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Problems associated with the measurement of chloride diffusion in concrete

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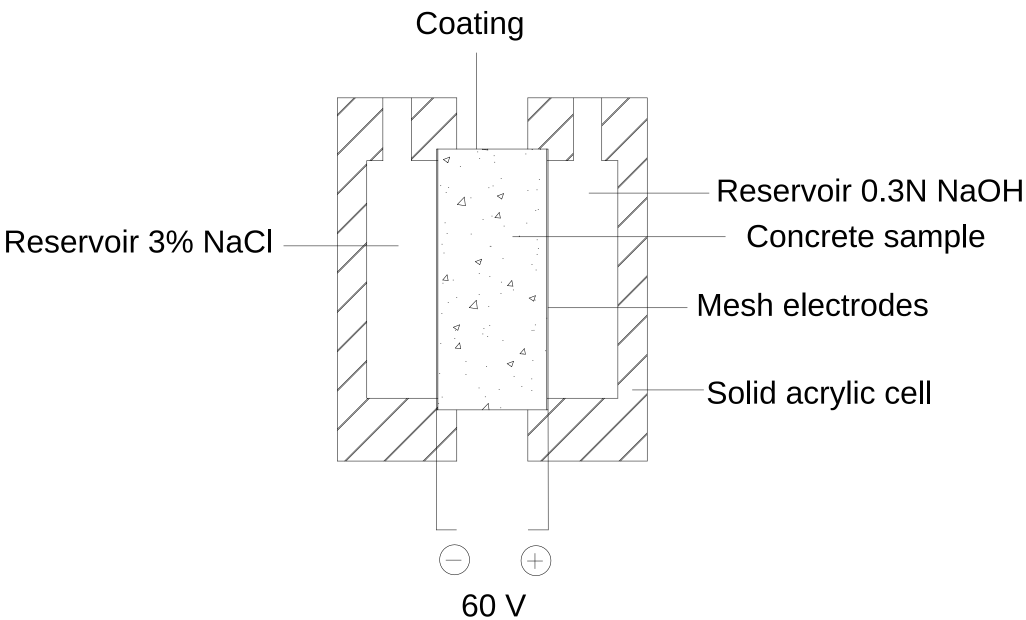
Presentation contents

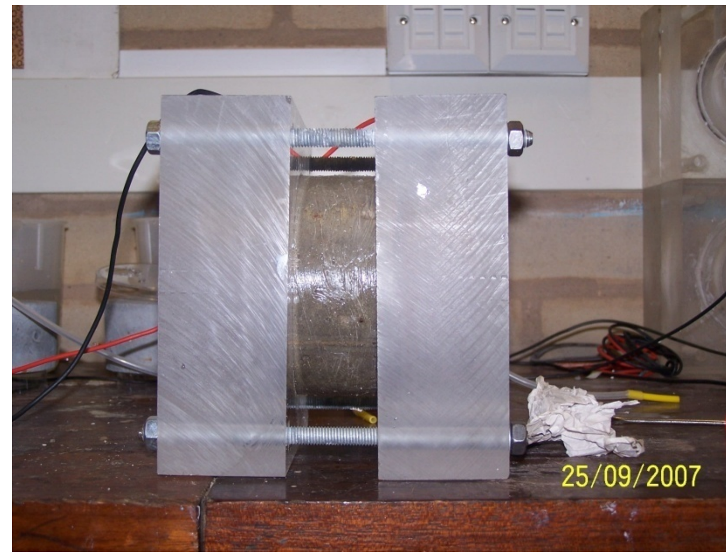
1. Electromigration tests
2. “Traditional” diffusion tests

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)



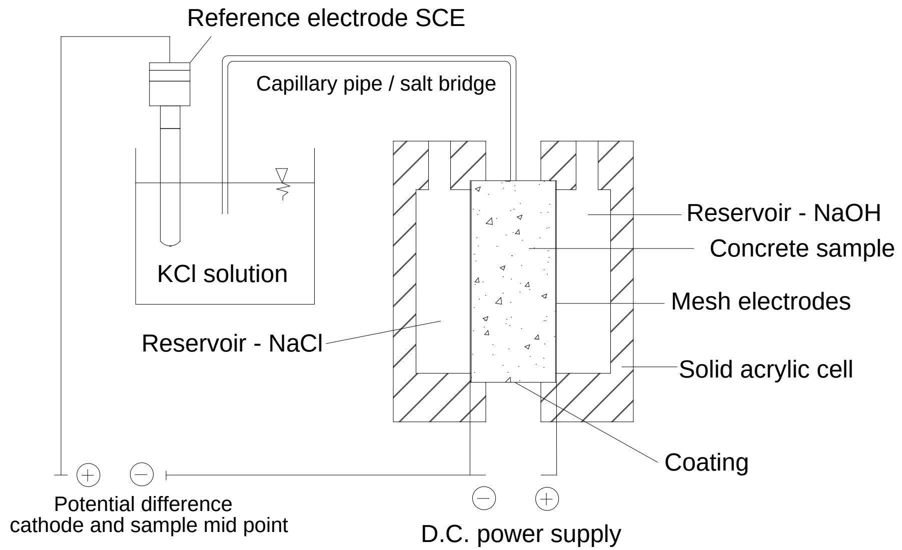


Charge Passed (coulombs)	Chloride Ion Penetrability
>4,000	High
2,000 - 4,000	Moderate
1,000 – 2,000	Low
100 – 1,000	Very low
<100	Negligible

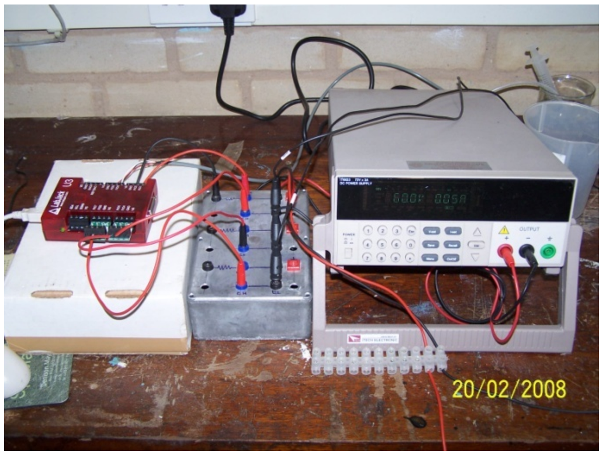
The Problem

- 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- and can give misleading low results.
- Adding some accelerators with nitrates or other conducting ions can give misleading high results.

