

**EFFECTS OF DISSOLUTION RATE AND FLOW CHARACTERISTICS  
ON SCALLOPING OF PIPE SURFACES**



**Suphanan Sinthuphan**

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**By:** Suphanan Sinthuphan  
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**Thesis Advisors:** Assoc. Prof. Thirasak Rirksomboon  
Prof. Derek H. Lister  
Prof. Frank R. Steward

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University, in partial fulfilment of the requirements for the Degree of Master of  
Science.

..... *Nantaya Yanumet* ..... College Director  
(Assoc. Prof. Nantaya Yanumet)

**Thesis Committee:**

..... *Thirasak Rirksomboon* .....  
(Assoc. Prof. Thirasak Rirksomboon)

..... *D. H. Lister* .....  
(Prof. Derek H. Lister)

..... *Frank R. Steward* .....  
(Prof. Frank R. Steward)

..... *Anuvat Sirivat* .....  
(Assoc. Prof. Anuvat Sirivat)

..... *Boonrod Sajjakulnukit* .....  
(Dr. Boonrod Sajjakulnukit)

## ABSTRACT

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The phenomenon of flow-accelerated corrosion (FAC) is a significant problem with steels in water-cooling systems. The sculpting of surfaces that undergo FAC normally develops a characteristic described as “scalping”. To obtain further insight into FAC it is of interest to understand the formation of scallops and their significance in the dissolution rate of steel piping. This study investigated how the dissolution rate and the flow characteristics lead to scalping by altering water chemistry, temperatures and flow velocities. Experiments comprised of twelve-conditions were carried out on the dissolution of pipe coated with gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ). Scallop morphology was characterised with a digital camera. Atomic Absorption Spectroscopy (AAS) was used to analyse the dissolution rate. It was found that the large population of scallops develops with increasing water flow rate. The average dissolution rate increases with flow rate and temperature but is not significantly affected by the pH. The dissolution rate increases with time at pH 3 and 7 but decreases with time at pH 10. The dissolution rate of gypsum is controlled by diffusion transport mechanism at room temperature (25°C). At a lower temperature (10°C), the dissolution rate of gypsum is first controlled by the surface reaction mechanism but changes to diffusion transport mechanism after 2 hours into the experiment.

## บทคัดย่อ

สุภานันท์ สิริพันธุ์ : ชื่อหัวข้อวิทยานิพนธ์ ผลกระทบจากอัตราการละลายและลักษณะการไหลต่อพื้นผิวชนิดสเกลอปบนพื้นผิวของท่อ (Effects of Dissolution Rate and Flow Characteristics on Scalping of Pipe Surfaces) อ. ที่ปรึกษา : รศ. ดร. ชีรศักดิ์ ฤกษ์สมบูรณ์ ศ. ดร. ดีเรก เอช ลิสเตอร์ และ ศ. ดร. แฟรงค์ อาร์ สจ๊วต 109 หน้า

ปรากฏการณ์การกัดกร่อนแบบเร่งด้วยความเร็วของของไหล (flow-accelerated corrosion) เป็นปัญหาสำคัญที่เกิดขึ้นกับท่อเหล็กในระบบน้ำหล่อเย็น โดยปกติการกัดเซาะของพื้นผิวที่เกิดขึ้นภายใต้ปรากฏการณ์นี้จะเกิดเป็นพื้นผิวที่มีลักษณะเฉพาะเรียกว่า พื้นผิวสเกลอป (scalping) ดังนั้นจึงจำเป็นต้องมีความเข้าใจเกี่ยวกับการก่อตัวของสเกลอปและความสัมพันธ์ของสเกลอปต่ออัตราการละลายตัวของท่อเหล็ก สำหรับงานวิจัยนี้ได้ศึกษาถึงอัตราการละลายและลักษณะการไหลที่จะนำไปสู่การเกิดสเกลอป โดยการเปลี่ยนคุณสมบัติทางเคมีของน้ำ อุณหภูมิ และความเร็วของของไหล โดยใช้สภาวะการทดลองทั้งหมดสิบสองสภาวะ เพื่อวิเคราะห์ค่าการละลายตัวของท่อที่เคลือบด้วยยิปซัม ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) ได้ศึกษารูปร่างของสเกลอปโดยใช้กล้องถ่ายภาพแบบดิจิทัล และวิเคราะห์อัตราการละลายโดยเครื่อง Atomic absorption spectroscopy จากผลการทดลองพบว่าจำนวนสเกลอปเพิ่มขึ้นเมื่อเพิ่มอัตราการไหลของของไหล อัตราการละลายโดยเฉลี่ยเพิ่มขึ้นที่อัตราการไหลสูงขึ้น โดยที่ค่าความเป็นกรด-ด่างของสารละลายมีผลต่อการเปลี่ยนแปลงอัตราการละลายโดยเฉลี่ยน้อย ที่สภาวะกรด (pH 3) และกลาง (pH 7) อัตราการละลายมีแนวโน้มเพิ่มขึ้นตามเวลา แต่มีแนวโน้มลดลงเมื่อสภาวะของสารละลายเปลี่ยนเป็นด่าง (pH 10) ที่อุณหภูมิห้อง ( $25^\circ\text{C}$ ) อัตราการละลายของยิปซัมถูกควบคุมโดยกลไกการเคลื่อนที่แบบแพร่ แต่ที่อุณหภูมิต่ำลง ( $10^\circ\text{C}$ ) อัตราการละลายของยิปซัมเมื่อเริ่มต้นถูกควบคุมโดยกลไกปฏิกิริยาบนพื้นผิว แล้วเปลี่ยนเป็นกลไกการเคลื่อนที่แบบแพร่หลังจากผ่านไปสองชั่วโมง

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**ABBREVIATIONS**

FAC	Flow-accelerated corrosion
AAS	Atomic absorption spectrophotometer
Conc.	Concentration
UNB	University of New Brunswick
CANDU	Canada deuterium uranium
PHWR	Pressurized heavy water reactor
SEM	Scanning electron microscope
LPM	Liters per minute
GPM	Gallons per minute
rpm	Revolutions per minute
USG	United States gypsum company
ID	Inside diameter
LRS	Laser raman spectroscopy

## LIST OF SYMBOLS

R	Overall dissolution rate
$C_s$	Concentration at the surface
$C_b$	Concentration of dissolved species in the bulk
$k_t$	Mass transfer coefficient
$\varepsilon$	Diffusion layer thickness
D	Diffusion coefficient
$\zeta$	Transport reaction factor
$\Omega$	$C_b/C_s$
$m_{eq}$	Molal equilibrium concentration
$E_a$	Activation energy
f	Friction factor
$R_o$	Ratio of mass of water to mass of plaster of Paris
$m_o$	Weight of plaster conduit before run experiment
$m_f$	Weight of plaster conduit after run experiment
$MW_{Ca}$	Molecular weight of calcium
$MW_G$	Molecular weight of gypsum
t	Running time (min)
A	Surface area ( $m^2$ ).
$C_i$	Initial calcium concentration
$C_f$	Final calcium concentration (ppm or mg/L)
U	Volumetric flow rate (L/min)
K	Dissolution coefficient (m/s)
$K_m$	Mass transfer coefficient (m/s)