

Problems associated with the measurement of chloride diffusion in concrete

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Problems associated with the measurement of chloride diffusion in concrete

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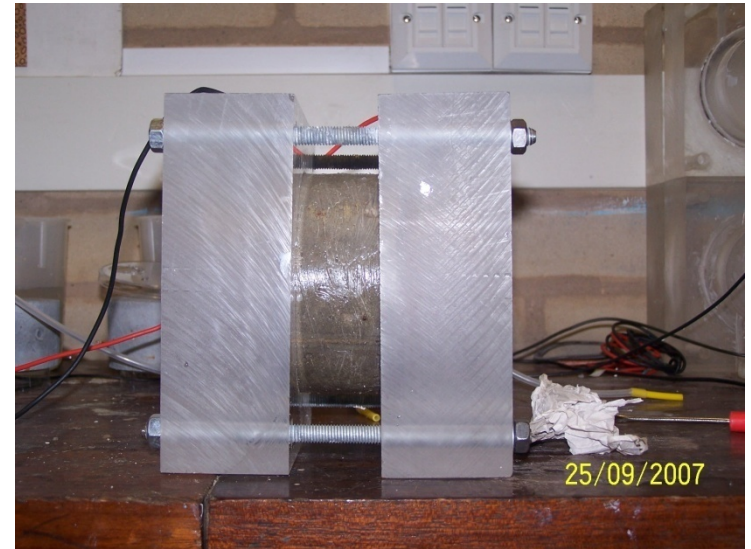
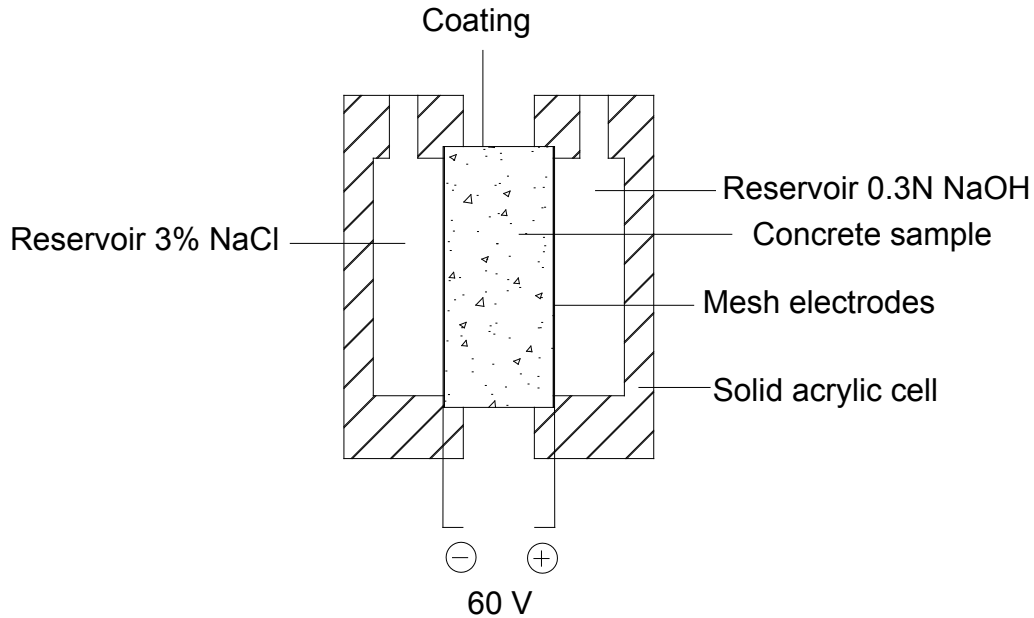
Presentation contents

1. Electromigration tests
2. “Traditional” diffusion tests

ASTM C1202 – Names for the Test

- Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration (in the ASTM).
- The Rapid Chloride Permeability Test (after Whiting – who invented the test)
- The Coulomb Test (it measures Coulombs)

ASTM C1202: Rapid Chloride Penetration Test (RCPT)

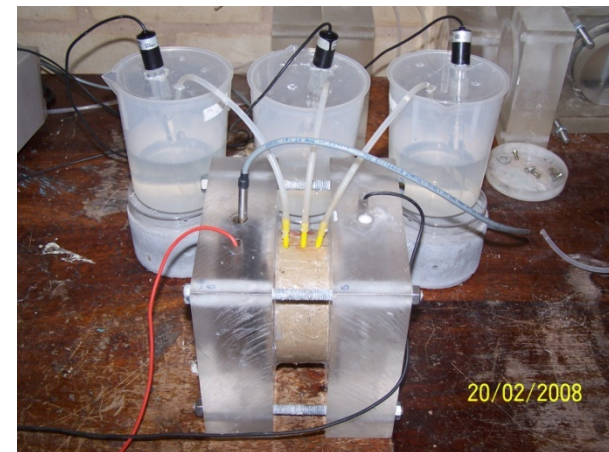
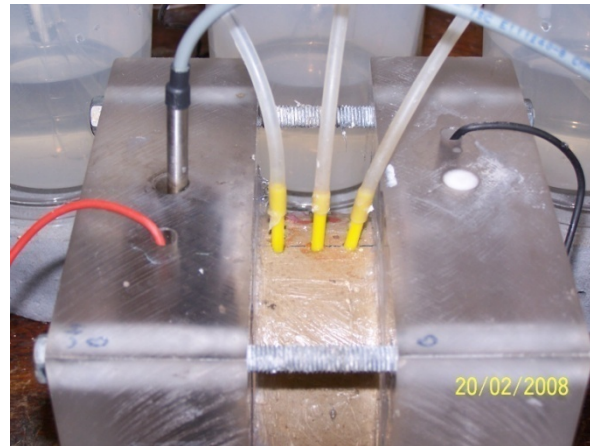
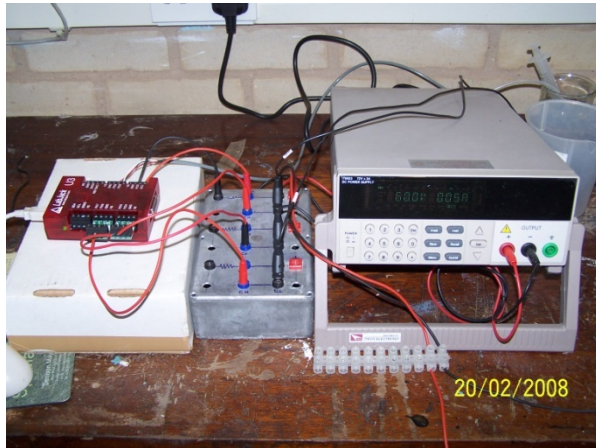
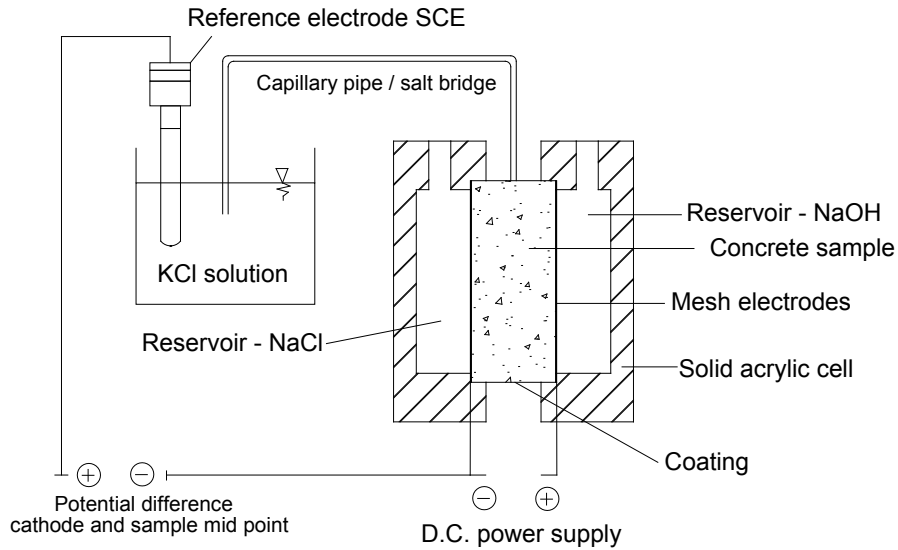