The new test


Reference electrode SCE
Capillary pipe / salt bridge
KCl solution
Reservoir - NaCl
Reservoir - NaOH
Concrete sample
Mesh electrodes
Solid acrylic cell
Coating
Potential difference
cathode and sample mid point
D.C. power supply


02/08/2008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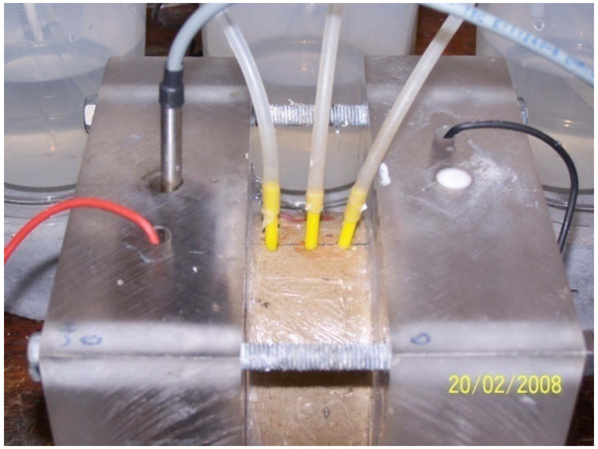
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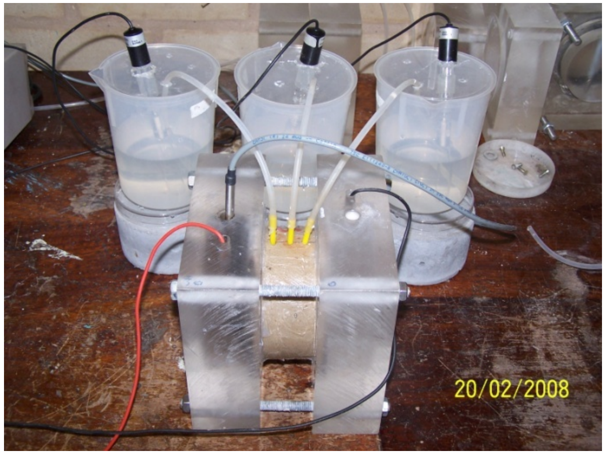
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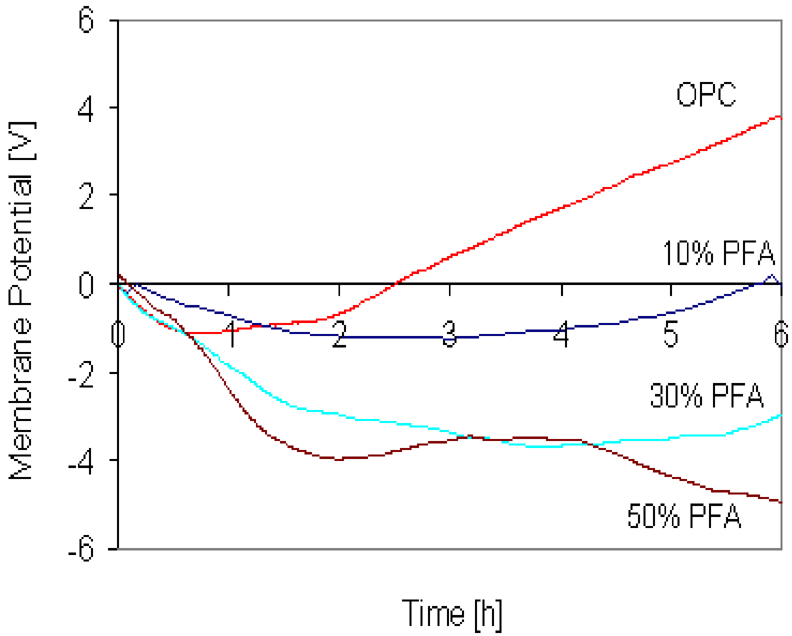
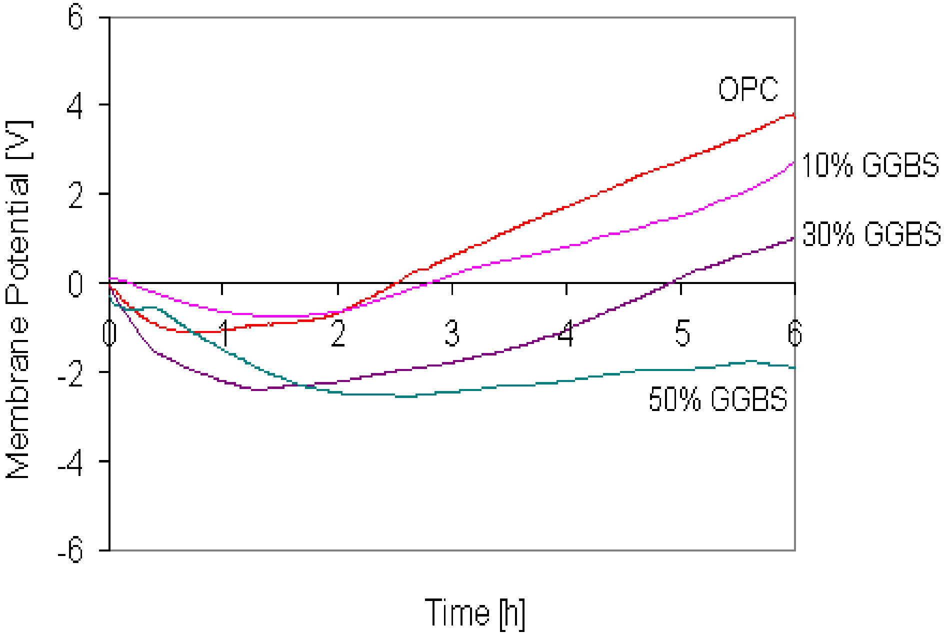
Using the mid-point voltage to identify cement replacements





Electro-diffusion model for chlorides in concrete

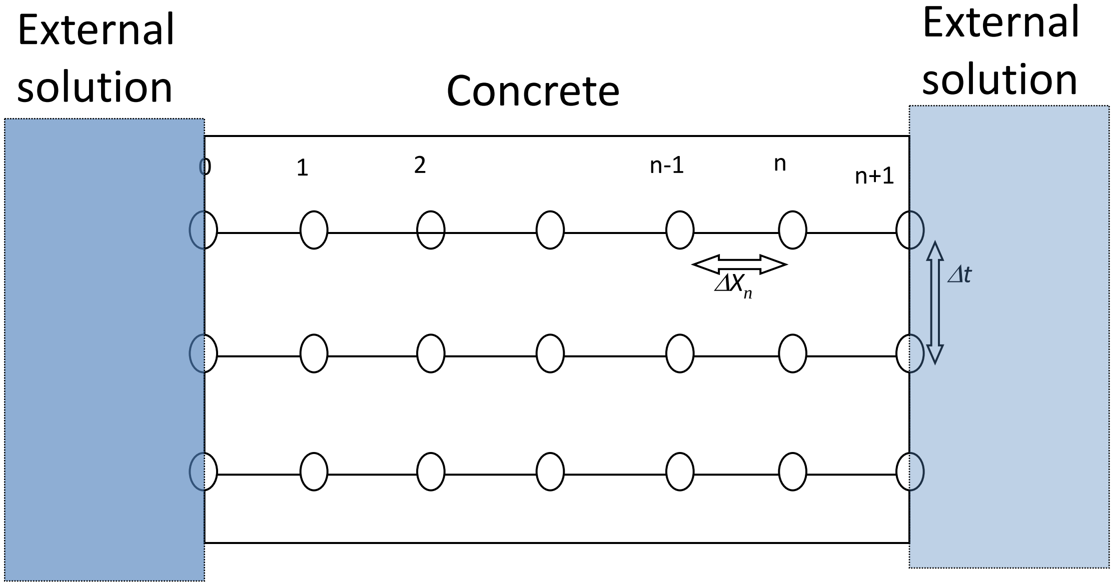
- **Nernst-Planck equation:**

$$J_i = D_i \frac{\partial c_i}{\partial x} + \frac{z_i F}{RT} D_i c_i \frac{\partial E}{\partial x}$$

