Assessment of the detritiation effect of the operating variables in the WTRF LPCE process

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1. Introduction

Korea has 4 CANDU units at the Wolsong site. The tritium inventory at the Wolsong NPPs will reach about 44 MCi by 2005. The regulatory body noting the relatively large tritium production in the heavy water systems recommended the construction of a tritium reduction or removal system and WTRF (Wolsong Tritium Removal Facility) is now under construction with the completion date of June 30, 2005. It is designed to maintain the tritium activity in the moderator to about 10 Ci/kg [1]. As the tritium removal efficiency of the WTRF depends on the various operating variables of the LPCE (Liquid Phase Catalytic Exchange) system such as the temperature, pressure, catalyst bed efficiency, number of sections, this study assessed the performance of the WTRF LPCE by varying the operation variables using the LPCE process model.

2. Description of the LPCE system

The detritiation process of the WTRF is made up of three parts as shown in figure 1. The first part involves the transfer of tritium from a heavy water molecule to a deuterium molecule. The second part of the process is the enrichment stage. This stage concentrates the tritium by a Cryogenic Distillation (CD) of the D_2/DT mixture, to produce streams of pure D_2 and T_2. The third part of the process is the measurement and packaging of the concentrated T_2 for a secure, long-term storage [2].

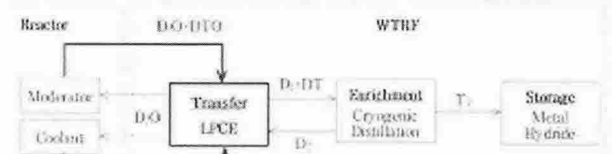

Figure 1. Detritiation process in the WTRF.

The LPCE system is designed to reduce the tritium content of the tritiated heavy water feed from the moderator with a removal efficiency of 97% in a single pass (equivalent to the detritiation factor 35).

The overall mechanism of the tritium transfer from the heavy water to the deuterium gas in the LPCE system can be represented by the following equations [2].

$$DTO(l)+D_2(g)\Leftrightarrow D_2O(l)+DT(g) \quad (1)$$

The reaction mechanism consists of two steps, the mass transfer and catalytic reaction. The mass transfer step involves the transfer of DTO from the liquid phase to the vapor phase as below,

$$DTO(l)+D_2O(v)\Leftrightarrow D_2O(l)+DTO(v) \quad (2)$$

The catalytic reaction of tritium in the vapor phase is

$$DTO(v)+D_2(g)\Leftrightarrow D_2O(v)+DT(g) \quad (3)$$

3. Modeling of the LPCE system

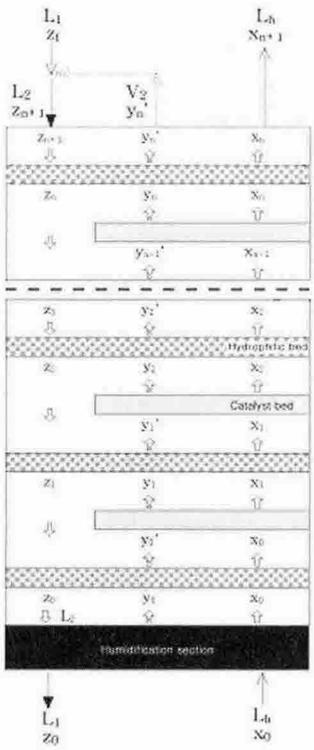

Figure 2. Model of the LPCE System

Figure 2 shows the n sections arranged in a counter-current cascade, where the sections are numbered up from the bottom and each section contains a catalyst bed by using a hydrophobic platinum catalyst and a hydrophilic bed. Tritiated heavy water is fed to the top of the column and allowed to flow downward counter-currently to the rising stream of the deuterium gas [3].

The tritium mole fraction of the deuterium gas and vapor stream leaving the catalyst bed in section n, x_n , y_n could be defined as follows;

$$x_n=\left(1-\frac{\eta_c\alpha_g}{\alpha_g+\gamma_g}\right)x_{n-1}+\left(\frac{\eta_c}{\alpha_g+\gamma_g}\right)y_{n-1}', \quad (4)$$

$$y_n=\left(\frac{\eta_c\alpha_g\gamma_g}{\alpha_g+\gamma_g}\right)x_{n-1}+\left(1-\frac{\eta_c\gamma_g}{\alpha_g+\gamma_g}\right)y_{n-1}', \quad (5)$$

From the component material balance for tritium in the hydrophilic bed in section n, y_n' is

$$y_n'=y_n-\frac{1}{\gamma_l}(z_n-z_{n+1}) \quad (6)$$

Where the z_n is the tritium mole fraction of the liquid leaving the n-th section, and η_c is the efficiency of the catalyst bed, α_g is the separation factor between the vapor and gas, γ_g and γ_l is the molar flow rate ratio of the deuterium gas to a vapor and the vapor to a water, respectively.