Charge Passed (coulombs)	Chloride Ion Penetrability
>4,000	High
2,000 - 4,000	Moderate
1,000 - 2,000	Low
100 - 1,000	Very low
<100	Negligible

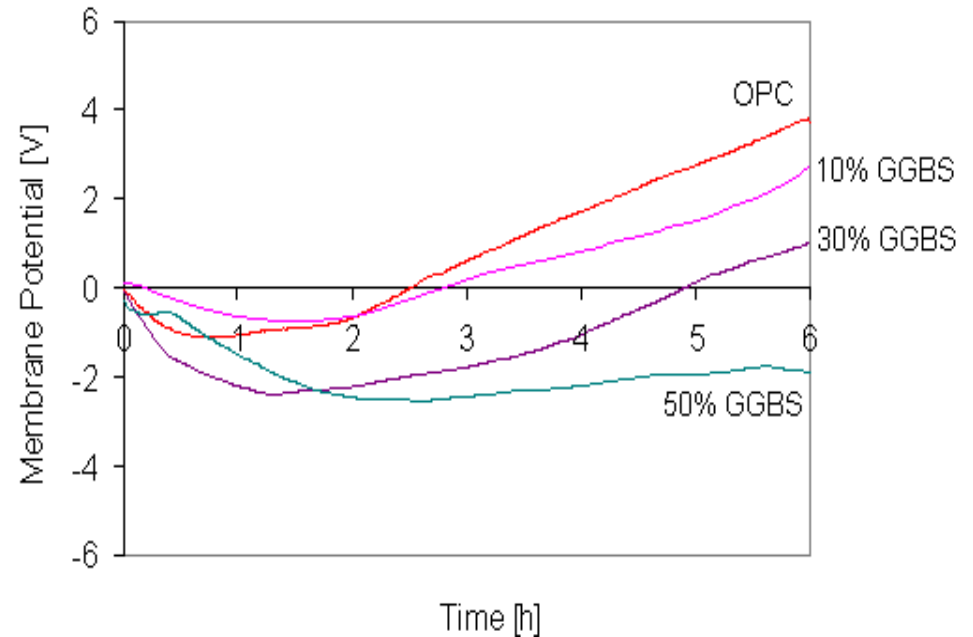
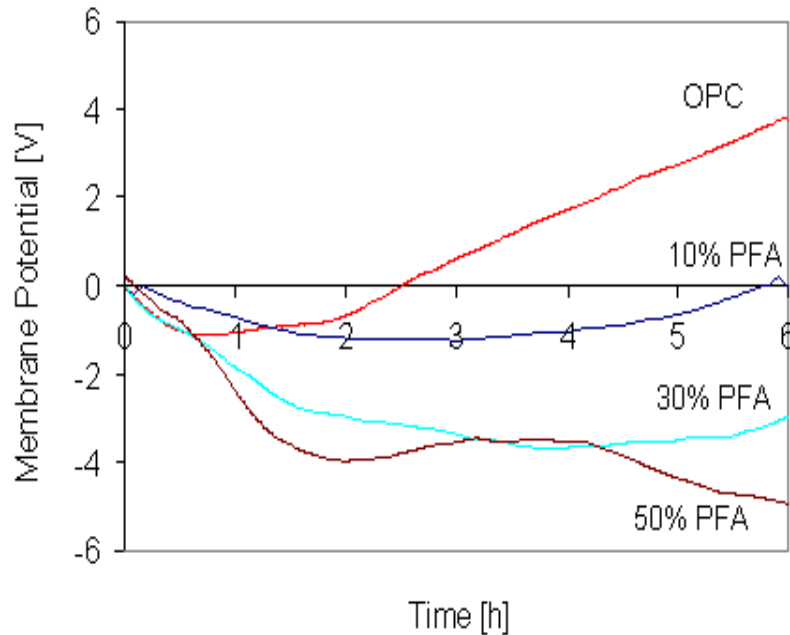
The Problem

- At the start of the test there is no chloride in the sample so the current depends on other charge carriers (primarily OH⁻)
- Adding pozzolans to concrete depletes the OH⁻
- Thus pozzolanic mixes can give misleading results

The new test



Using the mid-point voltage to identify cement replacements



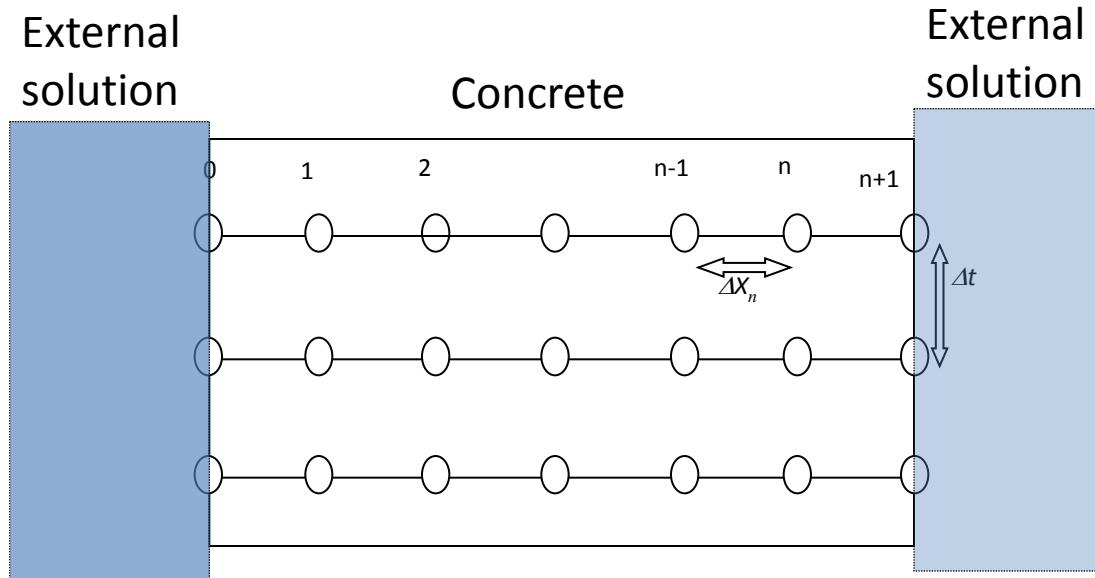
Electro-diffusion model for chlorides in concrete

