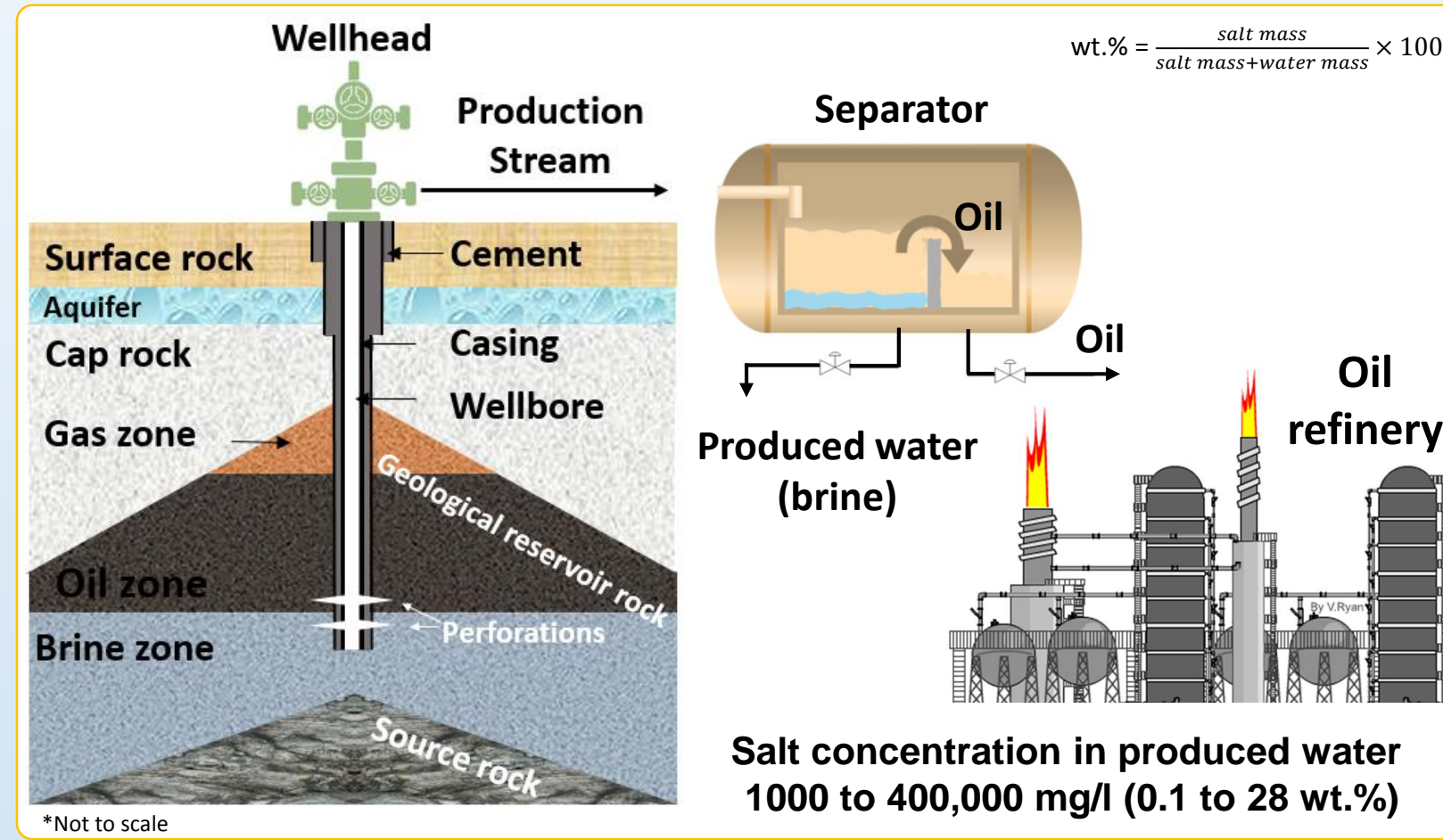


Introduction



Combination of dissolved salts with corrosive gases (CO₂ and H₂S) in produced water creates a complex corrosive environment for metallic equipment used throughout the production process. Corrosion prediction models must account for the influence of high salt concentrations on the corrosion rate of exposed equipment.

