currently available boron removal technology has chemical sedimentation, reverse osmosis, electrodialysis, ion exchange, etc. and is composed by combining them.

Although chemical erosion has the problem of having to rigorously limit temperature, acidity and chemical prerequisites to achieve high removal efficiency, the boron removal technique presented above has the advantage of being free from environmental conditions except for a slight change in acidity.

RO has a low removal rate of boron under low pH conditions, and high pressure is required for operation, so the energy loss is large, but CDI-EDIXR method is efficient for removing boron due to the lack of separate pH control and energy consumption. In addition, electrodes and membranes used in EDIXR can be replaced and managed more easily than RO membranes (Fig. 3).

Although electrodialysis has problems such as controlling a wide range of acidity, needing additional ions for economic operation, and consuming a lot of electrical energy depending on the state of inflow wastewater, the boron removal technique presented above has the advantages of narrow acidity control, no additional ions need to be added, and very low consumption power.

Although ion exchange has the substance and cost of regeneration of ion exchange resin, and the problem is that the ion exchange resin itself is contaminated with radioactive materials and may need to be disposed of without recycling, the boron removal technique presented above does not need to be periodically injected with certain materials, and internal parts do not need to be replaced unless they naturally reach the end of life.

2.2 Strategy

Figure 4 shows the conceptual diagram of boron removal process.

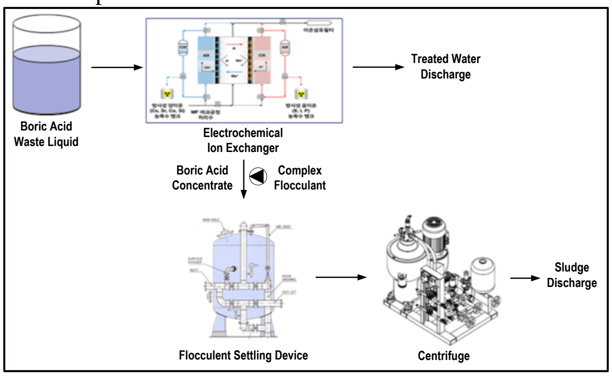

Fig. 4. Conceptual Diagram of Boron Removal Technology

- The design scale-up factor based on the optimal performance test for each unit process is derived.
- Quantitative evaluation modeling based on optimal parameters (current density, pH, charge density, mass transfer coefficient, diffusion coefficient, etc.) for process operation is established.
- Economic evaluation of the ROI (Return On Investment) under the assumption of the start-up operation of the introduction system is conducted.
- After selectively conducting agglomeration of concentrated boron in the coagulation and precipitation reactors, it is isolated using a centrifuge that can be continuously separated. It is dehydrated and dried, before it is put in a safety container and immediately disposed of or stabilized using polymer materials.
- By making simulated samples similar to the actual liquid waste samples of domestic nuclear power plants, verification experiment and device performance evaluation are performed.

3. Conclusions

As a result, the need for the development of technologies and processes for efficiently removing and recovering boron from nuclear liquid waste is increasing, from an environmental point of view as well as from an economic perspective and from various industrial protection level.

Therefore, the hybrid boron removal and recovery techniques to prevent marine pollution and boron leaks can be established, by removing boron from the discharge water of nuclear power plant liquid radioactive treatment systems without evaporator. Furthermore, it helps to relieve anxiety at nearby seaweed farms and promote safety of nuclear power plants by inhibiting the release of boron from nuclear power plants.

From an economic and industrial point of view, by introducing a new technology to remove boric acid, the cost of purchasing ion exchange resin generated when removing it from ion exchange resin and radioactive waste ion exchange resin treatment and disposal cost are reduced.

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