- Nernst-Planck equation:

$$J_i = \underbrace{D_i \frac{\partial c_i}{\partial x}}_{\text{Diffusion}} + \underbrace{\frac{z_i F}{RT} D_i c_i \frac{\partial E}{\partial x}}_{\text{Migration}}$$

- Charge electroneutrality (Kirchoff's law):

$$0 = F \sum_i z_i J_i$$



Solving the hard way –

assuming E is constant

$$I = FADc_o a \left[\frac{2}{\beta \sqrt{\pi}} e^{\left(\frac{\alpha}{2} - \frac{\alpha^2}{\beta^2} - \frac{\beta^2}{16} \right)} + \frac{1}{2} \operatorname{erfc} \left(\frac{\alpha}{\beta} - \frac{\beta}{4} \right) \right]$$

where

$$a = \frac{zFE}{RT}$$

$$\alpha = ax$$

$$\beta = 2a\sqrt{Dt}$$

Section through sample during test

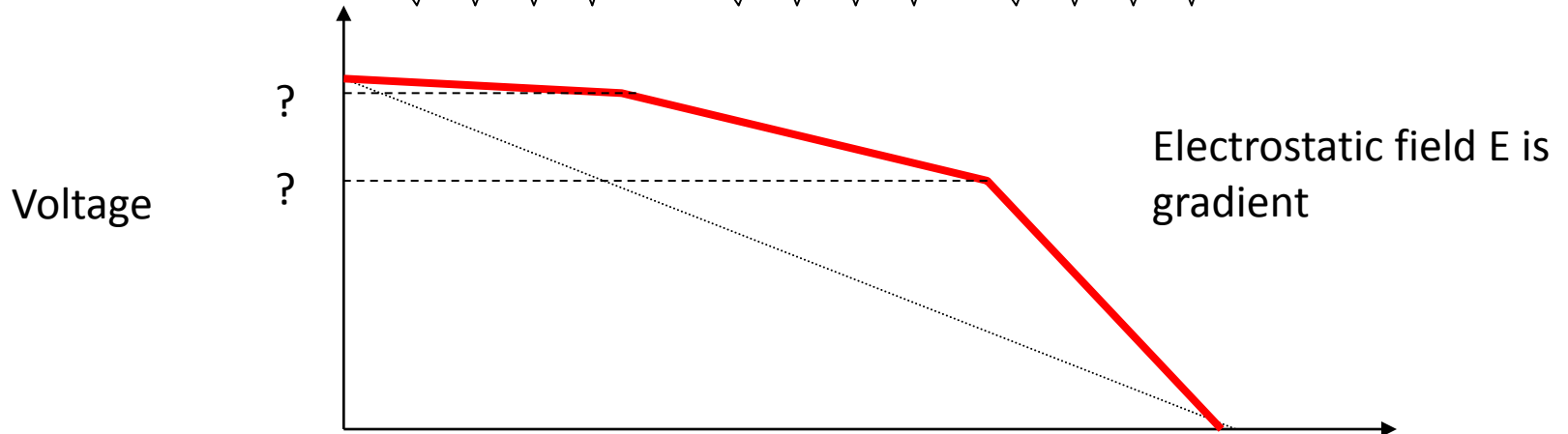


Chloride zone

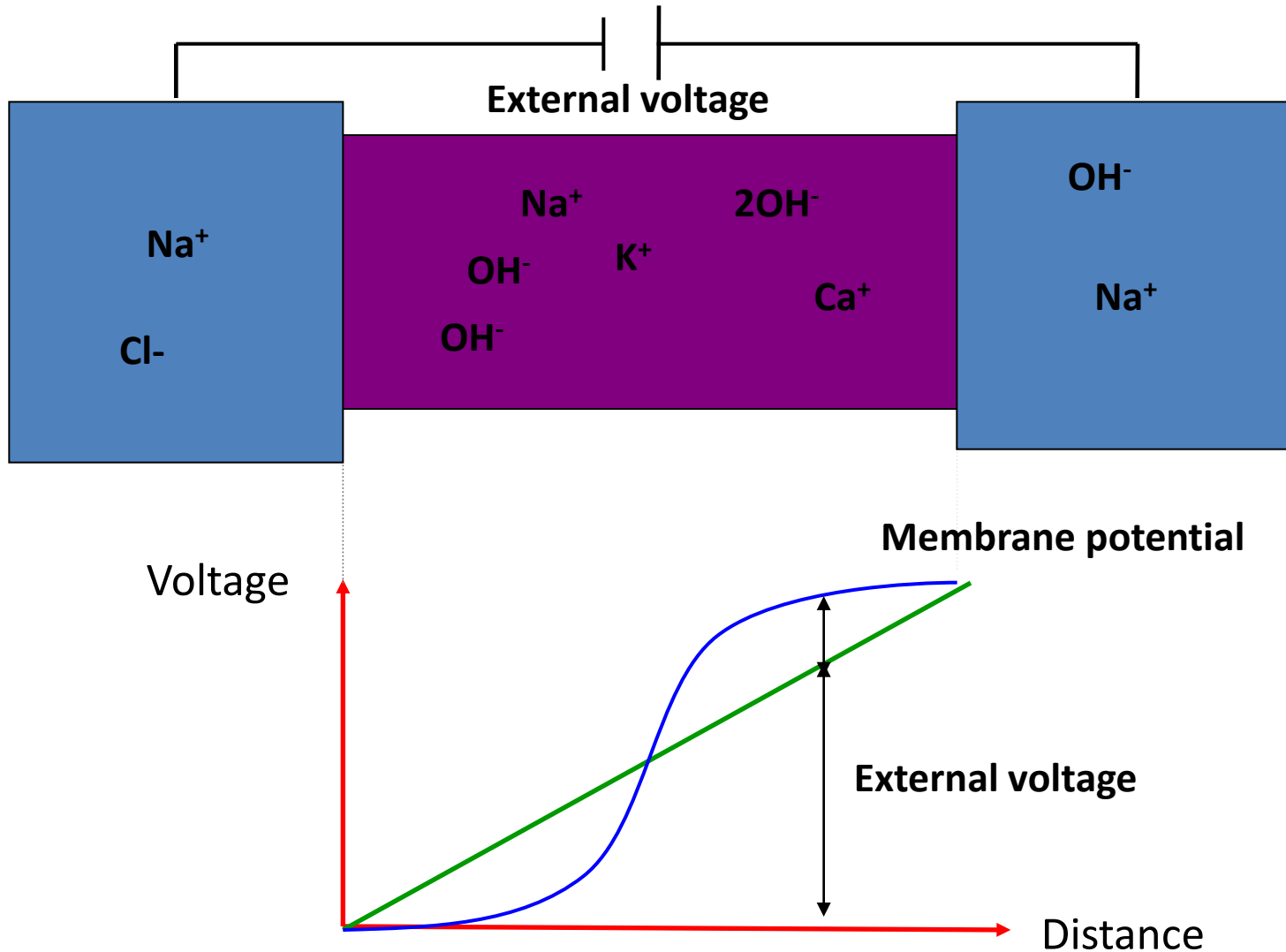
Sodium zone

Low resistance (high D)

High resistance (low D)

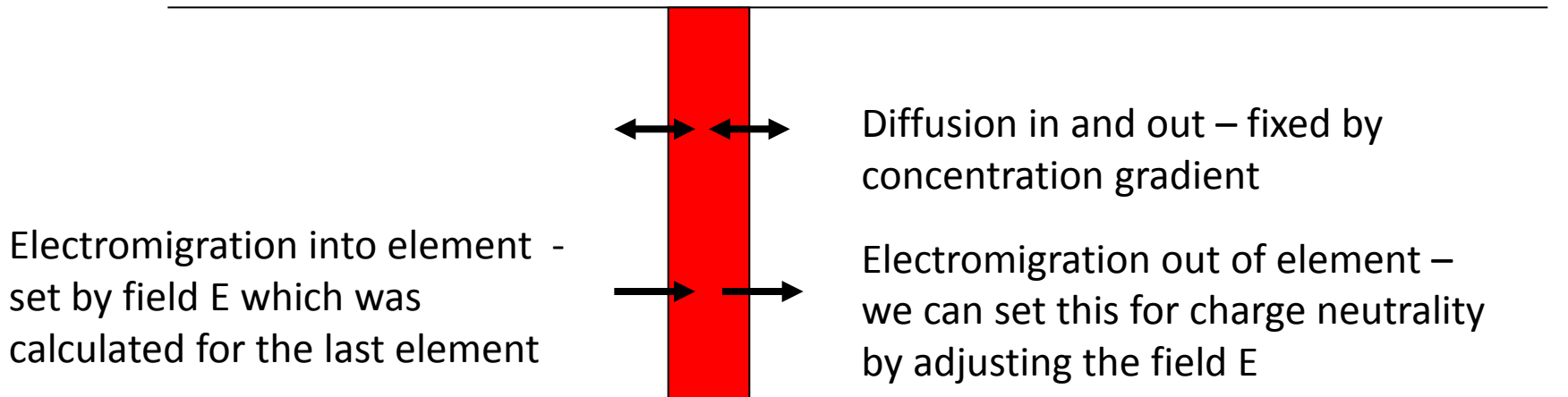


Membrane Potential



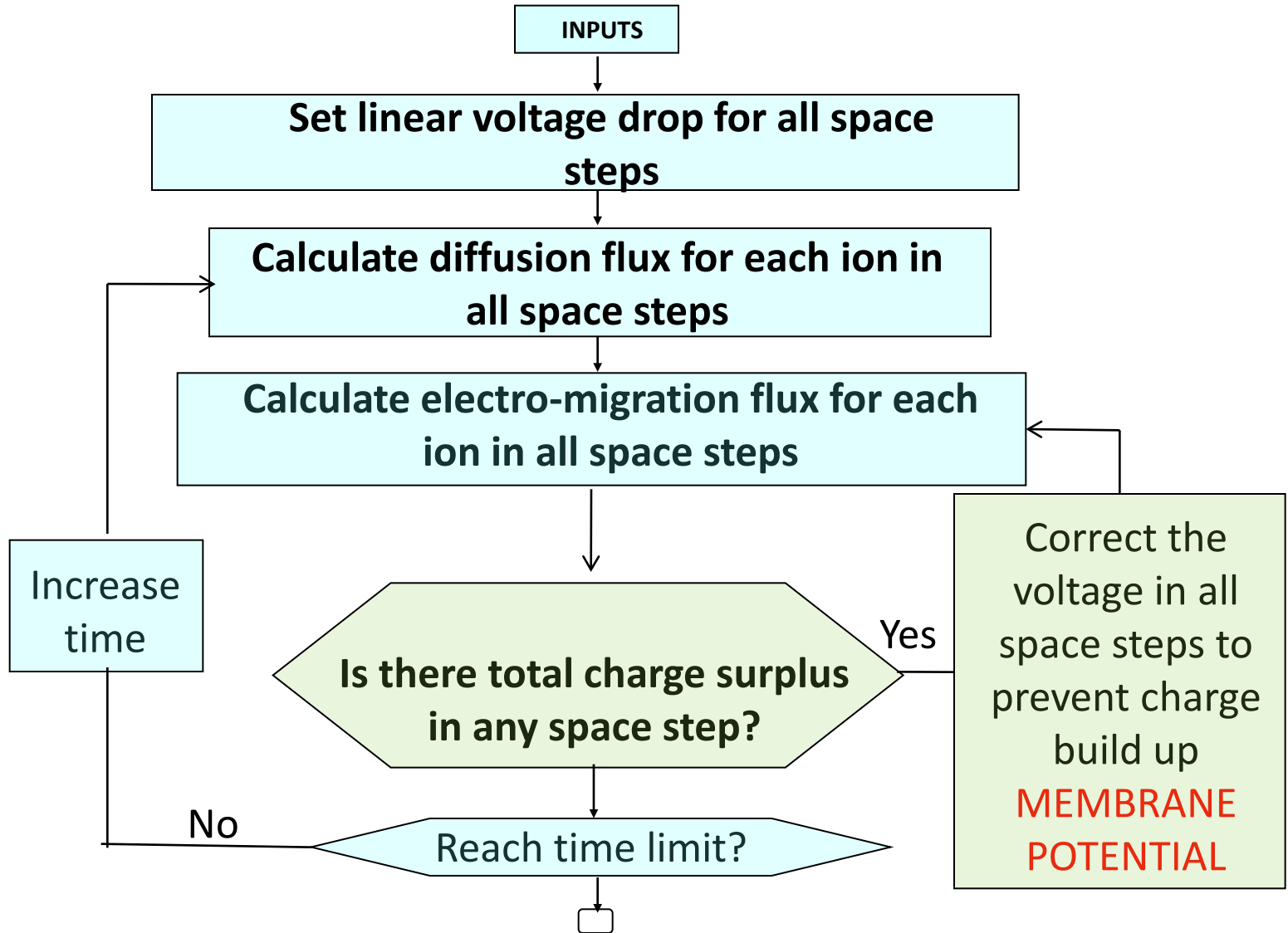
Modelling a thin slice of the sample for a short time step

