Optimized Configuration and Operation of CVCS Ion Exchangers

Byeong Ho Park, Yong Sang Ko, Do Hyun Kim, Sang Seob Lee, and Chang Kyu Chung
NSSS Safety Department, NSSS Engineering & Development, Korea Power Engineering Company, Inc.
150, Deokjin-Dong, Yuseong-Gu, Daejeon, hoya@kopec.co.kr

1. Introduction

Control of PWR primary water chemistry is essential to guarantee fuel and materials integrity and to maintain plant radiation fields as low as reasonably achievable. All PWRs have at least two ion exchangers in the Chemical and Volume Control System (CVCS) for chemical impurity control and radionuclide removal. Some nuclear power plants have several ion exchangers which can be operated in parallel. In order to remove boron near the end of a reactor core cycle some plants use separate anion beds downstream of the normal purification. [1]

The difference in design and operating philosophy has produced several practices for the ion exchanger operations in the CVCS. The purpose of this paper is to suggest an optimized configuration of ion exchangers for dealing with the resin usage and the liquid waste.

2. Typical Designs

2.1 Mixed Bed Ion Exchanger

The mixed bed ion exchangers (two or sometimes more) used for normal purification contain cation resin in the hydrogen or Li-7 form, and anion resin in the hydroxide form which shall be converted to the borate form prior to use. Since reactor coolant pH is maintained by $Li^{7}OH$, at least one of the ion exchangers used for normal purification shall contain cation resin in the Li-7 form.

2.2 Cation Bed Ion Exchanger

The cation bed ion exchanger used for lithium, cesium, and sodium removal can be operated in series with a bed used for normal purification. The resin in the cation vessel is initially in the hydrogen form. Since Li-7 is produced from B-10 by neutron absorption, the reactor coolant lithium levels shall be controlled by removing the lithium.

2.3 Anion Bed Ion Exchanger

The anion bed ion exchanger is fully charged with anion resin for removing the boron around the end of the reactor core cycle. The resin in the deborating bed is in the hydroxide form.

3. Design Features of Domestic PWRs

In this section, the ion exchanger design features of domestic PWRs are reviewed.

3.1 OPR 1000 Plants

OPR 1000 plants are Yonggwang units 3, 4, 5, 6, and Ulchin units 3, 4, 5, 6. OPR 1000 has three ion exchangers in the CVCS. Two mixed bed ion exchangers and one anion bed ion exchanger are provided in the letdown line (Fig.1). One mixed bed in the hydrogen-hydroxide form is lithiated and borated. The other mixed bed in hydrogen-hydroxide form is borated but not lithiated.

The anion bed ion exchanger is identical to the mixed bed ion exchangers in its mechanical design.

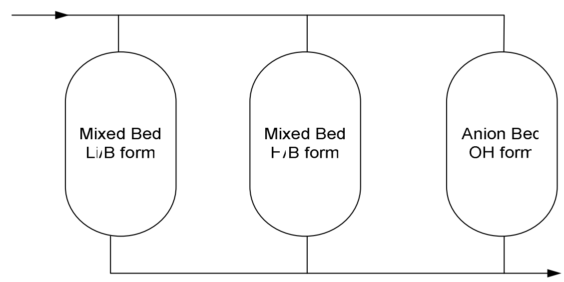

Fig.1. OPR 1000 Plants Ion Exchanger Design [2]

3.2 Westinghouse Type Plants

Westinghouse type plants are Kori units 1, 2, 3, 4, and Yonggwang units 1 and 2. The nuclear power plants designed by Westinghouse have two mixed bed ion exchangers and one cation bed ion exchanger (Fig.2). One mixed bed ion exchanger is in continuous service for purification and the cation bed ion exchanger can be used intermittently for lithium removal. The second mixed bed ion exchanger serves as a standby unit for the operating mixed bed ion exchanger.