Diffusion **Migration**

- **Charge electroneutrality (Kirchoff's law):**

$$0 = F \sum_i z_i J_i$$



Solving the hard way –

assuming E is constant

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

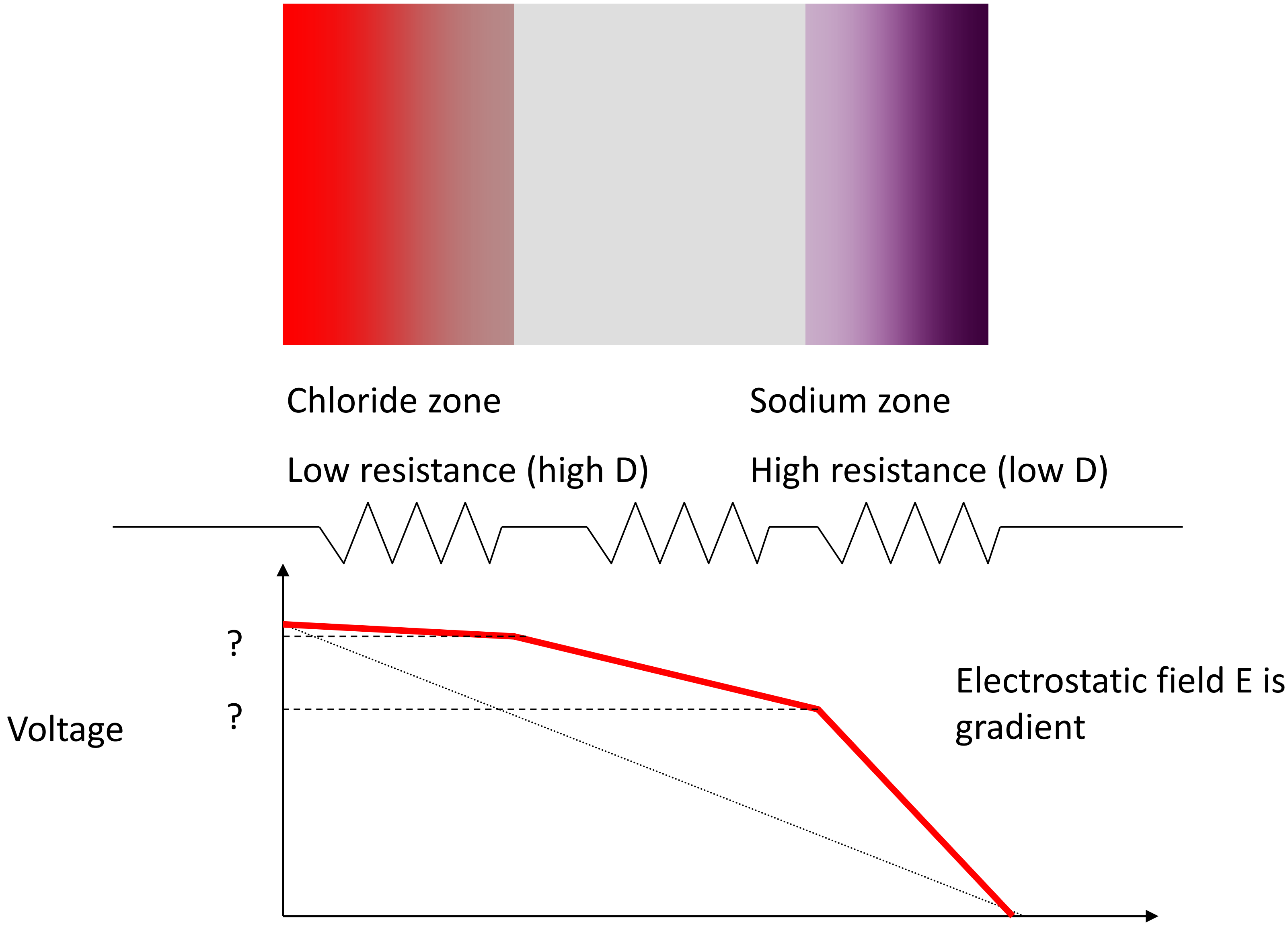
where

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

$$\alpha = ax$$

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

Section through sample during test



The Progress of a Chloride Ion

Cl-

A Chloride ion enters the sample...
what happens next?

Cl- OH-

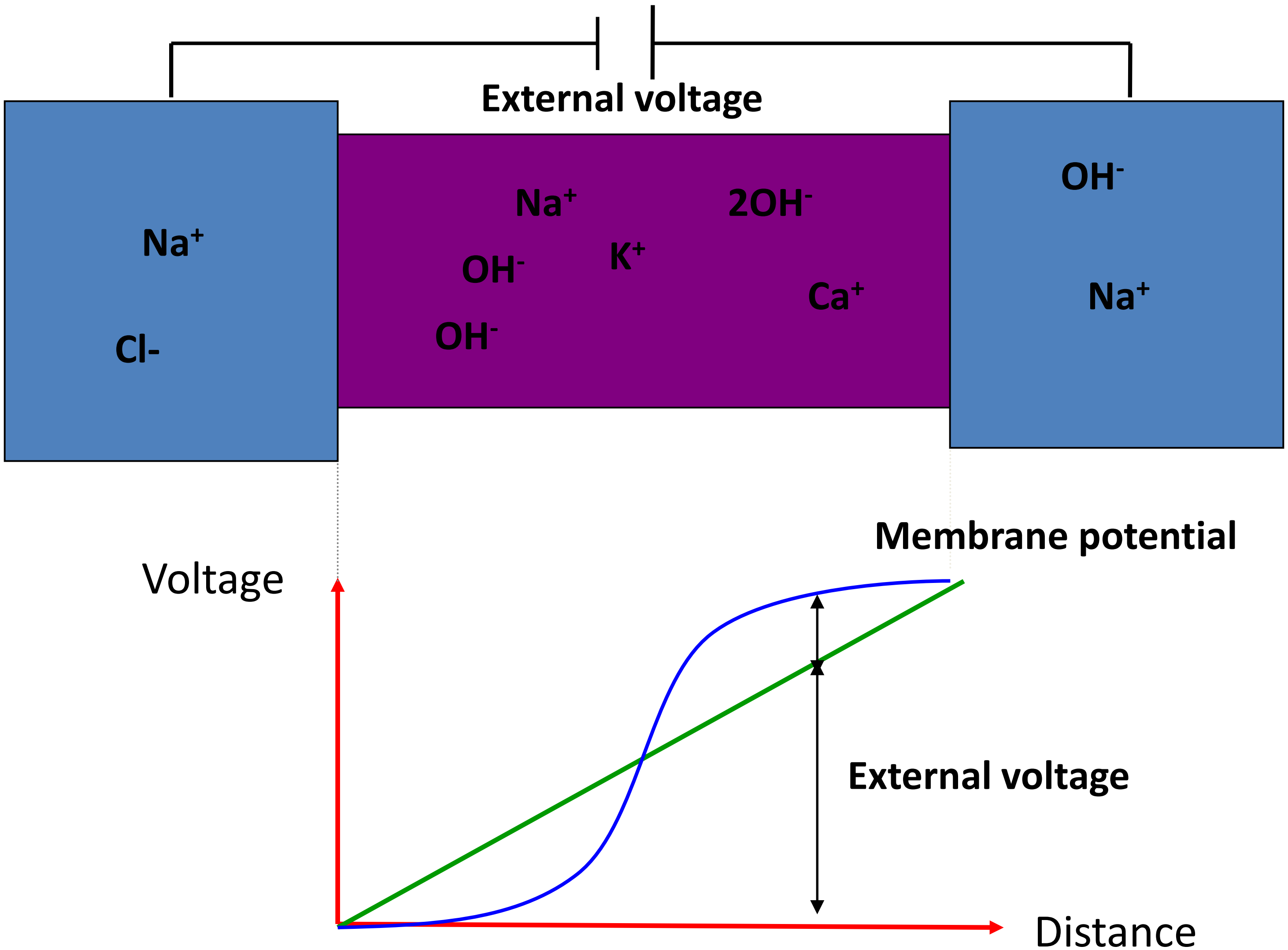
Either it finds another negative ion that can move away in front of it