Apply Kirchoff's law : current in = current out

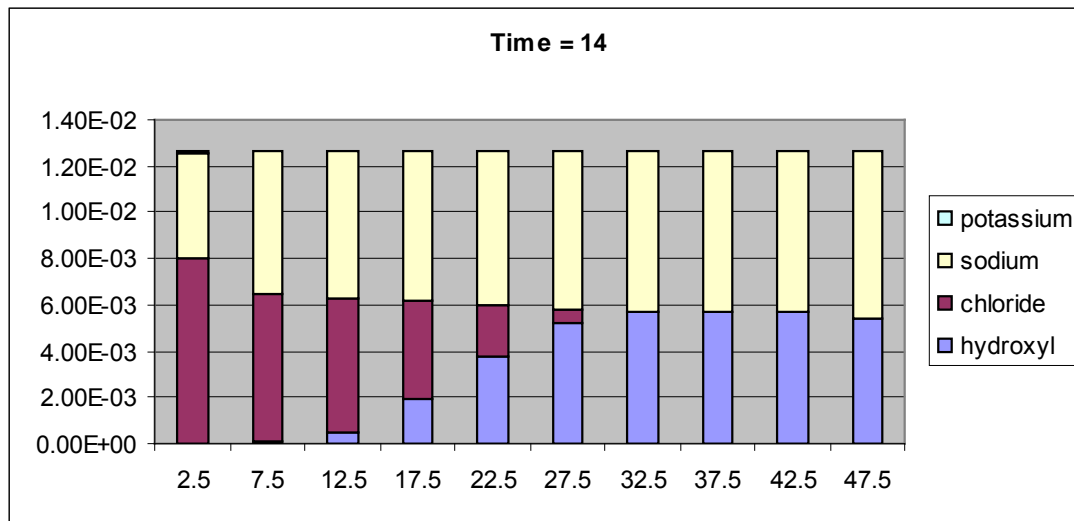
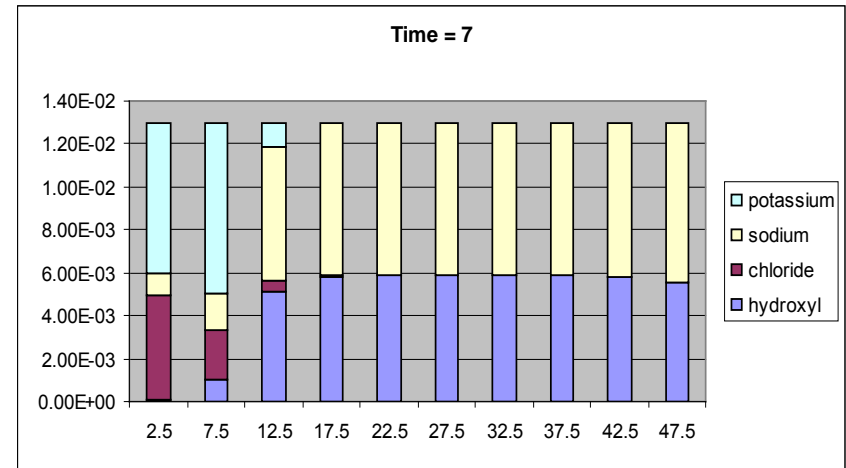
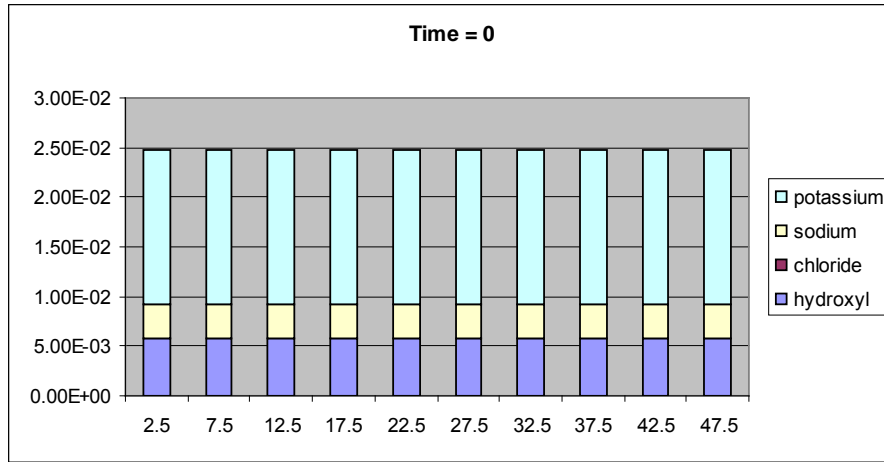


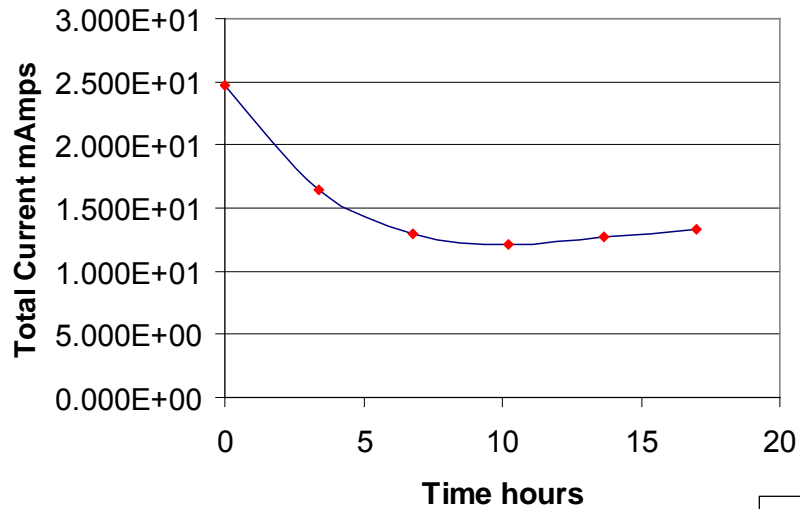
Final adjustments are needed to get the correct total voltage across the sample.