Objectives

- Study the effect of salt concentration on the rate of uniform CO₂ corrosion in a wide range of salt concentration (0 to 20 wt.%).
- Study the effect of salt concentration on the mechanism of the corrosion process (anodic and cathodic reactions).

Novelty

- Covers a wide range of salinity (0 to 20 wt.% NaCl), while most research have been conducted between 0.1 to maximum 3 wt.% NaCl.
- Mechanistically investigates the effect of salt on the corrosion process (anodic and cathodic reactions, and changes in surface morphology).

Theory

Effect of salt on corrosion process

Water chemistry

Solubility of CO₂

Activity coefficients of dissolved species

Transport phenomena

Density of solution

Viscosity of solution

Diffusion coefficients of species

Electrochemistry

Anodic reaction

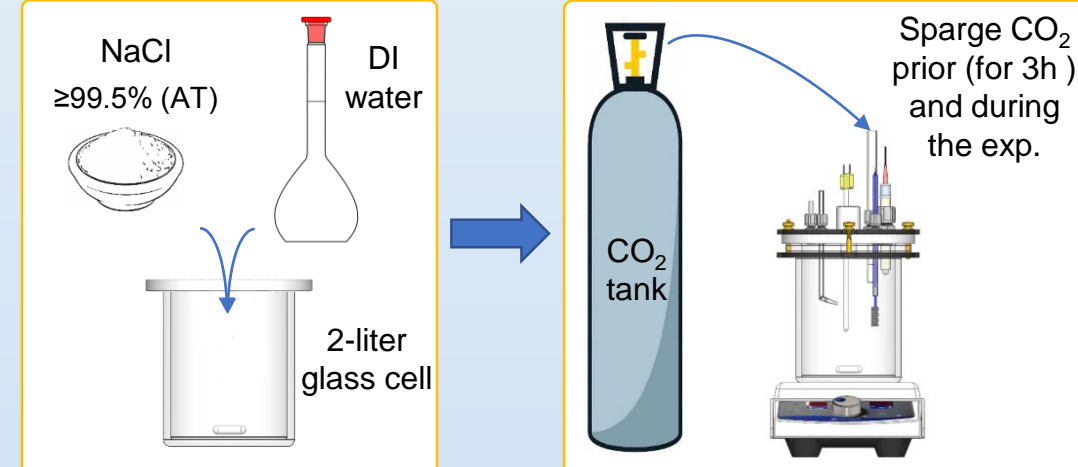
Cathodic reactions

Adsorption of species

Experimental Procedure

Experimental parameters

Parameter	Description
Specimen surface area (cm ²)	5.4
Temperature (°C)	30 ± 1
Total pressure (bar)	1
CO ₂ partial pressure (bar)	0.97
NaCl concentration (wt.%)	0, 0.1, 1, 3, 10 and 20
pH of solution	Autogenous pH
Stirring speed (rpm)	1000



Experimental methods

Effect of salt on corrosion rate

Weight loss (24 h)

Linear polarization resistance

Aqueous Fe²⁺ concentration (after WL)

