



## **Quantifying the effects of major factors affecting the effectiveness of cathodic protection of pipelines**

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# QUANTIFYING THE EFFECTS OF MAJOR FACTORS AFFECTING THE EFFECTIVENESS OF CATHODIC PROTECTION OF PIPELINES

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**SUMMARY:** Cathodic protection (CP) is widely applied as a principal means of protecting buried steel pipeline from soil corrosion. Unfortunately in practice the potential of a buried steel pipeline could be diverted from the standard 'safe' CP level (i.e. -850 mV vs copper/copper sulphate reference electrode) due to various reasons such as stray currents, flawed CP design or faulty CP control, leading to insufficient CP (in cases of anodic potential excursions) and over-protection (in cases of excessive negative potential excursions). This problem can be further complicated when the potential fluctuates due to complex forms of external electrical interference signals that may be direct current (DC), alternating current (AC) or AC superimposed on DC in nature. Some forms of potential excursions are known to be harmful to buried steel pipelines; however currently the exact effects of potential excursions on CP efficiency and corrosion have not been sufficiently understood preliminary due to difficulties in measuring these effects. Over-protection is known to cause cathodic disbondment of pipeline coatings. Traditional methods of evaluating cathodic disbondment of pipeline coatings are based on visual inspection of pipeline conditions, and laboratory testing of cathodic disbondment resistance using standard visual inspection based methods. Unfortunately these techniques have some limitations in quantitatively and instantaneously measuring and monitoring cathodic disbondment of thick pipeline coatings. There are needs for the development of new methods that are able to perform in-situ and quantitative measurements of stray current corrosion and cathodic disbondment of pipeline coatings. This paper provides an overview of our current approaches to quantifying the influence of electrical interference signals on CP and steel corrosion using newly designed electrochemical corrosion cells; as well as to monitoring cathodic disbondment of coatings using electrochemical impedance spectroscopy. Typical results from using these new techniques for measuring stray current corrosion and for probing the cathodic disbondment of pipeline coatings have been briefly discussed.

**Keywords:** Pipeline corrosion, Cathodic protection, Stray current, Protective coating

## 1. INTRODUCTION

In order to ensure the effectiveness of cathodic protection (CP) of buried pipelines, various industry standards and criteria have been developed for selecting appropriate CP design parameters, for instance the Australian Standard [1] and the NACE CP criteria [2] require the CP instant-off potential of a buried steel pipeline be set at -850 mV vs copper/copper sulphate reference electrode (CSE). Under this standard CP potential level, a steel pipeline buried in pH neutral soils is considered to be fully protected although doubts about the applicability of this standard CP potential to more complex environments still exist [3-5]. Unfortunately in practice the potential of a buried steel pipeline could be diverted from the designed 'safe' CP level due to various reasons such as flawed CP design and faulty CP control, stray currents and other forms of electrical interference signals [6-9]. Excursions from the standard CP potential (e.g. -850 mV<sub>CSE</sub>) due to various forms of electrical interference signals such as stray current, traction and telluric influences are observed and measured rather frequently on pipelines. These interference signals may be direct current (DC), alternating current (AC) or AC

superimposed on DC in nature. It has been shown that CP excursions can be over a huge potential range, for instance  $+5 V_{CSE}$  to  $-18 V_{CSE}$  [7,9]. Currently the exact effects of potential excursions especially fluctuating potential excursions (potential transients) on CP efficiency and corrosion have not been sufficiently understood. It is widely believed that potential transient is a major factor contributing to insufficient CP and pipeline corrosion [6-9], however currently there is no unified consensus on how 'big' such CP excursion (either in magnitude, frequency or duration) needs to be in order to cause major corrosion problems. Over the past decades attempts have been made in order to achieve a unambiguous understanding of the effects of electrical interference signals on the corrosion of cathodically protected buried steel pipelines, however most of the results remain empirical. For instance Peabody [10] described an empirical 'rule' that a DC excursion of 1 hour duration would lead to a 27% increase in buried pipeline corrosion risk while a DC excursion of 1 day duration would increase the 'chance' of corrosion by 50%. On the other hand Wakelin and Gummow [6] described another 'rule' that no corrosion would occur if AC excursion current density is less than  $20 A/m^2$ ; corrosion probably could occur when AC excursion current density is between  $20 A/m^2$  to  $100 A/m^2$ ; and corrosion is expected to occur when it is over  $100 A/m^2$ . It should be noted that these empirical relationships are mostly developed from field observations and experiences of inspecting pipelines, and therefore they could be distorted by many complex inter-related factors such as variable and dynamically changing soil environments. Indeed prior work in this area has been predominantly based on empirical findings that are insufficient for achieving fundamental understanding of the phenomenon.