Cl-

Na+

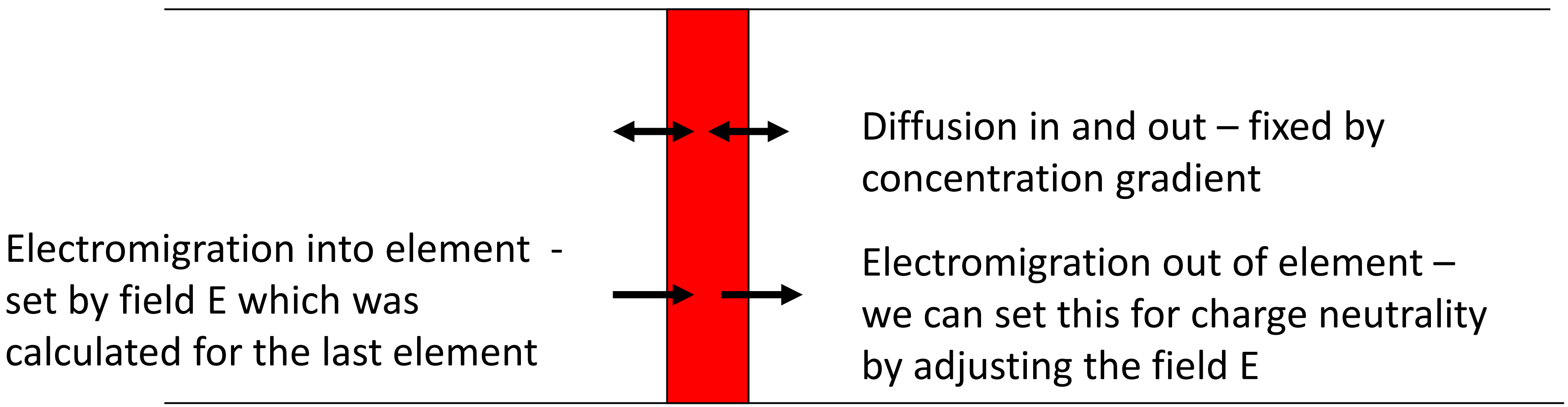
Or it has to bring a positive sodium ion with it

Membrane Potential



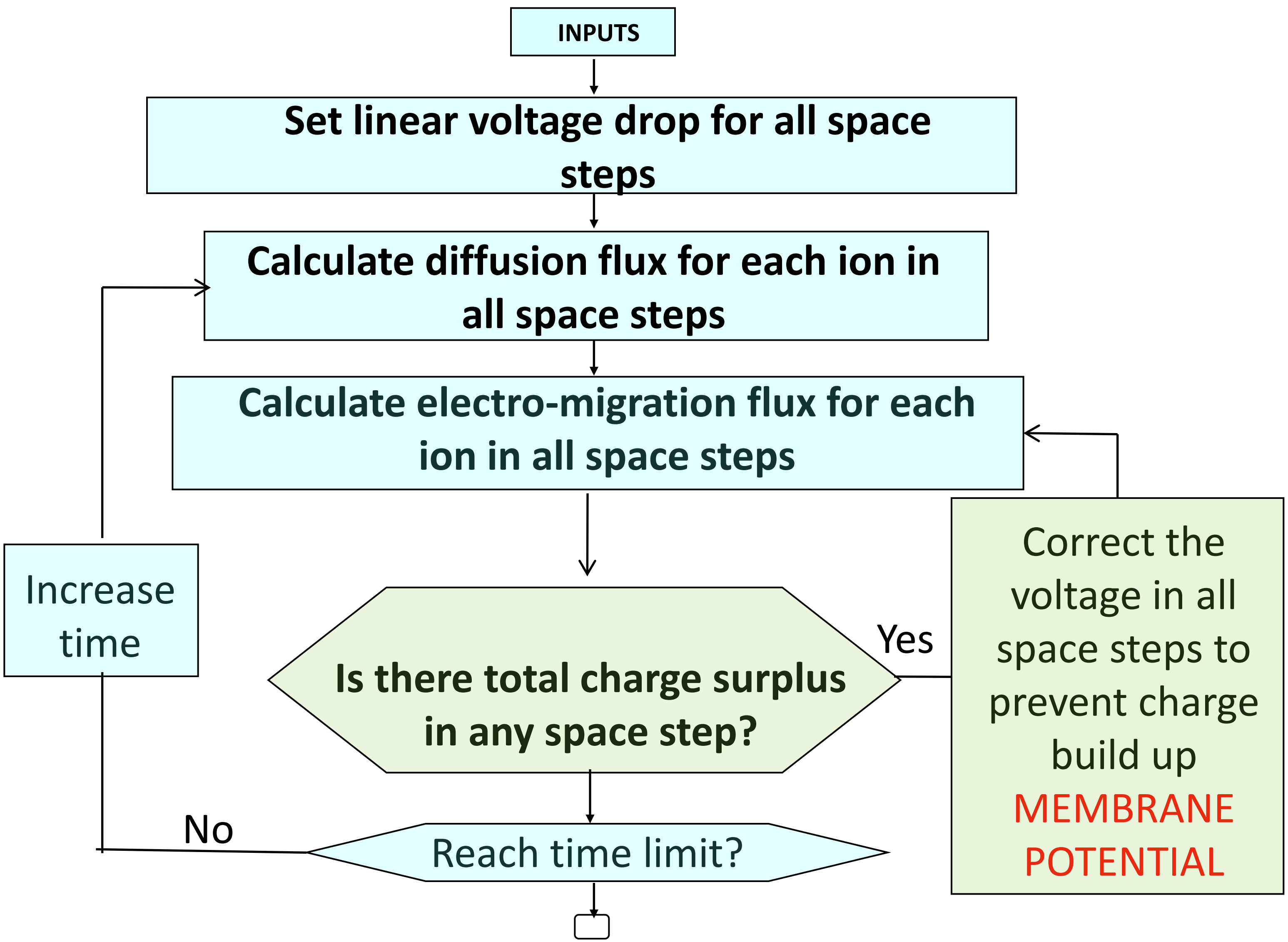
Modelling a thin slice of the sample for a short time step