These parameters are the functions of the temperature and pressure; therefore the tritium concentration of each phase in the LPCE system should depend on the operating variables.

If certain parameters and boundary conditions are given, the tritium concentrations in all the sections can be calculated step by step in connection with the operating variables by using the computer program developed in the study.

4. Results

The temperature and pressure variation effects on the DF of LPCE system are shown in figure 3. The operating parameters affected by the temperature and pressure variation are the molar flow rate of the vapor and separation factors. The variation ranges of the parameters are selected, considering the fluctuations in the designed operating condition.

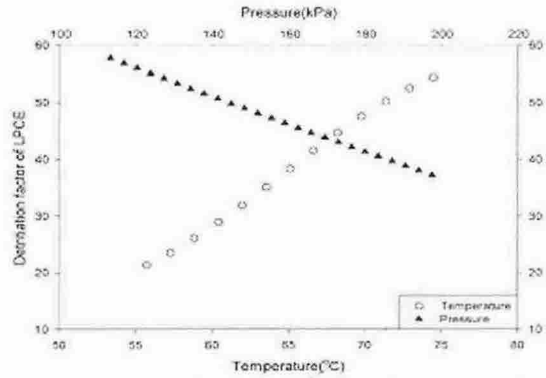

Figure 3. The DF of the LPCE system as functions of the temperature and pressure.

Figure 3 shows a steep increase of the detritiation factor with respect to the temperature increase and a mild increase with respect to the pressure decrease. Because the pressure variation is only affecting the molar flow rate of the vapor, on the other hand, the temperature variation is affecting both the molar flow rate of the vapor and tritium separation factors.

Expected values for the catalyst bed efficiency (η_c) and the number of stages of a hydrophilic bed (Ns) are 0.9 and 2 at the nominal condition. However, these variables are varied with the operating time and the environment. Thus, the variation ranges are selected to be from 0.6 to 1 for η_c, and from 1 to 3 for Ns.

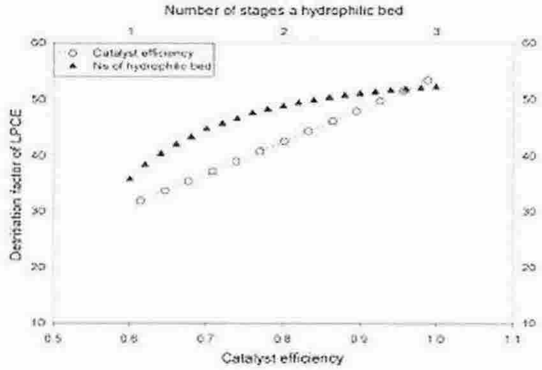

Figure 4. The DF of the LPCE system as functions of the catalyst bed efficiency and the number of stages of a hydrophilic bed.

Figure 4 shows a relatively mild variation of the detritiation factor with respect to both the catalyst bed efficiency and the number of stages in a hydrophilic bed. The DF is proportional to η_c and the second order of a logarithmic function of *Ns*.

5. Conclusions

A computer program was developed based upon the relations between the operating and design parameters derived from the mass transfer, catalytic reaction and material balance equations at a steady state in Fortran language. A parametric study was performed using the computer program to investigate the effects of the design and operating variables parameters on the detritiation factor of the LPCE system. The major operating variables chosen are the temperature, system pressure, catalyst bed efficiency, and the number of stages in a hydrophilic bed.

The calculated detritiation factor of the WTRF LPCE system is 47 at a nominal condition, which is higher by about 30%, than 35, which is the requirement value.

The molar flow rate of vapor and the tritium separation factor are major operating parameters determining the detritiation factor of the LPCE process. The temperature and pressure have an effect on the molar flow rate of vapor or the separation factor. The effect of the temperature variation on the detritiation factor is strong, because the temperature affects both the molar flow rate of vapor and the tritium separation factor. Deficiencies of the catalyst bed efficiency and the number of stages of a hydrophilic bed could be caused by the operating time of the WTRF. These deficiencies result in a relatively mild variation of the detritiation factor.

REFERENCES

[1] Safety Analysis Report, Wolsong Tritium Removal Facility, KHNP (2001).

[2] S.Paek, D.H. Ahn, H. Lee and H. Chung, "Tritium Activities in Korea," Fusion Science and Technology, Vol. 41, 329-333(2002).

[3] Development of tritium removal technology (I) phase 2, KHNP(2002).