MODELLING OF THE THINNING OF THE CANDU REACTOR FEEDER PIPES

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บทคัดย่อ

อรวีร์ ศิลป์ศรีกุล : การออกแบบสมการสำหรับการสึกกร่อนของท่อในถังปฏิกรณ์นิวเคลียร์ที่ชื่อว่า แคนดู (Modelling of the Thinning of the CANDU Reactor Feeder Pipes) อ. ที่ปรึกษา : ศ. แฟรงค์ อาร์ สจ๊วต (Prof. Frank R. Steward) และ ผศ. ธีรศักดิ์ ฤกษ์สมบูรณ์ เอกสารจำนวน 136 หน้า ISBN 974-130-710-1

ทางมหาวิทยาลัย New Brunswick ได้เสนอและพัฒนาสมการที่แสดงการสึกกร่อนของท่อในถังปฏิกรณ์นิวเคลียร์ที่มีชื่อว่า แคนดู (CANDU) สมการเหล่านี้ใช้อธิบายกลไกต่างๆของการสึกกร่อนของท่อที่ทำด้วยเหล็กคาร์บอน โดยมีน้ำโมเลกุลหนักซึ่งเป็นสารแลกเปลี่ยนความร้อนอยู่ภายในท่อ เพื่อความเข้าใจที่ดีขึ้นเกี่ยวกับกลไกการสึกกร่อน จึงได้มีการติดตั้งการทดลองโดยจำลองมาจากลักษณะการไหลวนของสารแลกเปลี่ยนความร้อนในเตาปฏิกรณ์ การทดลองนี้ได้ดำเนินการโดยมหาวิทยาลัย New Brunswick สำหรับในงานนี้ ได้ศึกษาอัตราการสึกกร่อนของท่อชื่อ S08 ที่อยู่ที่สถานีพลังงานนิวเคลียร์ Point Lepreau และ ส่วนชิ้นงานทดสอบในการทดลองที่ช่วงความเป็นกรดเบส 9.8-11.55 อุณหภูมิ 310 องศาเซลเซียส จากการวิเคราะห์สมการที่เกี่ยวข้องพบว่าอัตราการละลายของออกไซด์และพลังงานอิสระของการกระตุ้นสำหรับปฏิกิริยาการกัดกร่อนเปลี่ยนแปลงตามค่าความเป็นกรดเบส ความสัมพันธ์พระหว่างค่าคงที่ของการละลายของออกไซด์กับความเป็นกรดเบสแสดงในรูปโพลิโนเมียลอันดับหก ส่วนพลังงานอิสระของการกระตุ้นมีความสัมพันธ์เชิงเส้นตรงกับความเป็นกรดเบส ซึ่งเป็นที่น่าสนใจสำหรับการศึกษาความสัมพันธ์ของค่าพลังงานอิสระของการกระตุ้นกับความเป็นกรดเบสในลำดับต่อไป นอกจากนี้ สมการในขณะนี้เกี่ยวข้องกับหลักของผลจากไฟฟ้าเคมีต่อการสึกกร่อนซึ่งค่อนข้างสลับซับซ้อน สมการที่ใช้หลักการของปฏิกิริยาเคมีและการถ่ายโอนมวลสารซึ่งเป็นรูปแบบสมการที่ไม่สลับซับซ้อนได้ถูกเสนอขึ้นและพัฒนาต่อไป

ABSTRACT

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A model of the thinning of the CANDU reactor outlet feeder pipes has been developed by University of New Brunswick. This model describes the mechanisms of corrosion of outlet feeder pipes which are carbon steel in CANDU reactors. To understand the mechanisms better, an experimental loop simulating the primary coolant loop in a CANDU was constructed at the University of New Brunswick. This work focused on the corrosion rate of outlet feeders at the Point Lepreau Station and the test section in the experimental loop at various pH, 9.8-11.55 at 310°C. It was found in an analysis of the model that the dissolution rate and the free energy of activation of the corrosion reaction changed with pH. The relation between the dissolution rate constant and pH was represented by a sixth order polynomial. The free energy of activation was found to be a linear function of pH. Further study on the relation between this free energy of activation and pH should be undertaken to clarify the effect of the reaction rate on the flow assisted corrosion. The present model was based on electrochemical effects that are quite complicated. A simpler model based on chemical reaction and mass transfer was proposed and could be studied further.