Effect of salt on corrosion mechanism

Cathodic potentiodynamic polarization

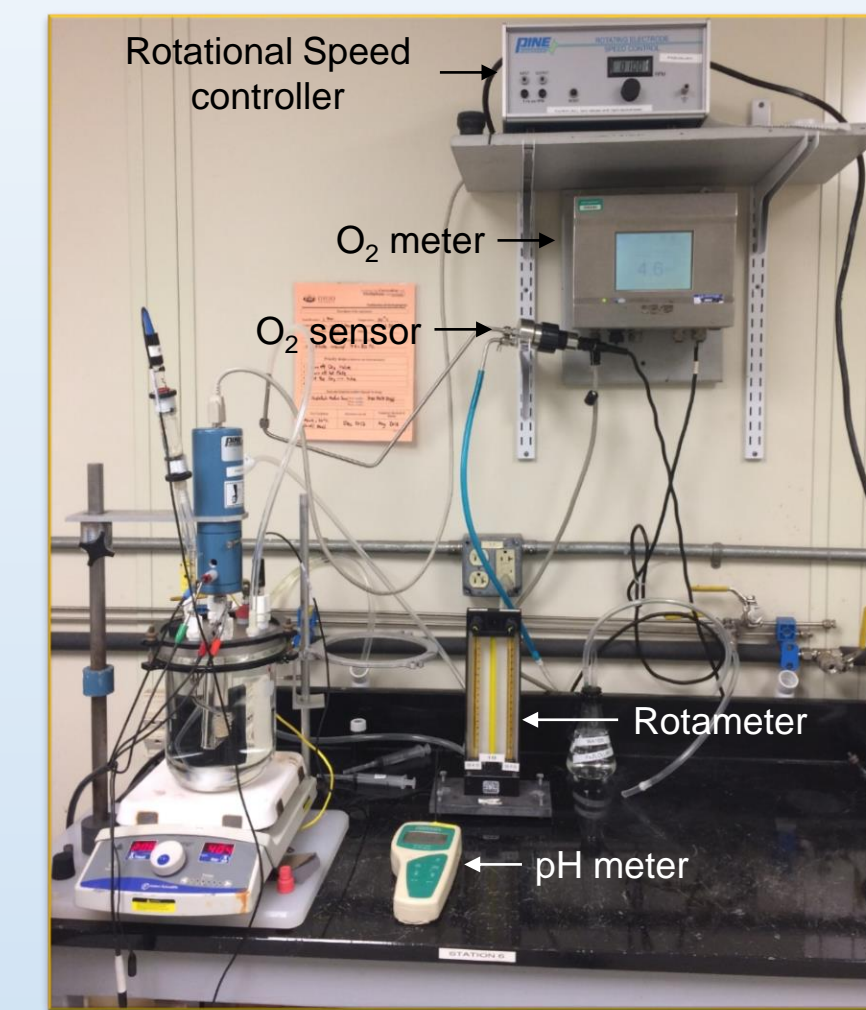
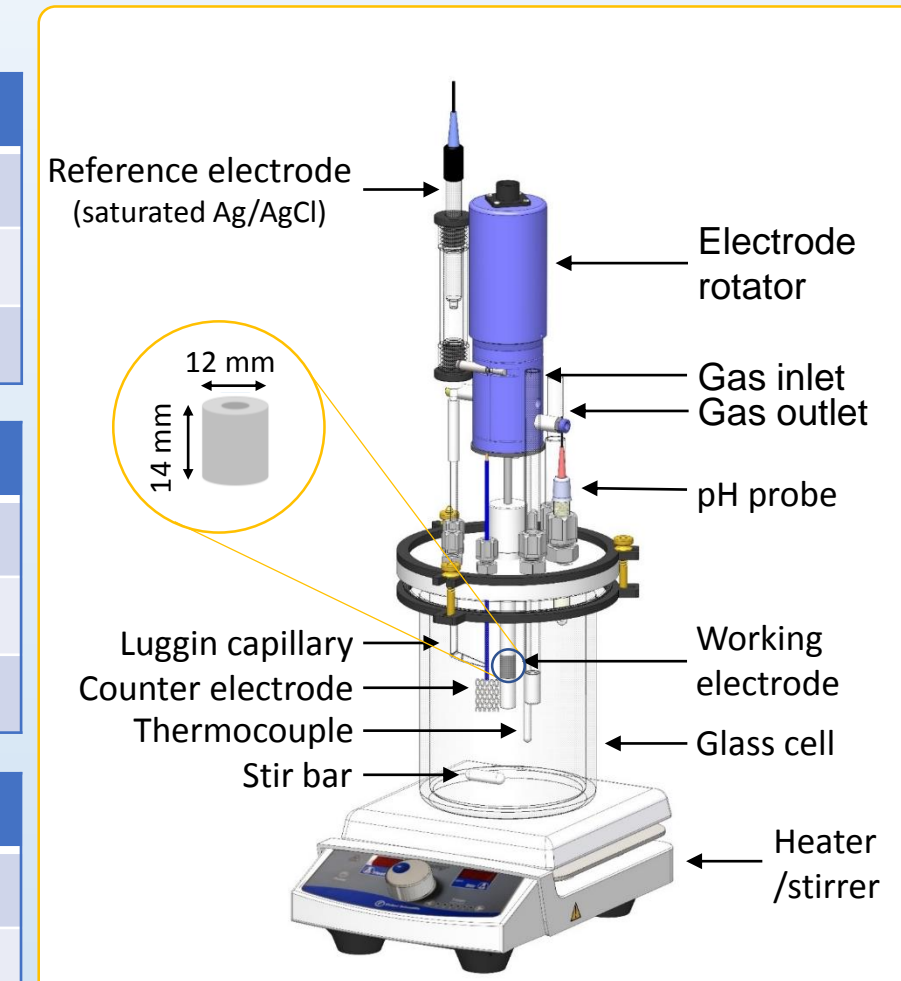
Anodic potentiodynamic polarization