Apply Kirchoff's law : current in = current out

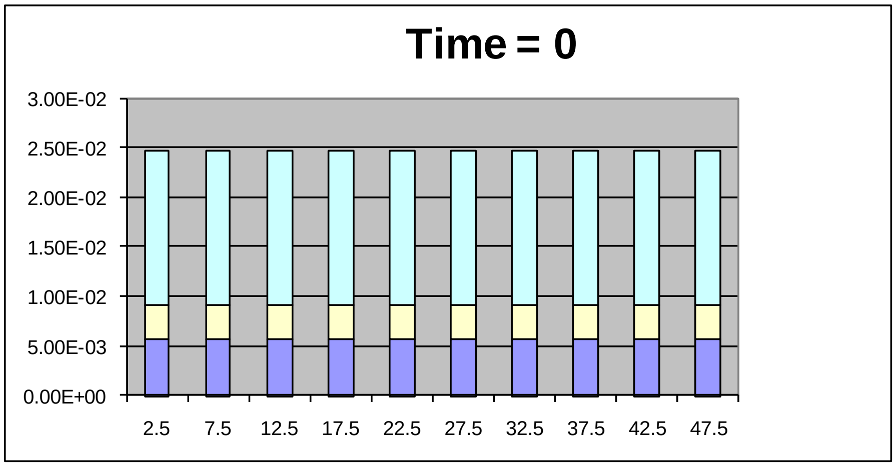


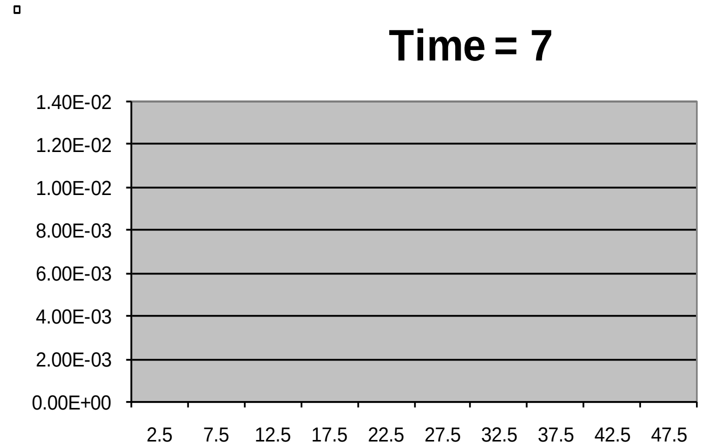
Final adjustments are needed to get the correct total voltage across the sample.

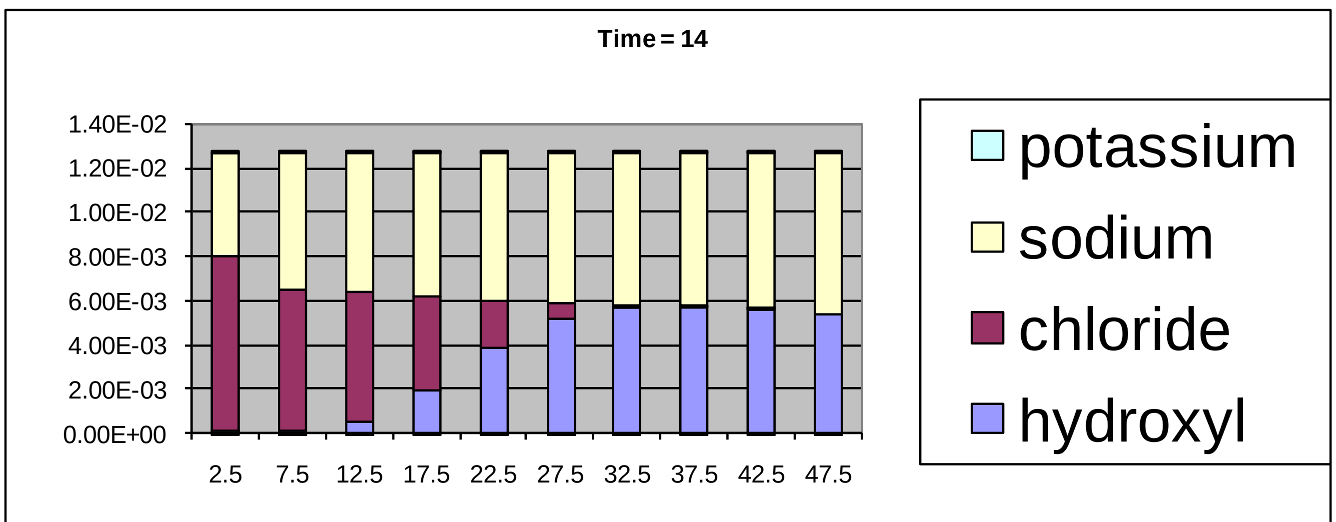
Key innovation in the computer code



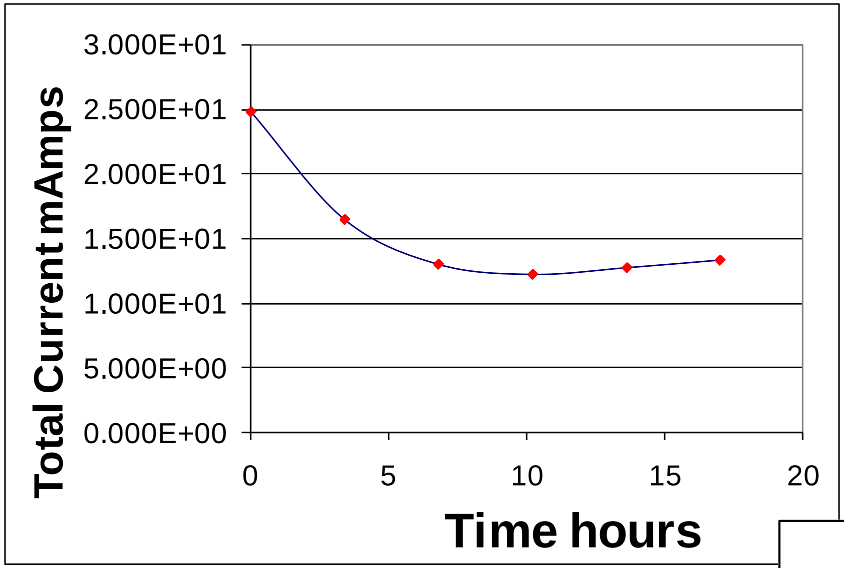
Current in amps at different times in hours vs position in mm from the negative side



