Performance Evaluation for Purification Ion Exchanger on the Breakthrough Curves

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1. Introduction

Ion exchange resins made of organic polymers such as polystyrene, are currently used in most reactor water purification systems for pressurized water reactors (PWRs) or boiling water reactors (BWRs), which are essential for the removal of radioactive nuclides, maintenance of water chemistry specification, and reduction of radiation exposure to maintenance personnel [1].

The purpose of this paper is to evaluate the CVCS Purification Ion Exchanger(PIX) performance by analyzing the effect of PIX design parameters such as flow loading, bed depth, resin particle size, pressure drop and break time on the breakthrough curves.

2. Methodology

Adsorption in PIX are modeled as follows. The liquid film diffusion is assumed in the system for this evaluation. The mass balance for the purification ion exchanger is given as

$$-\frac{\varepsilon}{\rho_b} V_Z \left(\frac{\partial C_A}{\partial Z}\right)_t = \left(\frac{\partial q_A}{\partial t}\right)_Z \qquad (1)$$

where, ε : void fraction in the PIX bed,

ρ_b : density of the PIX bed,

V_Z : linear flow velocity,

Z : bed depth of PIX

The rate of adsorption is given as

$$\left(\frac{\partial q_A}{\partial t}\right)_Z = \frac{K_f a}{\rho_b}(C_A - C_A^*) \qquad (2)$$

where, K_f : mass transfer coefficient,

$a = \frac{3}{R}$: effective area

The following linear isotherm relationship is assumed :

$$q_A = K_D\, C^* \qquad (3)$$

where, q_A : concentration of A in solid resin,

K_D : distribution coefficient,

C_A^* : concentration of A in fluid that is equilibrium with solid resin,

Following analytical solution for the isothermal model[2-4] is given as follows :

$$X = \frac{C_A}{C_{A0}} = \frac{1}{2}[1 + erf(\sqrt{\xi} - \sqrt{\tau})] \qquad (4)$$

where, $\xi = \frac{ZK_f a}{\varepsilon V_Z}$, $\tau = \frac{K_f a}{K_D \rho_b}(t - \frac{Z}{V_Z})$

3. Computational Results

3.1 Breakthrough Behaviors

3.1.1 Effect of Flow Loading for Each Plant

The breakthrough curves of normal and maximum flow loading (F.L), flow per ion exchange resin volume for each plant are shown in Figures 1. As the flow loadings are decreased, the effluent concentration appears longer. The breakthrough curve becomes progressively smoother. The performance of PIX is better. The life time of resin is increased, as flow loadings decreased. The flow loading of normal, and maximum cases for the UCN 1&2 plant have smaller than those of the other nuclear power plants. The about 2 gpm/ft^3 of operating and 4 gpm/ft^3 of maximum flow loadings are recommended[5].

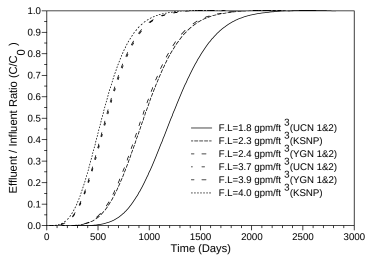

Figure 1. Breakthrough curves normal and maximum flow loading of each plants (@ resin particle size =0.55 mm).

3.1.2 Effect of Bed Depth

The breakthrough curves with variation of resin bed depth for KSNP plants are shown in Figure 2. As the resin bed depth increases, the effluent concentration appears longer and the breakthrough curve becomes progressively smoother. As the bed depth increases, adsorption capacity and adsorption times are increased. At least 914 mm of bed depths are recommended[6].

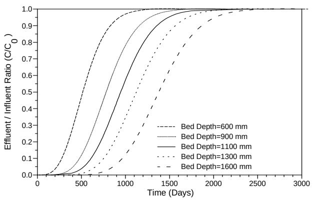

Figure 2. Breakthrough curves with variation of resin bed depth of KSNP plants(@ resin particle size =0.55 mm, normal flow loadings, 2.3 gpm/ft^3).

3.1.3 Effect of Resin Particle Size and Pressure Drop

The breakthrough curves with various resin particle sizes of KSNP plants are shown in Figure 3. As the resin particle sizes decrease, the slope of breakthrough curves become steeper and the effluent concentration appears longer as shown in Figure 3. As the size of resin particle decreases, the surface area and adsorption capacity are increased. The small resin particle size is preferred for complete contact of the fluid and resin.

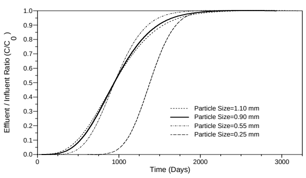

Figure 3. Breakthrough curves for various resin particle sizes of KSNP plants(@ normal flow loading, 2.3 gpm/ft^3).

The breakthrough curves with variation of PIX pressure drop for KSNP plants are shown in Figure 4. As the PIX pressure drop increases, the effluent concentration appears longer as shown in Figure 4. As the resin particle size decreases, the pressure drops are increased. The pressure drops across the PIX are limited to 10 – 20 psid[5].

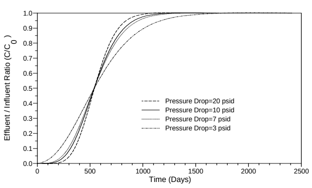

Figure 4. Breakthrough curves with variation of pressure drop of KSNP plants(@ maximum flow loading, 4.0 gpm/ft^3, PIX pressure drop with resin).

3.2 Break times for Each Plants

The break times for each nuclear plants are shown in Table 1. During the normal flow loadings case, the break time for YGN 1&2 plants is the shortest one among those operating plants. For the maximum flow loadings case, the break time for KSNP plants is the shortest one among those operating plants. On the contrary, the break times for UCN 1&2 plants are the longest one among the operating plants for the normal and maximum flow loading cases. For this reason, the breaktime is increased, as the flow loading decreased. The longer the break time has, the more efficient the ion exchange resin has. The break time for KSNP is extended, as bed depth is increased, CVCS letdown flowrate is decreased and resin particle size is decreased, respectively as shown in Table 2 and 3.

Table 1. The break times of the PIX for each plants

Items*	YGN 1&2		UCN 1&2		KSNP	
normal/max. flowrate, gpm	nor.	max.	nor.	max.	nor.	max.
	75	120	60	120	80	140
flow loading, gpm/ft^3	2.4	3.9	1.8	3.7	2.3	4.0
bed depth,mm	1,676		1,600		1,092	
break time,days	511	262	731	268	527	236

*For 0.55 mm of resin particle size is assumed.

Table 2. The break times of the PIX for KSNP plants

Items**	bed depth, mm				
	600	900	1100	1300	1600
break time,days	222	405	527	660	859

**For 0.55 mm of resin particle size and 80 gpm of normal flowrate is assumed.

Table 3. The break times of the PIX for KSNP plants

Items#	resin particle size, mm				
	0.25	0.35	0.55	0.90	1.1
break time,days	1017	604	527	452	411

For 0.55 mm of resin particle size and 80 gpm of normal flowrate is assumed.

4. Conclusions

CVCS PIX performance was evaluated and compared for the operating Nuclear Power Plants in Korea. The breakthrough curves enable to predict the effect of the PIX design parameters and the break times of PIX in the operating plants. From the point of flow loading, bed depth and pressure drop, the PIX design of the YGN 1&2, UCN 1&2 and KSNP plants are reasonable.

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