Electrochemical impedance spectroscopy

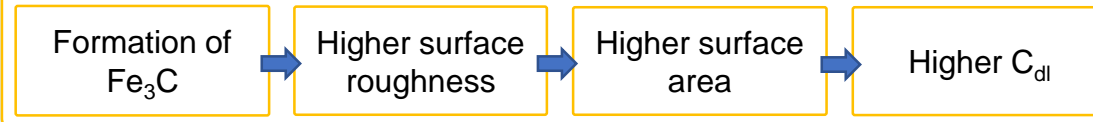
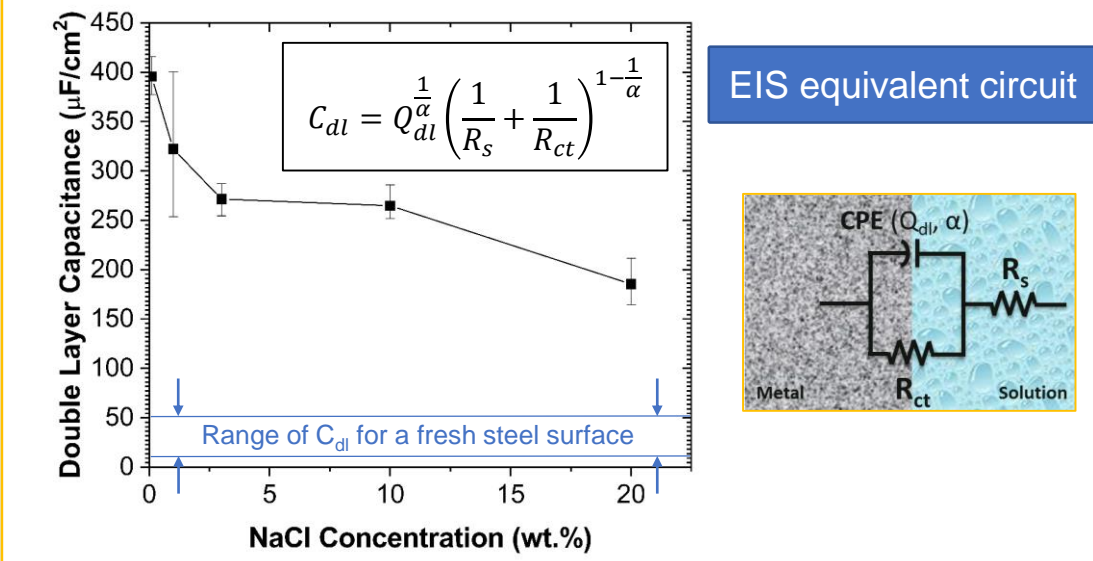
Effect of salt on surface morphology