Key innovation in the computer code



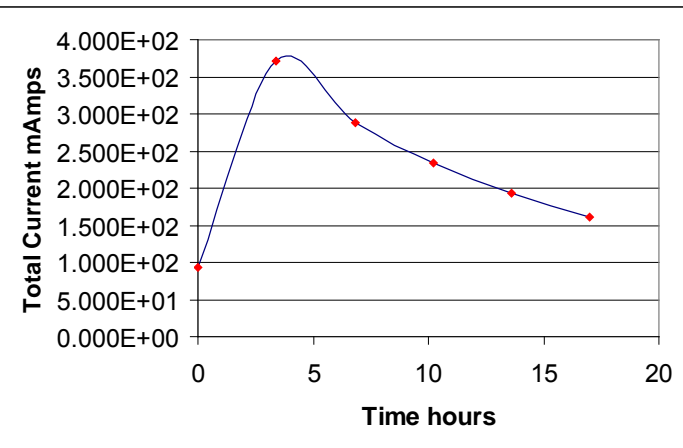
Current in amps at different times in hours vs position in mm from the negative side



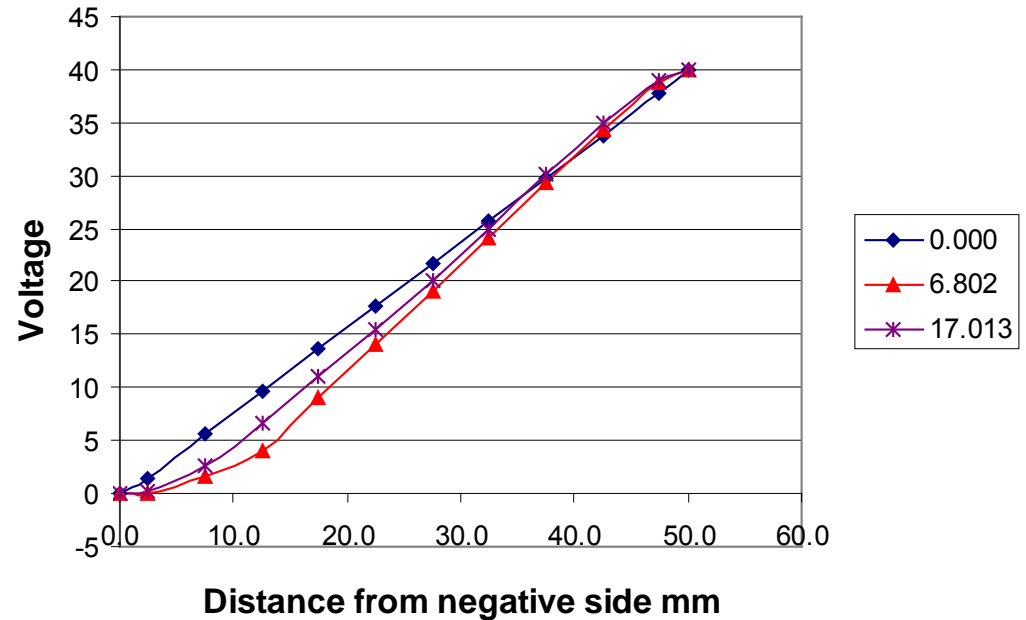


Model output for current and voltage

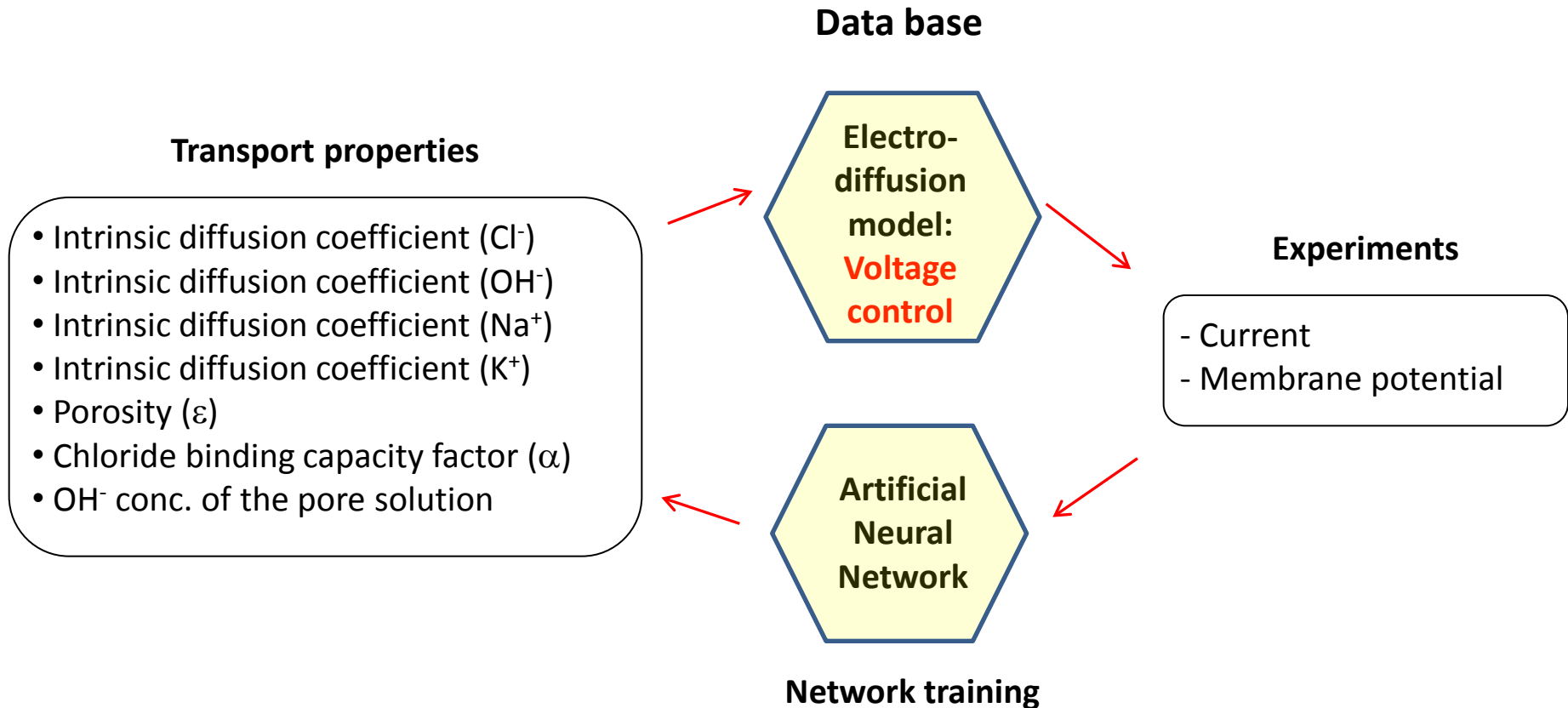
Current vs time with no voltage correction (average)