In cases of excessive negative potential excursions, over-protection could occur, leading to cathodic disbondment of pipeline coatings. Cathodic disbondment of protective organic coatings has been a widely reported pipeline coatings failure mode in the oil and gas pipeline industry. Traditional methods of evaluating cathodic disbondment of pipeline coatings are based on visual inspection of pipeline conditions, and laboratory testing of cathodic disbondment resistance using standard visual inspection based methods such as ASTM G8. Unfortunately current techniques have some limitations in accurately, quantitatively and instantaneously measuring and monitoring cathodic disbondment of thick pipeline coatings. There are needs for the development of new methods that are able to perform in-situ and quantitative measurements of stray current corrosion and cathodic disbondment of pipeline coatings.

This paper describes an overview of our new approaches to quantifying the influence of electrical interference signals on CP and steel corrosion using newly designed electrochemical corrosion cells; as well as to monitoring cathodic disbondment of coatings using electrochemical impedance spectroscopy (EIS). Typical results from using these new techniques for measuring stray current corrosion and for probing the cathodic disbondment of pipeline coatings are briefly discussed.

## **2. DEVELOPING ELECTROCHEMICAL CELLS FOR QUANTIFYING THE EFFECTS OF CP EXCURSIONS ON CORROSION**

Although significant effort has been made to systematically categorise and quantify the level and nature of damage of pipeline as a result of CP excursions, there are still major difficulties in drawing decisive conclusions because of the complexity of the electrochemical corrosion processes occurring at the complicated soil/buried steel interface. Technological difficulties in measuring buried steel corrosion under CP are believed to be the prime reason responsible for the lack of conclusions on the exact effects of CP excursions on pipeline corrosion. Currently potential recording is the most commonly used method for inspecting stray current activities in the pipeline industry; however potential recording does not provide sufficient information about corrosion rates and patterns. Weight-loss coupons have been used to determine corrosion rates of steel buried in soil [11], however weight-loss coupons are unable to provide in situ corrosion rate data required for quantifying the effects of relatively short duration CP potential excursions. An electrical resistance probe array has been used to measure corrosion on CP protected steel coupons buried in soil boxes under the effect of anodic potential transients [12]. Although the electrical resistance probe is able to collect useful corrosion data, it usually cannot measure localized attack because localized corrosion may not lead to much resistivity changes of the probing element. Electrochemical testing methods have also been used for measuring soil corrosion [13]; however their application for measuring localized corrosion under CP can be restricted by theoretical limitations associated with conventional electrochemical methods in monitoring localized corrosion. Localized corrosion is often the key process triggering corrosion failure of steel in soil under CP. On the other hand traditional electrochemical techniques are often not applicable at an externally applied CP potential that is usually far away from the open circuit corrosion potential [14-16]. Although efforts have been made to determine corrosion rates of steel coupons buried in soil under CP [11,17], corrosion measurement of buried steel pipeline remains challenging when complex mechanisms and environmental conditions are taken into consideration.

A major difficulty in stray current corrosion research is the lack of reliable and reproducible experimental methodologies that are able to systematically categorise and quantify the level and nature of damage as a result of various modes of CP excursions. Given the large number of variables, it is an important task to develop and adopt suitable research methodologies and strategies. Our strategy to systematically categorise and quantify the level and nature of damage as a result of various modes of CP excursions has been to conduct several different types of complementary tests and computational modelling. Major effort has been made to develop an aqueous cell that could improve experimental control and address issues associated with experiment reproducibility. This is an important step towards overcoming ambiguities in