Scanning electron microscopy (SEM/EDS)

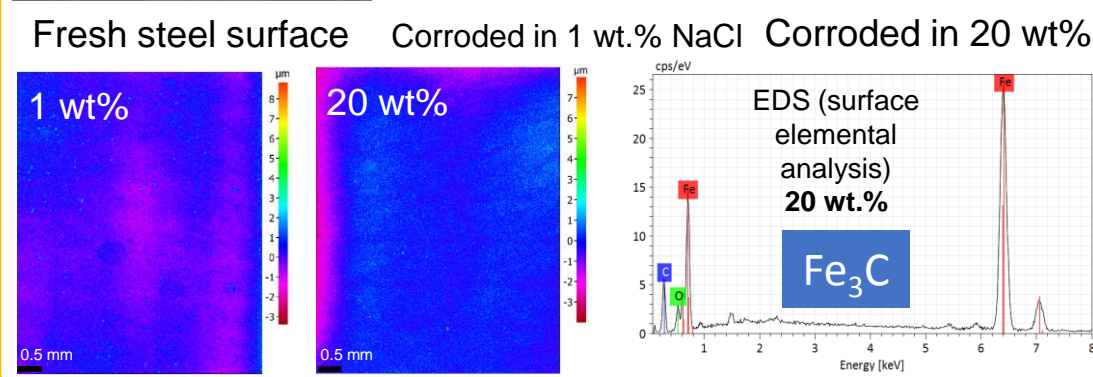
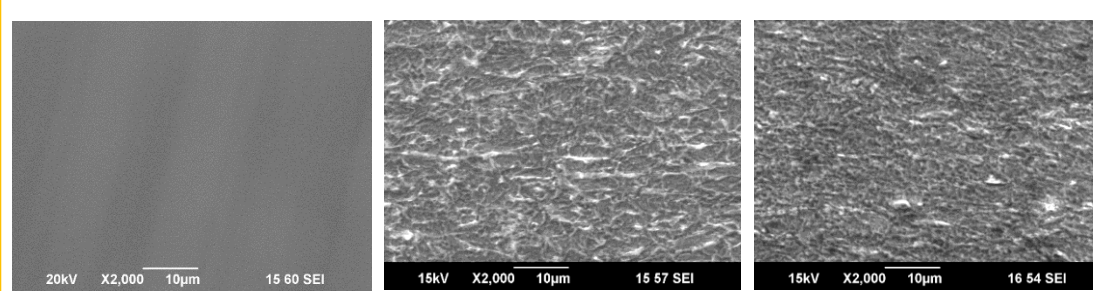
Optical profilometry