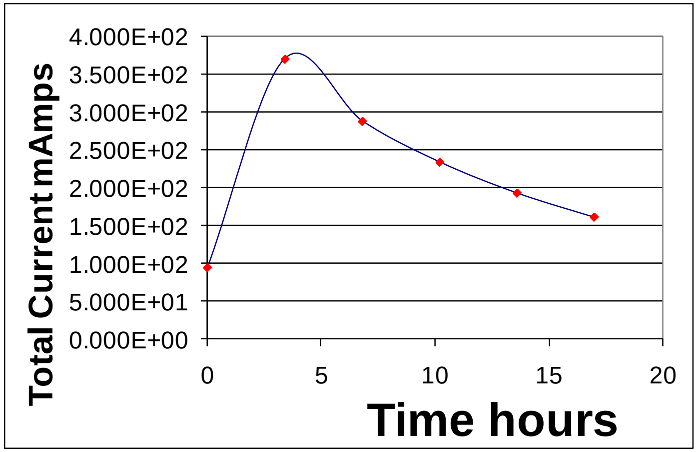


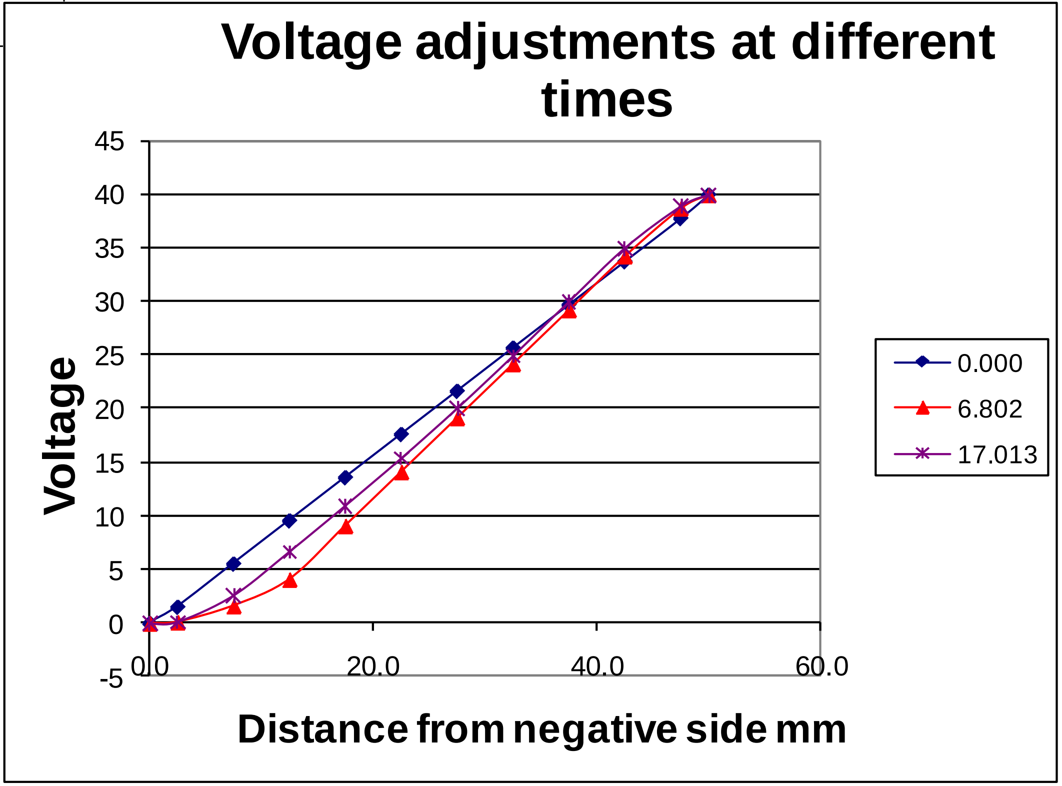


Model output for current and voltage

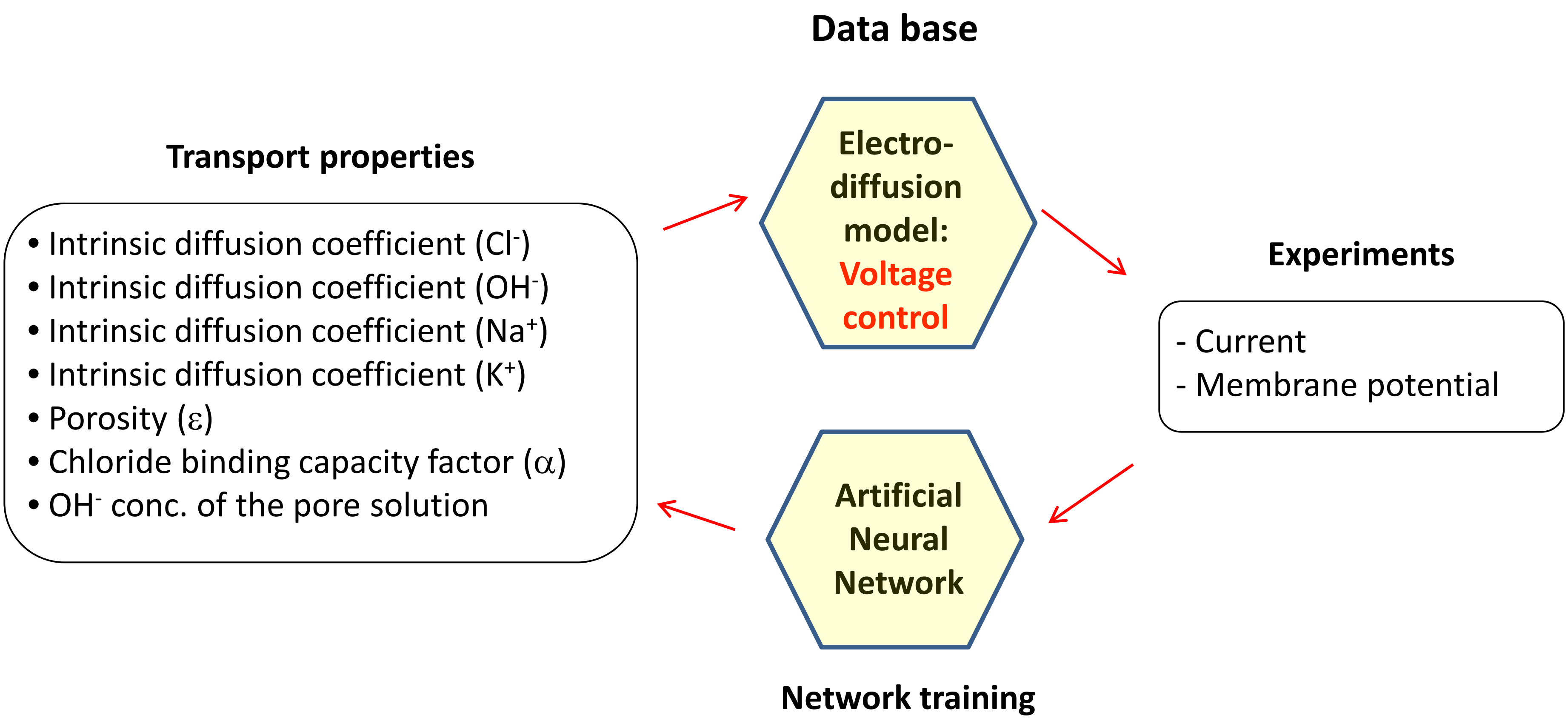


Current vs time with no voltage correction (average)



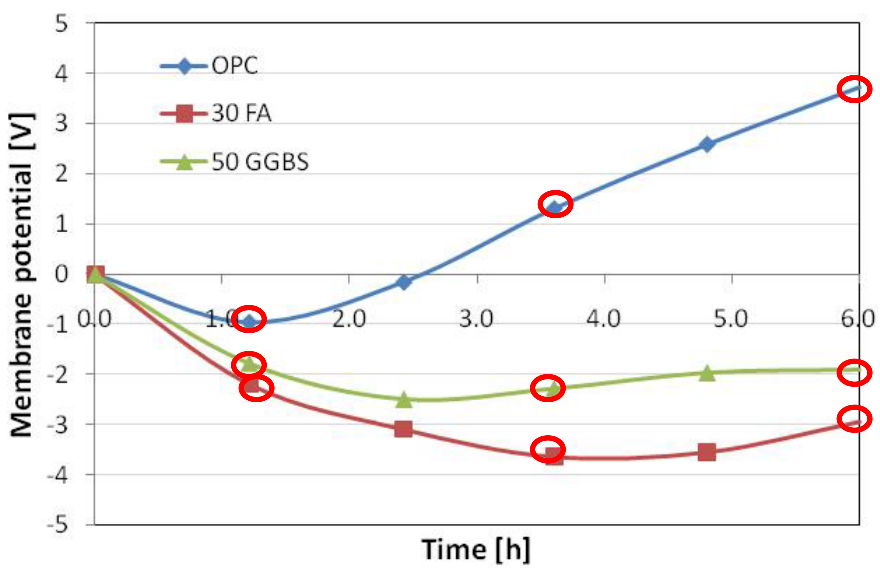