CP excursions test results; however initial trial using an aqueous corrosion cell was not successful, because of the mixing up of  $\text{OH}^-$  and  $\text{H}^+$  ions from anodic and cathodic reactions, and failure of simulating true high pH conditions over CP protected surfaces. In order to better simulate the pH environment on steel surface, a novel electrochemical cell, as shown in Figure 1, has been designed by utilising an electrolyte that mimics the high resistivity of soil and an ion selective membrane that separates the electrolytes in the anodic and cathodic zones. The membrane avoids pH changes due to the mixing of solutions from the anodic and cathodic zones, while maintaining conductivity to ions in the electrochemical cell. The improved experimental method exhibited expected CP behaviour with high pH value recorded in the cathodic zones and lower pH recorded in the anodic zones. This experimental setup was further enhanced by improving uniform current distribution using multiple CP anodes. Electrolytes of 1000 ohm.cm resistivity have been selected as ‘baseline’ moderate corrosive media which are appropriate for completing accelerated corrosion tests in a relatively short period of time. The predesigned ‘baseline’ CP excursion signals are  $\pm 250$  mV sine wave superimposed on the standard CP potential of  $-850$  V<sub>CSE</sub> with 1 cycle per minute. It has been shown that this new corrosion cell is able to simulate the conductivity, pH and CP excursion conditions over a bare pipeline surface. It also enables in-situ observation of accelerated corrosion processes and patterns, and the correlation of corrosion behaviour with different forms of potential excursions over various experimental periods. Steel corrosion as a result of several selected forms of CP excursions has been categorised and quantified using this aqueous corrosion cell under simulated energy pipeline environmental and cathodic protection conditions. As shown in Figure 2, after 15 days of testing in the cell shown in Figure 1, the corrosion behaviour of these specimens indicated localised corrosion with a few pits observable on the steel coupon surface with standard CP potential of  $-850$  mV vs. CSE applied for the first 24 hours and  $\pm 250$  mV sine wave excursion from the  $-850$  mV vs. CSE with 1 cycle per minute applied on the steel specimen for the next 14 days. This behaviour is similar to that observed on practical buried pipeline surfaces under CP. Corrosion pattern and rates were found to change significantly with varying CP excursions signal amplitudes ( $\pm 250$ mV and  $\pm 500$ mV), CP potential levels ( $-850$ mV and  $-900$ mV vs CSE) and pH conditions. It is clear that localised corrosion rates are much higher than general corrosion rates. Corrosion rate results from surface profilometry analysis and from Faraday’s law calculation are similar in most cases if only general corrosion rates on general surface area are considered. Using the electrochemical setup described above, the pH of the cathodic zones was maintained at a relatively high pH value (above 9) while the anodic zones had a low pH value (around 3). Although the pH values and distributions may not fully simulate the buried pipeline CP system yet, they still produce a passive condition and corrosion behaviour similar to that observable on buried pipeline surface, ie. localised attack. This experiment also confirms the critical effects of the surface pH value on steel corrosion behaviour and needs further investigation with respect to its interplay with stray currents. More details on this new aqueous testing cell have been presented elsewhere [18].

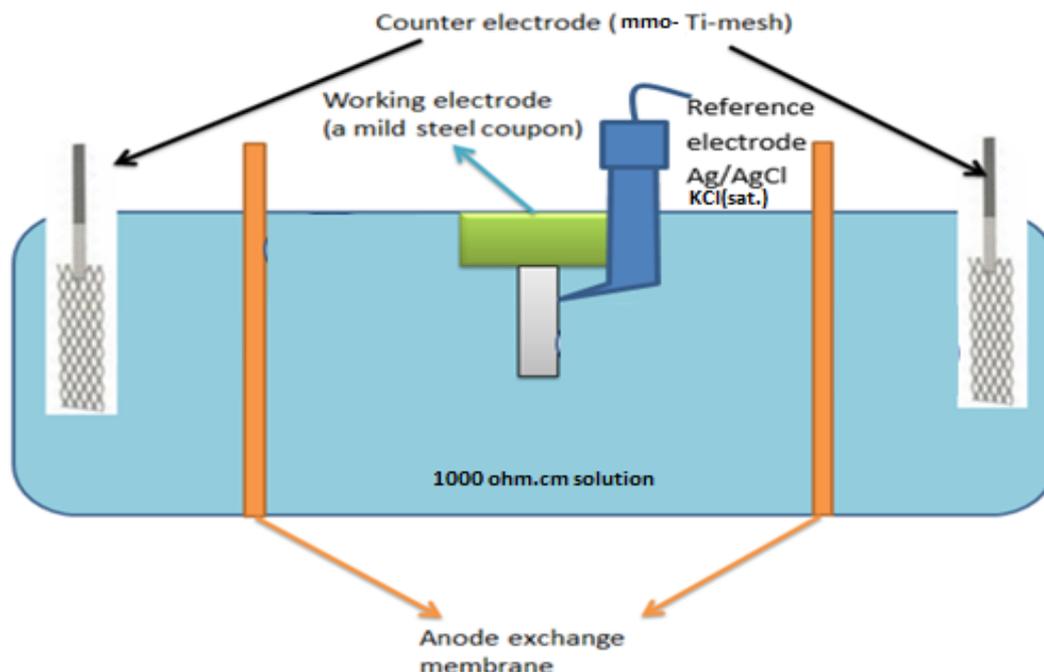


Figure 1 Novel aqueous cell for simulating and measuring soil corrosion under CP excursions.