C_{dl} vs. salt concentration

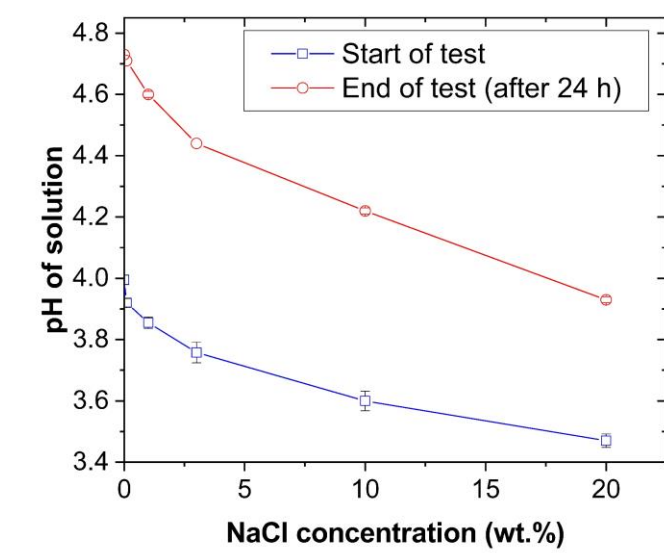


Surface morphology



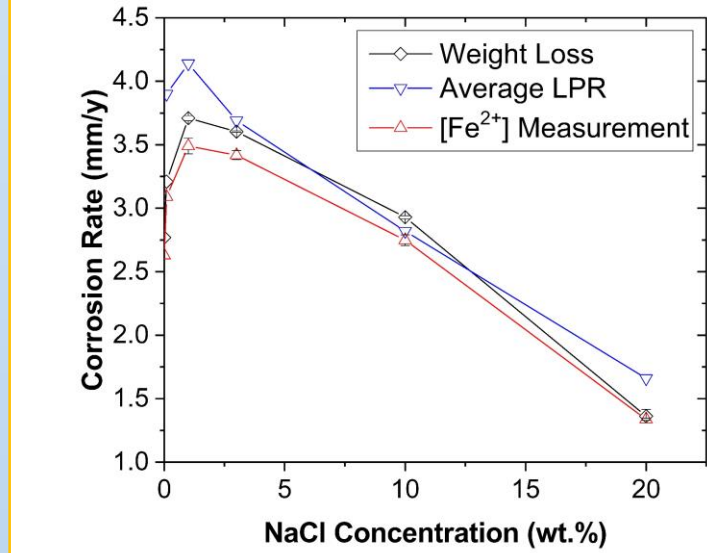
Results and Discussion

Solution pH vs. salt concentration



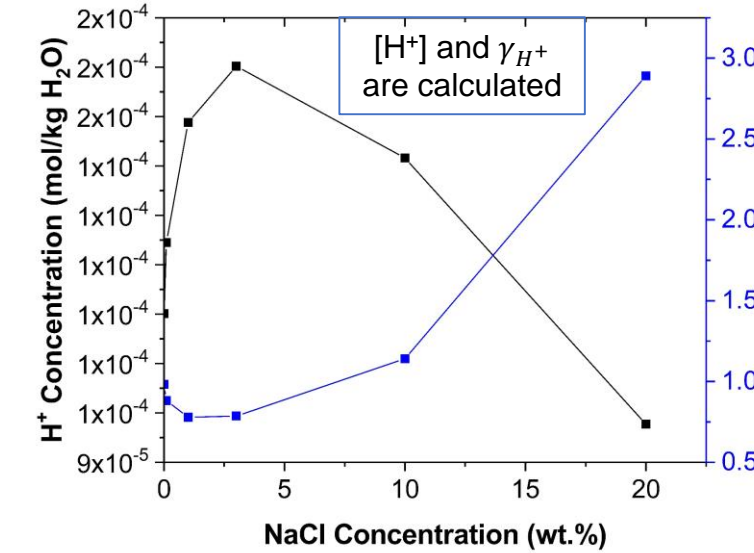
- Decrease in the initial pH was because of decrease in the CO₂ solubility.
- A higher final pH than the initial pH was because of increase of [Fe²⁺] in the solution.

Corrosion rate vs. salt concentration



- All three methods showed the same trend with very similar values.
- A significant decrease in the corrosion rate with increasing salt concentration.

[H⁺] and γ_{H⁺} vs. salt concentration



- A similar trend in [H⁺] to the corrosion rate with increasing salt concentration.
- γ_{H⁺} increased from 1 at zero wt.% NaCl (ideal condition) to ~3 at 20 wt.% NaCl.