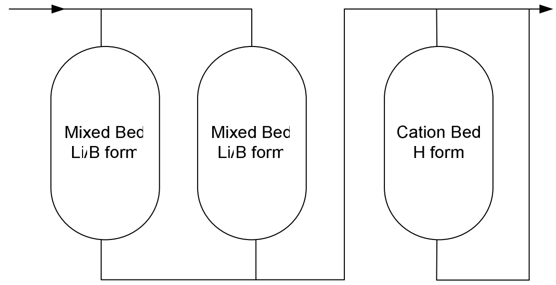

Fig.2. Westinghouse Type Plants Ion Exchanger Design [3]

3.3 Framatome Type Plants

The Ulchin nuclear power plants units 1 & 2, based on Framatome reactor type, have two mixed bed ion exchangers and one cation bed ion exchanger. Basic components and operation are similar to those of the Westinghouse type plants. [4]

The deborating ion exchangers of Ulchin units 1 & 2 are located in boron recycle system. For Westinghouse type plants (except for Kori unit 1), the boron thermal regeneration system is used to remove boron near the end of the reactor core cycle. [5]

4. Optimized Ion Exchanger Configuration

The optimized ion exchanger configuration is shown in Fig.3. The resin forms indicate the initial status of ion exchangers. The individual flow indicator for each ion exchanger is installed to provide operational convenience and to minimize the power change caused by the difference of boron concentrations between the process water and the ion exchange resin at the intermittent operation of ion exchangers.

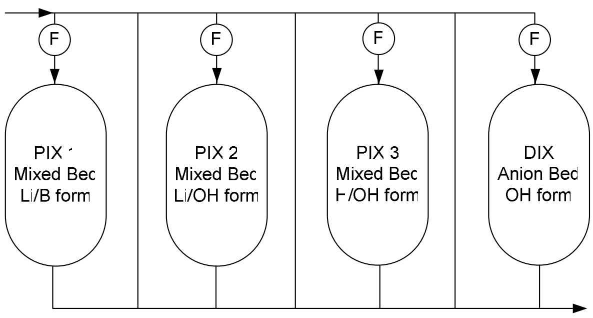

Fig.3. Optimized Ion Exchanger Configuration

4.1 For Normal Purification

The mixed bed PIX 1 is filled with the cation resin in the lithium form and the anion resin in the borate form to purify reactor coolant during normal power operation.

The mixed bed PIX 2 in the hydrogen-hydroxide form is lithiated but not borated. During the power operation, this bed is used for boron reductions as needed. This boron reduction operation can reduce the liquid waste in comparison with the feed-and-bleed method. The reduced liquid waste can decrease the burden of the boron recycle system.

After the resin is saturated with the boron, the mixed bed PIX 2 serves as a standby unit for the operating mixed bed ion exchanger.

4.2 For Lithium Removal and Shutdown Chemistry

The mixed bed PIX 3 is filled with cation and anion resin in the hydrogen-hydroxide form at the initial stage. The resin of PIX 3 shall be changed at every reactor core cycle between the reactor coolant system fill and vent operation after refueling and lithium injection during startup. In this period of time, the reactor coolant is lithium free and boron concentration is more than 2000 ppm. Prior to the lithium injection, the mixed bed in the hydrogen-hydroxide form must be borated but not lithiated. This mixed bed could be used for lithium removal as needed for one reactor core cycle.

During the plant shutdown operation, the mixed bed PIX 3 serves to control the shutdown chemistry. Since the coolant chemistry changes dramatically during plant shutdown and cooldown such as crud bursts, plant should preserve an adequate cleanup capability. The mixed bed PIX 3 has relatively new resin for purification purpose.

The mixed bed PIX 1 can serve as a standby mixed bed during the shutdown, or can be aligned with the mixed bed PIX 3 to maximize cleanup capability.

4.3 For Boron Removal

The anion bed DIX is used to control boron concentration. Getting the near the end of the reactor core cycle, the quantity of liquid waste production due to feed-and-bleed operation becomes excessive. The anion resin, initially in the hydroxide form, is converted to a borate form as boron is removed.

5. Conclusion

An optimized ion exchanger configuration is suggested to optimize the resin usage and to minimize the liquid waste. The dedicated mixed bed for shutdown chemistry controls could improve the water quality of the primary coolant.

The individual flow indicator for each ion exchanger can minimize the power change caused by the difference of boron concentrations between the process water and the ion exchange resin at the intermittent operation of ion exchangers.

REFERENCES

[1] TR-105714, PWR Primary Water Chemistry Guideline. Rev. 05, EPRI.

[2] Plant System Description for Yonggwang Nuclear Power Plant Units 3 & 4, KEPCO.

[3] System Operating Manual for Kori Nuclear Power Plant Units 3 & 4, KEPCO.

[4] System Description for Ulchin Nuclear Power Plant Units 1 & 2, Framatome – KEPCO.

[5] Final Safety Analysis Report for Kori Nuclear Power Plant Unit 1.