Voltage adjustments at different times

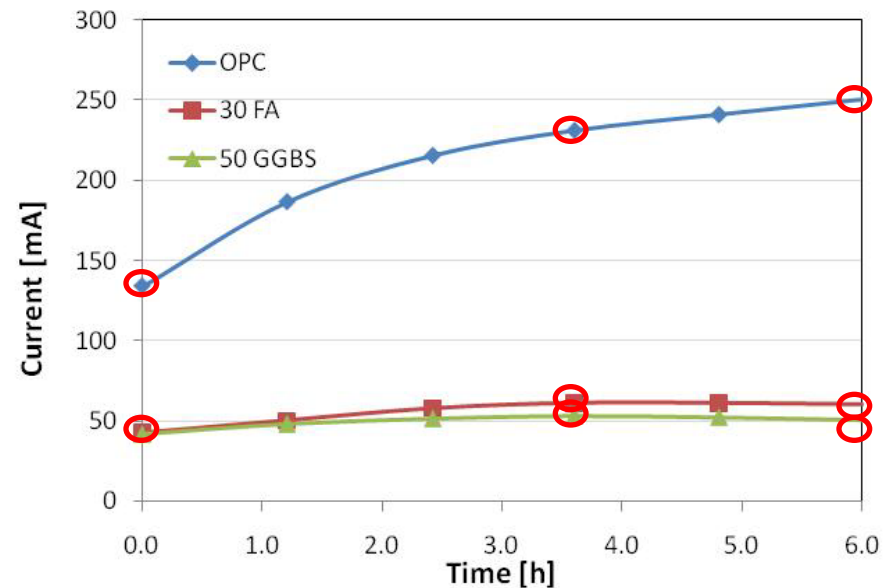
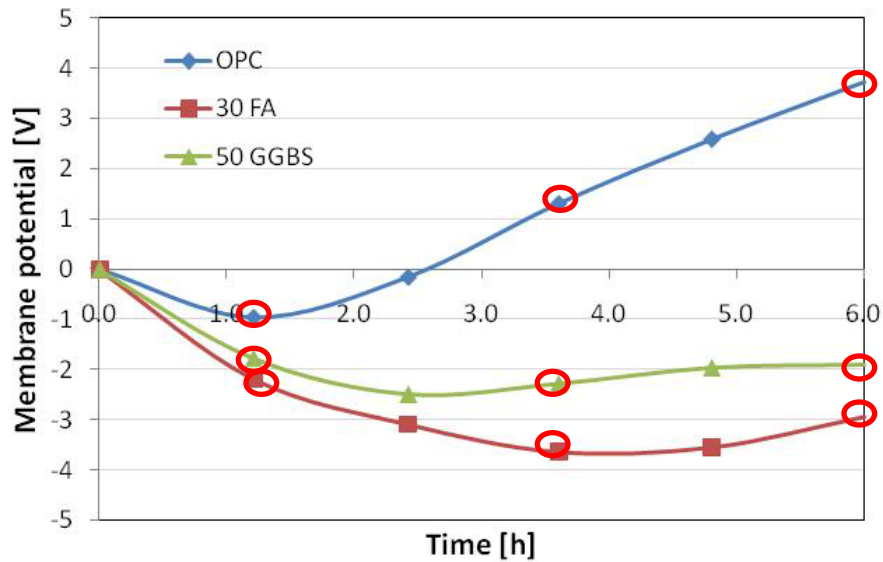


Optimization Model



Experimental programme

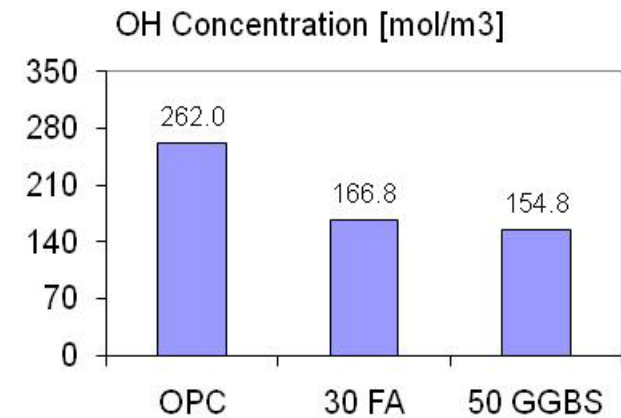
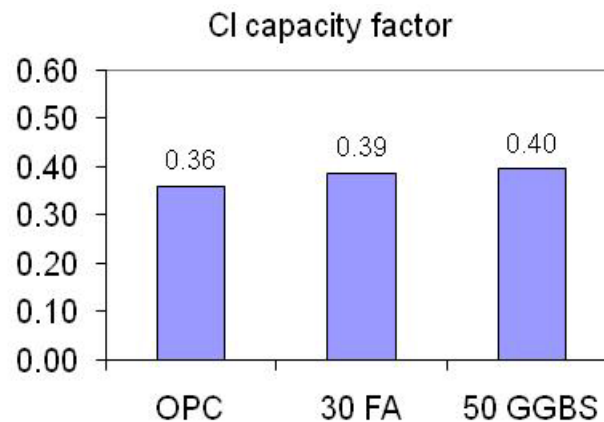
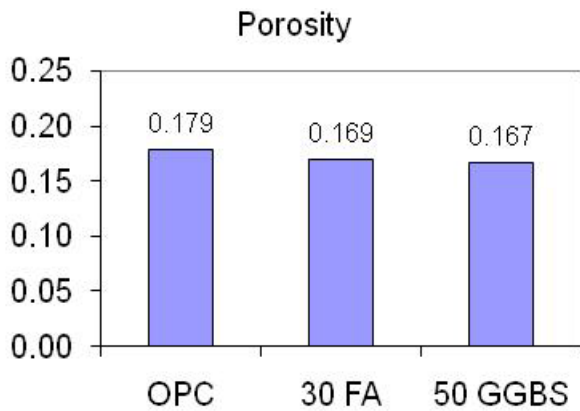
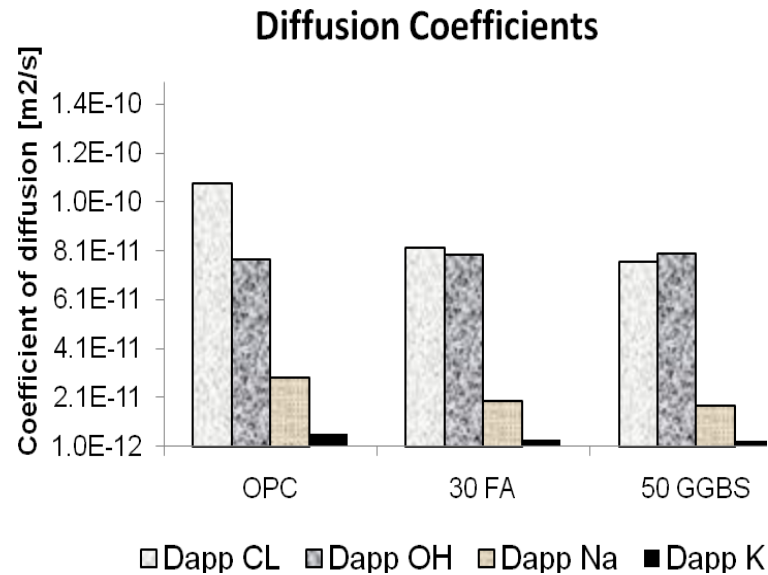
Mix	w/b	%		
		OPC %	PFA %	GGBS %
OPC	0.49	100	0	0
30%PFA	0.49	70	30	0
50%GGBS	0.49	50	0	50