Limiting current vs. salt concentration

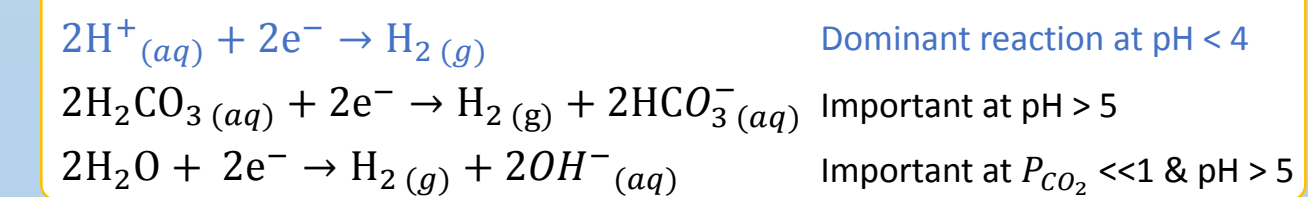
$$i_L = \frac{0.0791 \times n \times F \times V^{0.7}}{d_{RCE}^{0.3}} \rho^{0.344} \times \mu^{-0.344} \times D^{0.644} \times c_0$$

With increasing NaCl concentration:

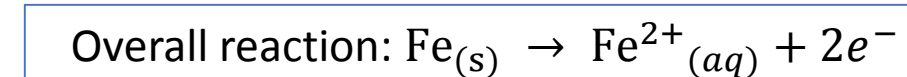
- n, V and d_{RCE} are constant.
- ρ and μ increase.
- D of H⁺ and other species decrease.
- c₀ first increases and then decreases.
- Limiting current first increases and then decreases.

i _L	limiting current, A/cm ²	d _{RCE}	diameter of RCE, cm
n	valence change of reacting ion	ρ	solution density, g/cm ³
F	Faraday constant	μ	solution viscosity, g/cm-s
V	linear velocity of RCE, cm/s	D	diffusion coefficient, cm ² /s
c ₀	bulk concentration of reacting ion, mol/cm ³		

Cathodic reactions



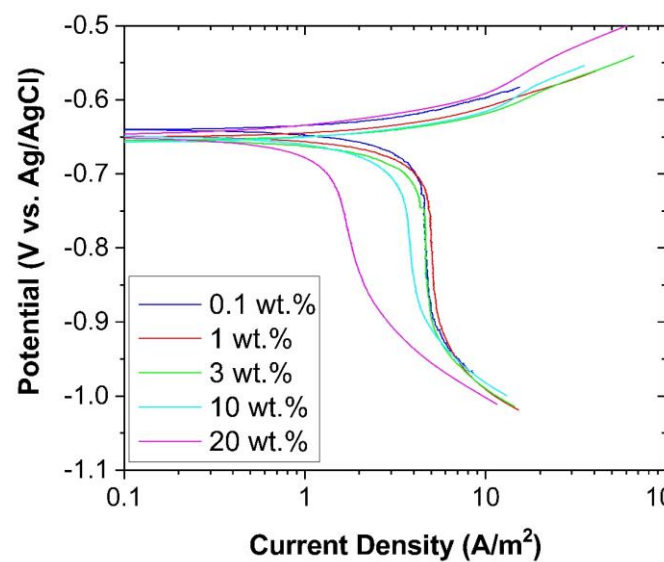
Anodic reaction



- (1) Adsorption of water molecules on the surface:
Fe + H₂O ⇌ Fe(H₂O)_{ads}
- (2) Adsorption of chloride on the surface:
Fe(H₂O)_{ads} + Cl⁻ ⇌ FeCl⁻_{ads} + H₂O
- (3) Substitution of chloride with hydroxyl/ dissolution of iron
 $FeCl^-_{ads} + OH^- \xrightarrow{RDS} FeOH^+ + Cl^- + 2e^-$
- (4) Decomplexation of ferrous ion
(FeOH)⁺ + H⁺ ⇌ Fe²⁺ + H₂O