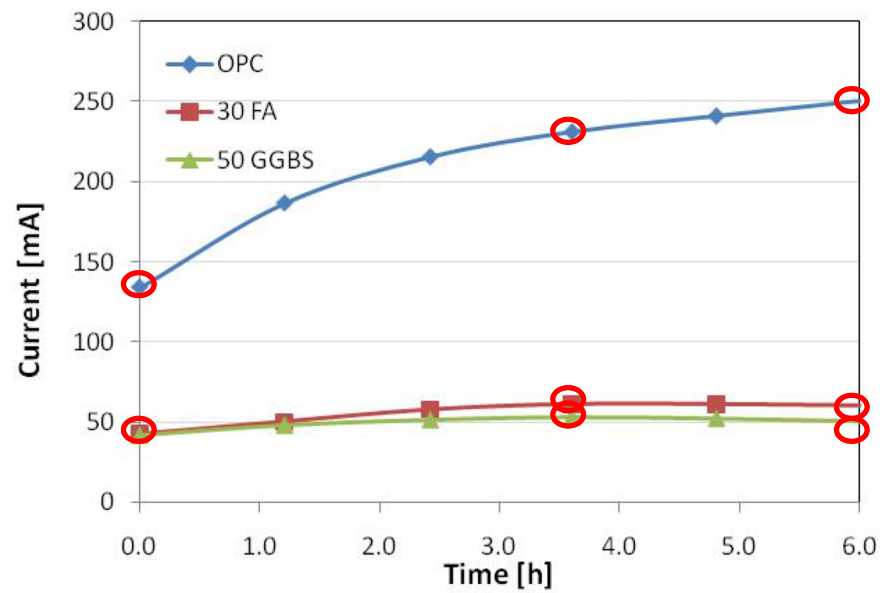
Optimization Model



Experimental programme

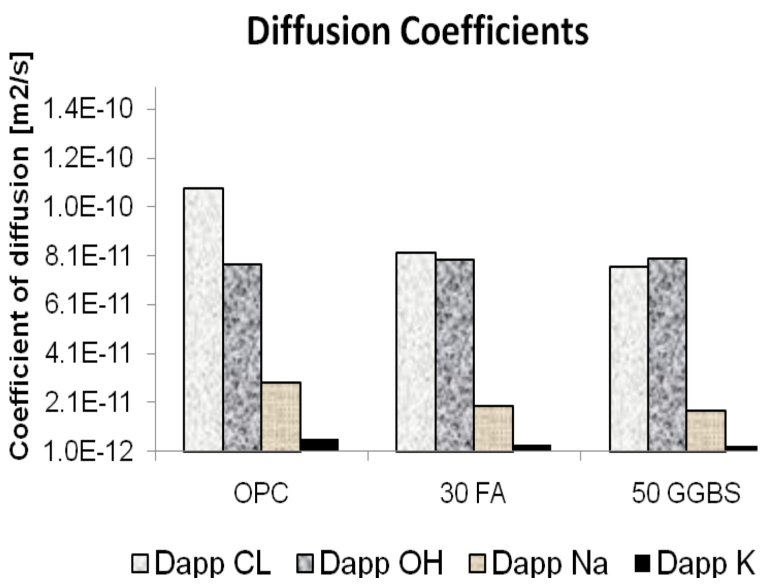
		%		
Mix	**w/b**	**OPC %**	**PFA %**	**GGBS %**
OPC	**0.49**	**100**	**0**	**0**
30%PFA	**0.49**	**70**	**30**	**0**
50%GGBS	**0.49**	**50**	**0**	**50**