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ABBREVIATIONS

FAC	Flow-assisted corrosion
Ox	Oxidized species
Re	Reduced species

LIST OF SYMBOLS

A	Factor of frequency
A	Cross sectional area
a_{Ox}	Activity of oxidized species
a_{Re}	Activity of reduced species
C_b	Dissolved iron concentration in bulk solution (g/cm^3)
C_O	Concentration of oxidized species
C_{os}	Dissolved iron concentration at oxide/solution interface (g/cm^3)
C_R	Concentration of reduced species
C_{sol}	Solubility of iron dissolved
C_w	Iron dissolved concentration at wall
D	Diffusion coefficient (cm^2/s)
D_h	Hydraulic diameter
d	Diameter
d	Diameter of particle to be removed (μm)
$\frac{dm}{dt}$	Rate of mass loss
E	Potential
E_e	Equilibrium potential
$E_{O/R}$	Potential difference for reduction reaction
$E°_{O/R}$	Standard potential difference for reduction reaction
e^+	Dimensionless roughness height
e-	Electron
F	Faraday constant (96480 C/mol)
F*	Surface area factor
f	Friction factor
f'	Mass fraction of iron in oxide

h	Mass transfer coefficient
h	Planck's constant = 6.62×10^{-34} J s
I_0	exchange current density.
i	Current (Amps)
i_a,	Anodic current
i_c	Cathodic current
i_{corr}	Corrosion current
J	= mass flux (g/cm^2 s)
K	Equilibrium constant of reaction
K	Correlation factor
k"	The number of times per second that the rate process occurs (Boltzmann constant = 1.38×10^{-23} J K^{-1})
$k_{d,adj.}$	Adjusted dissolution rate constant by electrochemical effect
k_d	Dissolution rate constant
k_f	Rate constant for forward reaction
k_L	The entrance loss effect
$k_{p,adj.}$	Adjusted precipitation rate constant by electrochemical effect
k_p	Precipitation rate constant
k_r	Rate constant for reverse reaction
L	Distance from the duct entrance
l	The length for tube probe
MW	Molecular weight
m	The amount of metal loss per unit area (g/cm^2 s)
n	The number of electrons involved in the reaction
P	Pressure
P_s	pressure at upstream (inlet)
R	Gas constant (8.314 J/mol K)
R	Electrical resistance
R_K	Kinetic rate of oxide dissolution

R_{MT}	Mass transfer limited rate
R_T	Overall rate of flow-assisted corrosion
Re	Reynolds number
r_f	Rate of forward reaction (reduction)
r_r	Rate of reverse reaction (oxidation)
Sc	Schmidt number
Sh	Sherwood number
s	Proportionality spalling (erosion) constant
T	Absolution temperature (K)
t	Time (seconds)
u	Fluid velocity
$\Delta E°$	Standard potential difference
$\Delta E_f^{\neq}$	Activation energy for forward reaction
$\Delta E_r^{\neq}$	Activation energy for reverse reaction
ΔG	Gibbs Free energy
$\Delta G°$	Gibbs free energy at standard state
$\Delta G^{\neq}$	Free energy of activation
$\Delta G_f^{\neq}$	Free energy of activation for forward reaction
$\Delta G_r^{\neq}$	Free energy of activation for reverse reaction
$\Delta G_{0,c}^{\neq}$	Free energy of activation for cathodic reaction caused by chemical reaction
$\Delta G_{0,a}^{\neq}$	Free energy of activation for anodic reaction caused by chemical reaction
$\Delta H^{\neq}$	Enthalpy of activation
$\Delta S^{\neq}$	Activation entropy
α_c	Cathodic transfer coefficient
α_a	Anodic transfer coefficient
β	Symmetry Factor

δ	The amount of oxide in oxide layer per unit area (g/cm^2)
ρ	Fluid density
ρ	Resistivity of the probe
ρ_{metal}	Density of metal (g/cm^3)
ρ_{ox}	Density of oxide (g/cm^3)
ϕ	Porosity
μ	Fluid viscosity
τ	Tortuosity factor
τ_w	Wall shear stress