Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

A Study on the Analytical Solution of the Tritium and Helium Inventory in Stainless Steel

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1. Introduction

There are a variety of reasons for wanting to know the tritium inventory in stainless-steel which is the most common material used to contain tritium. Recently, in Korea, a study on the tritium handling system for recycle of tritium which is collected by Wolsong Tritium Removal Facility (WTRF) was started. Some tritium enters the steel and subsequently decays to helium. This helium can result in severe deterioration of the mechanical properties of the steel [1]. In the previous study, analytical solutions of tritium and helium concentration profile in the wall of stainless steel were suggested [1] and tritium inventory in the wall of stainless steel was evaluated by numerical method [2]. The aim of this study is to obtain analytical solutions of tritium and helium inventory and to compare with the numerical result.

2. Methods and Results

It is well known that time-dependent diffusion of radioactive material into a wall of which is taken to be a planar sheet with x=0 at the inner surface as shown in Fig. 1.

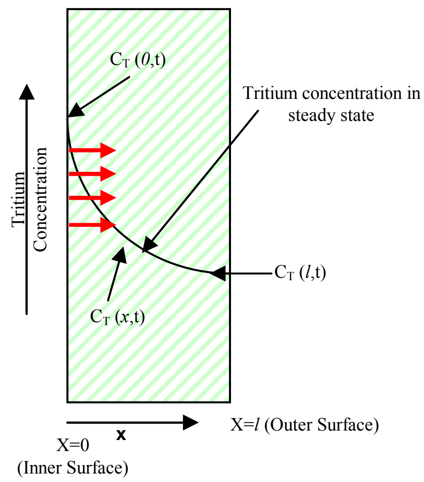

Fig. 1. Tritium diffusion into a wall of stainless steel

The governing equation is described by:

$$\frac{\partial C_T(x,t)}{\partial t} = D\frac{\partial^2 C_T(x,t)}{\partial x^2} - \lambda C_T(x,t) \qquad (1)$$

In steady state permeation the tritium concentration is linear through the sheet. In all calculations in this study $C_T(l,t)$ and $C_T(x,0)$ are assumed to be zero. The concentration $C_T(0,t)$ is set by the tritium gas pressure and temperature, i.e., $C_T(0,t) \equiv C_{ST}$. C_{ST} is the tritium solubility in the surface of stainless steel. Masayasu SUGISAKI et al. derived and suggested the tritium solubility in SUS-316 stainless steel from the experimental data [3].

2.1 Analytical solutions of tritium and helium inventory in the wall of stainless steel

An analytical solution of Eq. (1) is tritium profile in the wall of stainless steel and the time integral of tritium profile is the helium profile in the wall of stainless [1]. To obtain tritium inventory, the solution of tritium profile will be integrated with length and the result is described by;

$$\frac{l}{2} - \sum_{n=1}^{\infty} \frac{2kl(1-con(n\pi))}{\pi^2 n^2\left(k+\frac{Dn^2\pi^2}{l^2}\right)} - \sum_{n=1}^{\infty}\frac{2Dn(1-\cos(n\pi))}{l\left(k+\frac{Dn^2\pi^2}{l^2}\right)}\exp\left(-\left(\lambda+\frac{Dn^2\pi^2}{l^2}\right)t\right) \qquad (2)$$

Also, helium inventory in the wall of stainless steel can be obtained by integration with length of helium profile and the result is described by;

$$\frac{\lambda}{\alpha}\left[\frac{l}{2} - \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{kl(1-\cos(n\pi))}{n^2\pi\left(k+\frac{Dn^2\pi^2}{l^2}\right)}\right](1-\exp(-\alpha t)) - \frac{2\lambda}{\pi}\sum_{n=1}^{\infty}\frac{D\pi(1-\cos(n\pi))}{l\left(k+\frac{Dn^2\pi^2}{l^2}\right)\left(\lambda+\frac{Dn^2\pi^2}{l^2}\right)} \times\left(1-\exp\left(-\left(\lambda+\frac{Dn^2\pi^2}{l^2}\right)t\right)\right) \qquad (3)$$

where λ is tritium decay constant (sec^{-1}), $\alpha = \lambda/2$, $k=\lambda-\alpha$, t is time (sec^{-1}), D is diffusion coefficient ($cm^2 \cdot sec^{-1}$)

2.2. Model comparison to numerical solutions

Tritium and helium inventory as a function of time of storage vessel is shown in Fig. 2. under assumptions as follows;

(1) The thickness of stainless steel is 10 mm

(2) The temperature of steel is 349K
(3) Tritium is initially charged in the vessel and there is no additional charging

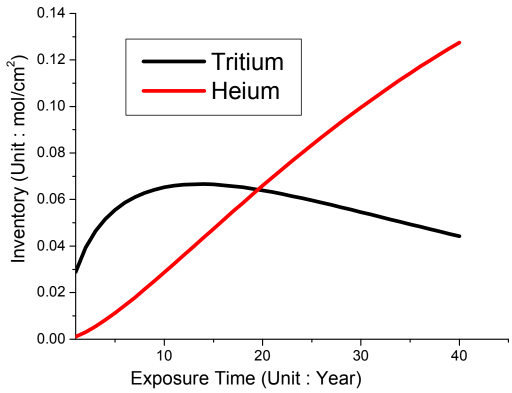

Fig. 2 Tritium and helium inventory as a function of time of stainless steel

To validate analytical solutions of Eq. (2) and (3), these solution's results are compared with the numerical results which is obtained by Simpson's integral method. The error between analytical results and numerical results are calculated and shown in Fig. 3.

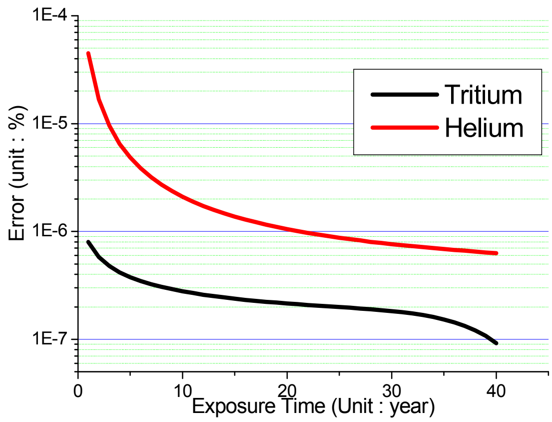

Fig. 3 The error of tritium and helium inventory between analytical results and numerical results ,corresponding to the result of Figure 2.

3. Conclusions

In this study, analytical solutions of tritium and helium inventory in the wall of stainless steel were derived and suggested. Also, these solutions were validated by comparison with numerical results. In the previous study [2], simplified analytical model of tritium inventory was suggested but that model is only available under the limited time and partial pressure. As shown in Fig 2, tritium inventory is increased and decreased as a function of time due to the radioactive decay. Once the helium originates from decay of tritium, there is little diffusion of helium in the steel. Therefore, helium inventory as a function of time is gradually being increased. These analytical solutions can be used to evaluate the tritium and helium inventory in the wall of stainless steel which is used the tritium storage vessel, tank, and the tritium handling system.

ACKNOWLEDGMENT

This work was supported by Electric Power Industry Foundation Fund Project of MOCIE. Authors are grateful to MOCIE.

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