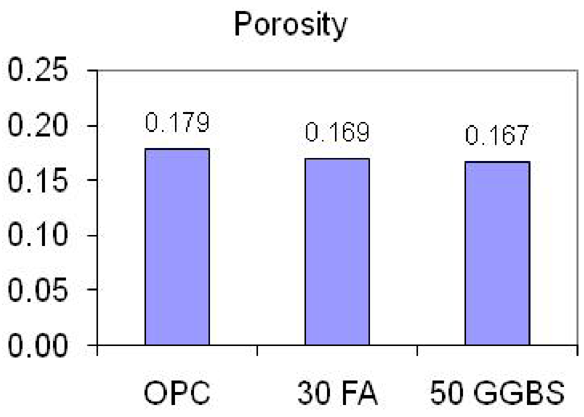


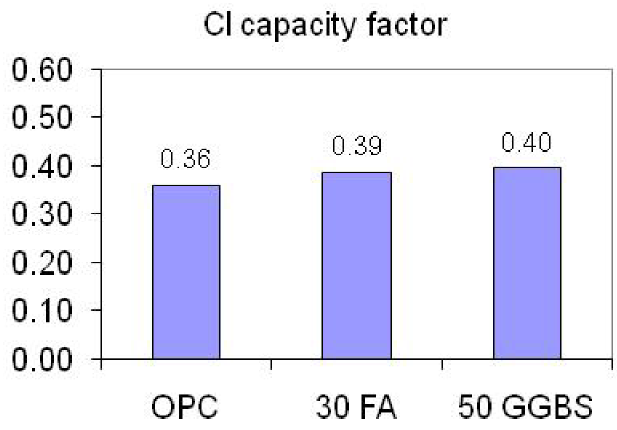


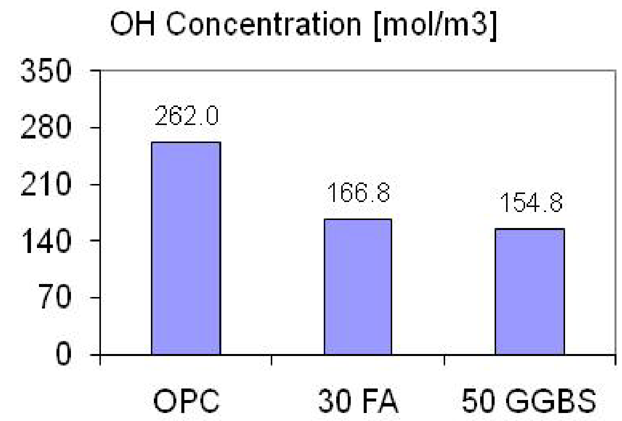
Inputs of the neural network

Chloride related properties from voltage control model **You can't get these with a 5 minute test!**

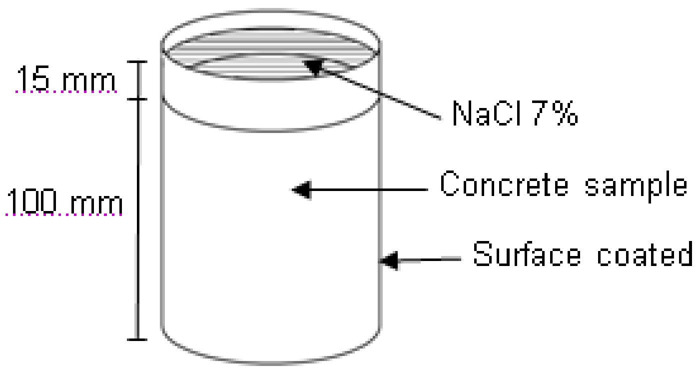








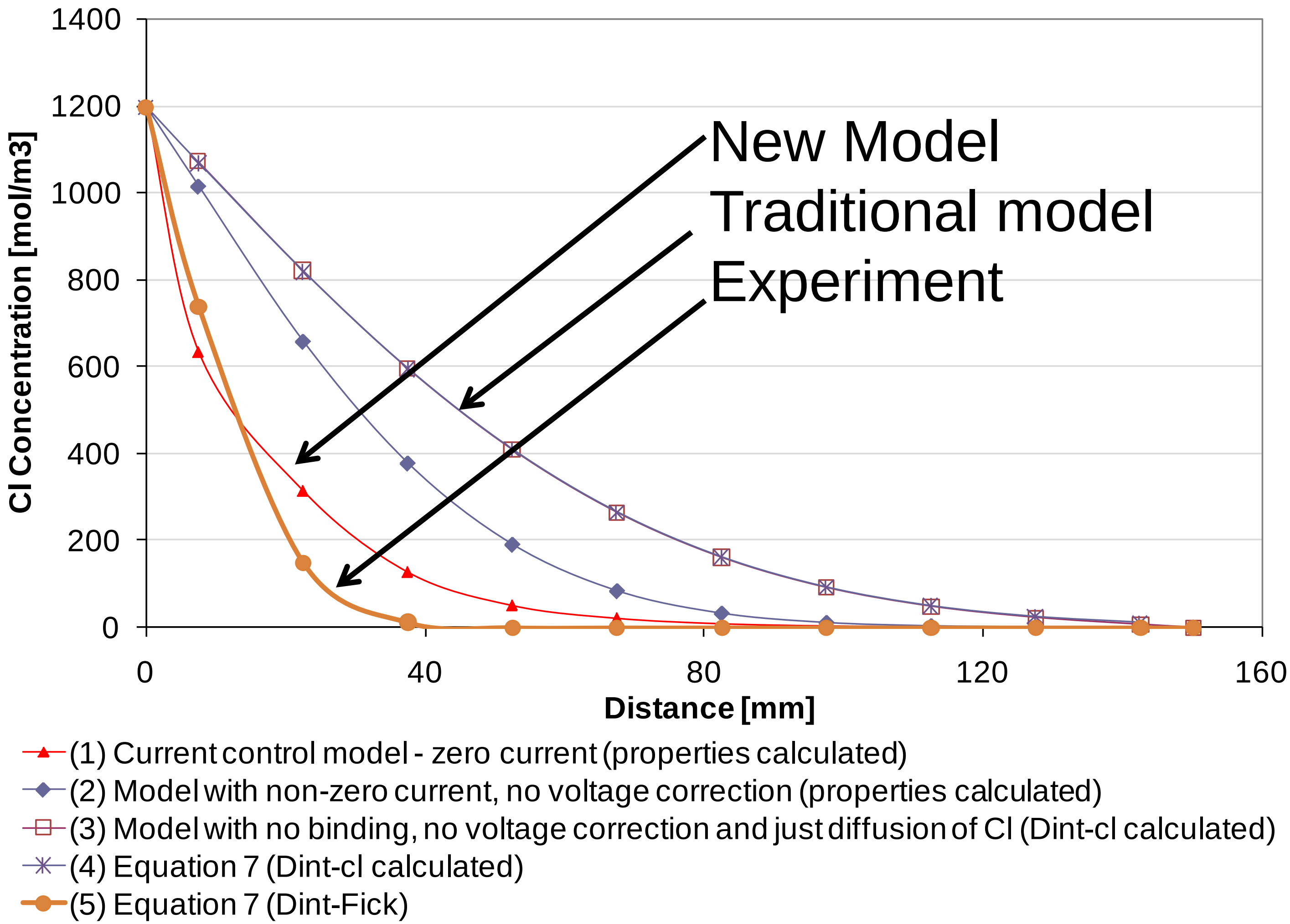
“Traditional” diffusion test



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)



Equation (7) is the integral of Fick's law. Dint = 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 on the Voltage Driven Test

- Controlled power tests to avoid overheating.
- Voltage steps (or similar technique) to get the same results but 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

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