Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Preliminary Corrosion Model for Steels in Isothermal Pb and LBE Loops

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1. Introduction

HYPER(Hybrid Power Extraction Reactor) is the accelerator driven transmutation system developed by KAERI(Korea Atomic Energy Research Institute). HYPER is designed to transmute long-lived transuranic actinides and fission products such as Tc-99 and I-129. Lead-Bismuth eutectic(LBE) alloy was determined as a spallation target and coolant material of HYPER due to its high production rate of neutrons and its effective heat removal. However, LBE has a considerable corrosion problem at high temperature[1].

In this study, **a** parameteric study for a corrosion model was performed. A preliminary corrosion model in isothermal Pb and LBE flow loops was also developed to predict the corrosion rate.

2. Methods and Results

2.1 Modeling the Mass Transfer Coefficient

Mass transfer is the process of transporting species from the liquid-solid interface to the bulk flow. In a mass transfer controlled regime, the corrosion rate is limited by a diffusion and it is calculated from the following expression [2]:

Corrosion rate $q = k(C_s - C_b)$ (1)

Where, k = mass transfer coefficient(m/s). C_s = concentration of the the liquid–solid interface, C_b = concentration in the bulk flow

The corrosion model is based on solving the mass transport equation in the boundary layer. For a closed loop flow, several mass transfer coefficient expressions have been developed in an aqueous media based on experimental data [2].

- Berger and Hau :
  - $K_{B\text{-}H} = 0.0203u^{-0.53} D^{0.67} \mathbf{Q}^{0.86} d^{-1.86}$ (2)
- Silverman :
  - $K_{Silverman} = 0.0219u^{-0.579} D^{0.704} \mathbf{Q}^{0.875} d^{-0.1875}$ (3)
- Harriott and Hamilton:
  - $K_{H\text{-}H} = 0.0120u^{-0.567} D^{0.654} \mathbf{Q}^{0.913} d^{-1.913}$ (4)

Where, u = kinematic viscosity (m^2/s)
D = diffusion coefficient (m^2/s)
Q = volume flow rate (m^3/s)
d = hydraulic diameter (m)

2.2 Estimation of the Parameters for the Model

The diffusion coefficient can be calculated as following equation [2]:

$$D(m^2/sec) = 4.9\times10^{-7}\exp[-Q/RT(K)] \quad (5)$$

Where Q: 10500±1500cal/gmol, R: gas constant, 1.987cal/gmol^{o}K.

For an isothemal loop, the surface concentration, $\mathbf{C_s}$ does not vary along the loop axis. The main equilibrium corrosion product concentration (C_s) at the liquid–solid interface is obtained by the following equations [3]

- $\log C_s(ppm) = 4.34-3450/T(K)$: Pb loop (6)
- $\log C_s(ppm) = 6.01-4380/T(K)$: LBE loop (7)
- C_s (ppm, Fe) $= Co^{-1.333}10^{11.35-12844/T}$ (8)

The values of the bulk concentration, C_b for the corrosion model used the results estimated by Ning Li et al. [3].

- Pb loop

· $C_{b\ B\text{-}H} = 9.784 g/m^3$, · $C_{b\ silverman} = 9.189\ g/m^3$

· $C_{b\ H\text{-}H} = 9.768\ g/m^3$

2.3 A preliminary Corrosion Model

For a isothemal closed loop, the bulk concentrati-on reaches the value of the surface concentration after a short time. Therefore, there is a corrosion initially and no more corrosion occurs at the steady state for an isothermal loop flow. Under a constant temperature, the wall corrosion product concentration remains constant along the loop axis. The corrosion rate for this case is estimated by the following equation [4].

$$q/C = \sqrt{D/\pi t} \qquad (8)$$

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The required time for the steady state(C_b=C_s) by solving eq(8) is assumed as $1x10^6$sec(11.57 day).

The following parameters for a corrosion model are used: temperature, T = 550°C, hydraulic diameter, d =0.0254m, kinematic viscosity, u = 1.3 x 10^{-7}(LBE), u = 1.65 x 10^{-7}(Pb), liquid velocity, V = 2.0 m/sec, oxygen concentration = 0.001 ppm(LBE).

The diffusion coefficient of iron in liquid metals caculated by eq(5) is 7.97 x 10^{-10} m^2/sec.

According to the three equations(2-4), the values of the mass transfer coefficients for Pb and LBE loops are calculated as follows:

· $K_{B\text{-}H}$ = 1.56 x 10^{-4} m/sec (Pb loop)

= 2.2 x 10^{-4} m/sec (LBE loop)

· $K_{Silverman}$ = 1.69 x 10^{-4} m/sec (Pb loop)

= 1.94 x 10^{-4} m/sec (LBE loop)

· $K_{H\text{-}H}$ = 8.87 x 10^{-5} m/sec (Pb loop)

$K_{H\text{-}H}$ =1.0 x 10^{-4} m/sec (LBE loop)

The concentration of the liquid–solid interface, C_s was calculated by equations (6-8). The values of C_s are 1.41 ppm = 14.5g/m^2 (Pb) and 4.88 ppm = 49.04g/m^2 (LBE), respectively.

Based on the estimated input parameters for the corrosion model, the corrosion rate, q in the isothermal Pb and LBE loops is modeled as follows:

- Pb-loop:

· $q_{B\text{-}H}$ = 7.35 **x 10^{-4}** g/m^2s = 92 μm

· $q_{silverman}$ = 8.98 **x 10^{-4}** g/m^2s = 112.4 μm

. $q_{H\text{-}H}$ = 4.2 **x 10^{-4}** g/m^2s = 52.6 μm

- LBE loop:

· $q_{B\text{-}H}$ = 7.35 **x 10^{-4}** g/m^2s = 92 μm

· $q_{silverman}$ = 8.98 **x 10^{-4}** g/m^2s = 112.4 μm

· $q_{H\text{-}H}$ = 4.2 **x 10^{-4}** g/m^2s = 52.6 μm

3. Conclusions

This corrosion model is based on solving the mass transport equation in the boundary layer. A parametric study illustrates the effects of the input parameters on a corrosion. Based on the results, the corrosion rate increases with an increase of flow rate and temperature. The present study provides important information to predict the corrosion rate and to interpret the experiment data in the isothemal corrosion loop.

REFERENCES

[1] Y. Kurata et al., J. of Nucl. Mater., 301, p28-34 (2002).

[2] F. Barbier et al., J. of Nucl., 289,p227-233 (2001).

[3] N. Li et al. Nucl. Technol., 144, p379-387 (DEM. 2004).

[4] J. Zhang et al., Corrosion, 40(4) p331 (2004).