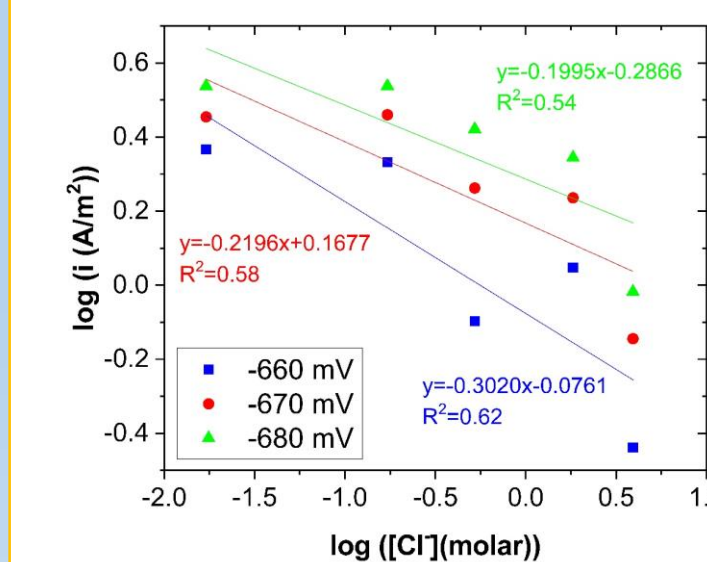
*Rate-determining step

Anodic and cathodic sweeps



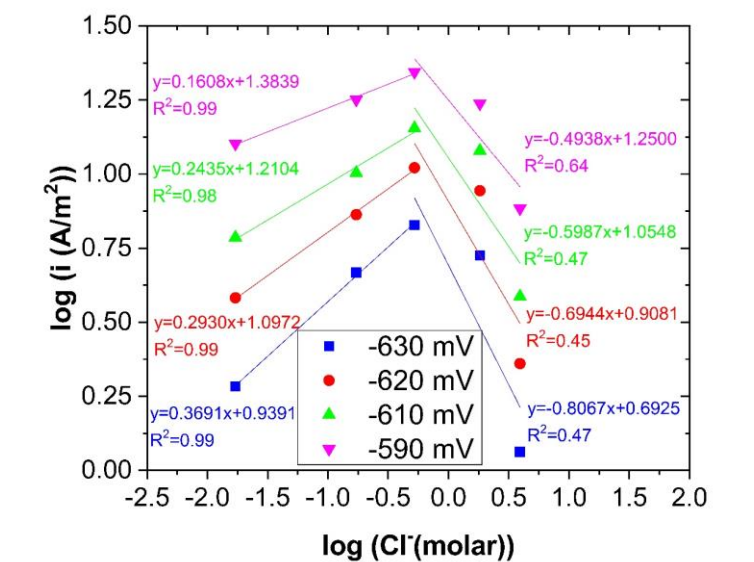
- A significant decrease in the mass-transfer controlled current.
- Mass transfer controlled the corrosion process.
- Retardation of the anodic current.

H⁺ reduction reaction order in [Cl⁻]



- Average reaction order of 0.24.
- The charge transfer might be masked by the anodic part.

Iron dissolution reaction order in [Cl⁻]



- Average reaction order of 0.24 for NaCl concentrations lower than 3 wt.%.
- Average reaction order of -0.64 for NaCl concentrations greater than 3 wt.%.

Conclusions

- The corrosion rate reached a maximum at 1 wt.% NaCl and then decreased continuously with further increase in NaCl concentration. This was because of changes in [H⁺] vs. NaCl wt.%.
- Both cathodic and anodic reactions were retarded by increasing NaCl concentration.
- Changes in the concentration and the diffusion coefficients of electroactive species were the most influential factors in the corrosion process.
- It was expected to have an anodic reaction order with respect to [Cl⁻] of -1. The experiments showed 0.24 for < 3 wt.% and -0.64 for > 3 wt.%.
- Higher NaCl concentrations causes a lower surface roughness.

Acknowledgements