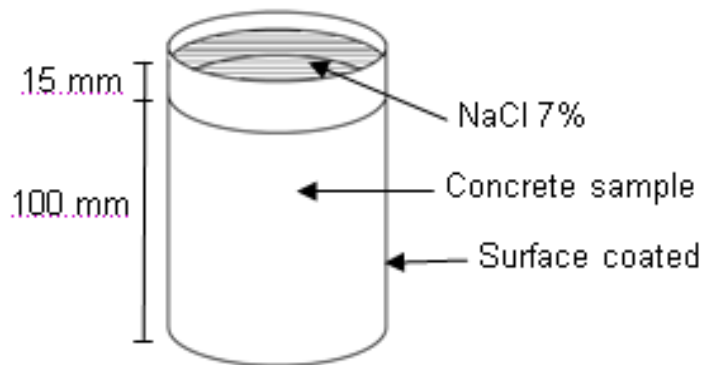
○ Inputs of the neural network

Chloride related properties from voltage control model

You can't get this lot with the new 5 minute test!



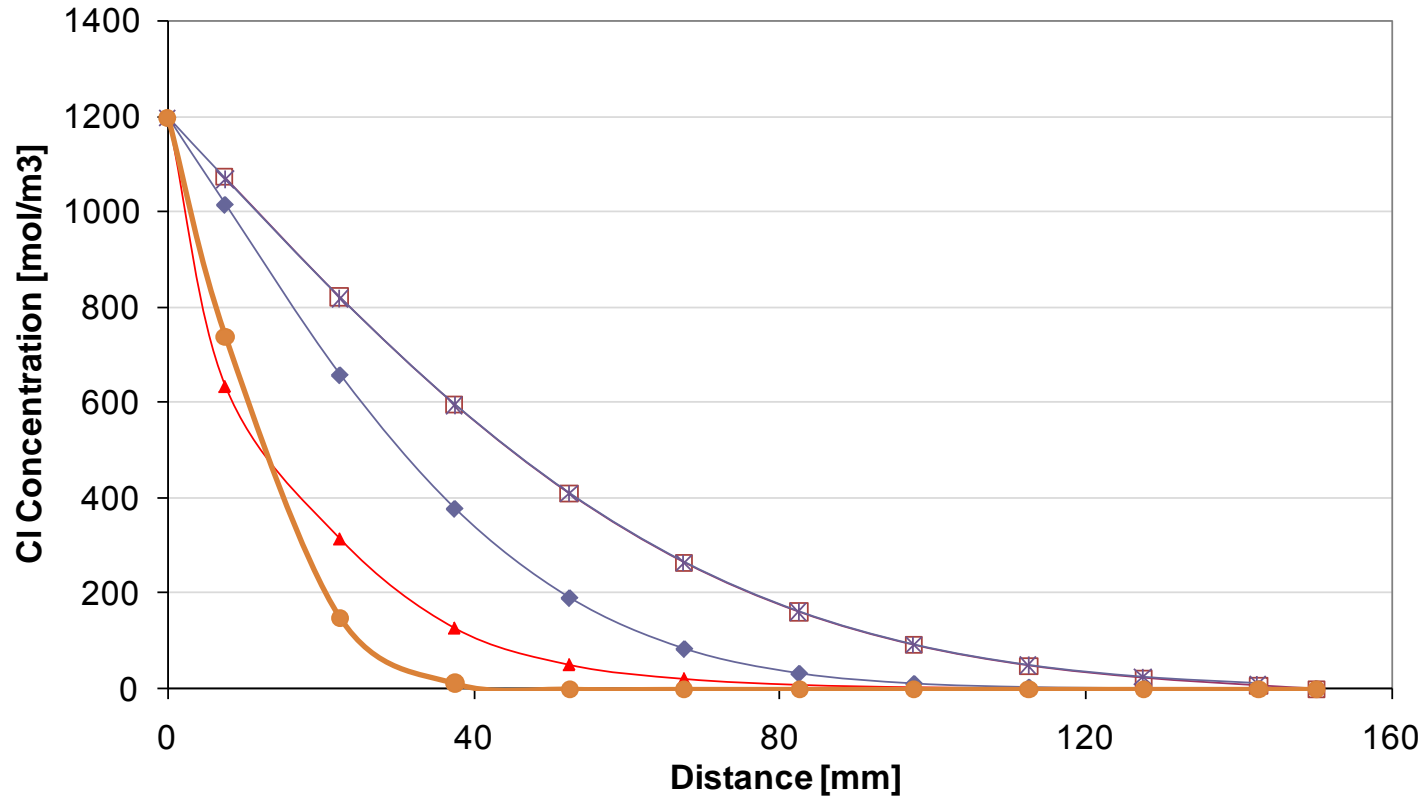
“Traditional” diffusion test



For modelling:

- The boundary condition is not zero voltage because the ends of the sample are not short-circuited.
- A voltage can be measured.
- The voltage in the model is set to give zero current.

Traditional diffusion test (no applied voltage)



- ▲ (1) Current control model - zero current (properties calculated)
- ◆ (2) Model with non-zero current, no voltage correction (properties calculated)
- ◻ (3) Model with no binding, no voltage correction and just diffusion of Cl (Dint-cl calculated)
- * (4) Equation 7 (Dint-cl calculated)
- (5) Equation 7 (Dint-Fick)

Equation (7) is the integral of Fick's law. D_{int} = Intrinsic diffusion coefficient
(3) and (4) coincide – showing that the computer model gives the same results as integrating Fick's law if the ion-ion interactions are switched off.
(5) Is based on experimental data

Future work

- Controlled power tests to avoid overheating.
- Voltage steps to avoid the need for a salt bridge.

Conclusions

- The electrical model can be used with an artificial neural network (ANN) to give good values for transport properties.
- Even when no voltage is applied, an electrical model is needed to simulate a diffusion test because of ion-ion interactions.

Thank you

www.claisse.info

References:

J Lizarazo Marriaga and P Claisse

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Electrochimica Acta Volume 54, Issue 10, 1 April 2009, Pages 2761-2769 2008.

Juan Lizarazo-Marriaga, Peter Claisse

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Materials Chemistry and Physics. VOL 117; NUMBER 2-3 (2009) pp. 536-543 (15 October 2009)

J Lizarazo and P Claisse

Determination of the transport properties of a blended concrete from its electrical properties measured during a migration test

Submitted to Magazine of Concrete Research. September 08.

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Second International Conference on Sustainable Construction Materials and Technologies

June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.

<http://www4.uwm.edu/cbu/ancona.html>