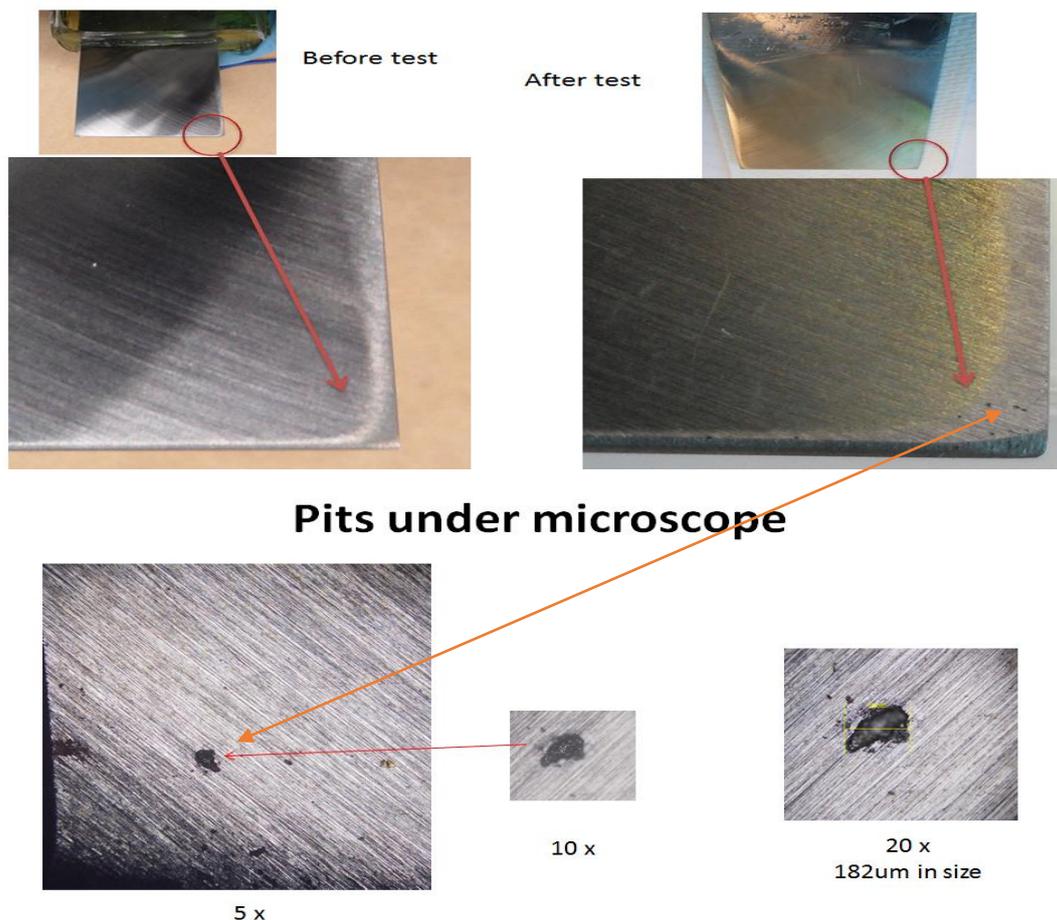


Figure 2 Localised pits observed over the coupon surface after 15 days of test. The surface was cleaned with Clark solution before microscopic observations.

Although the aqueous corrosion cell shown in Figure 1 is very useful in fundamental research of stray current corrosion, eventually it does not fully simulate soil and field conditions, especially the pH and oxygen and ions diffusion conditions. Therefore experiments have been further extended from an aqueous corrosion cell to a sand corrosion cells. Various forms of soil and clay cells have been designed in order to achieve upscale of the lab testing of pipes subjected to CP excursions in buried environmental conditions. A typical sandy soil cell experimental setup is shown in Figure 3. The medium in the soil test was 1000 ohm.cm sandy soil. The resistivity was adjusted by a 0.5mol/L NaCl solution. The whole cell was sealed to preventing evaporation during the experiment period. The testing cell parameters are the same as the aqueous cell, except that no membrane was needed in this sandy soil cell. In a typical test, a pre-designed interference signal of  $\pm 500\text{ mV}$  on CP  $-850\text{ mV}_{\text{CSE}}$  was applied to a steel specimen, after a constant CP of  $-850\text{ mV}$  vs CSE was applied to it for 24 hours. After 15 days test in the sandy soil cell, as shown in Figure 3, localised corrosion occurred on the coupon surface. Our test results suggest that pH condition over a simulated pipeline surface is critical in corrosion behaviour. Under high pH conditions, the steel coupon surfaces were passive. Although this passive film can reduce general metal dissolution, it can lead to localised corrosion when a large interference signal, e.g.  $\pm 500\text{ mV}$ , was imposed on the steel surface. This result also suggests that the aqueous corrosion cell of its current design could only mimic several features of the sandy soil cell. Therefore our current tests are carried out in both aqueous and soil cells to take advantage of both testing cells.

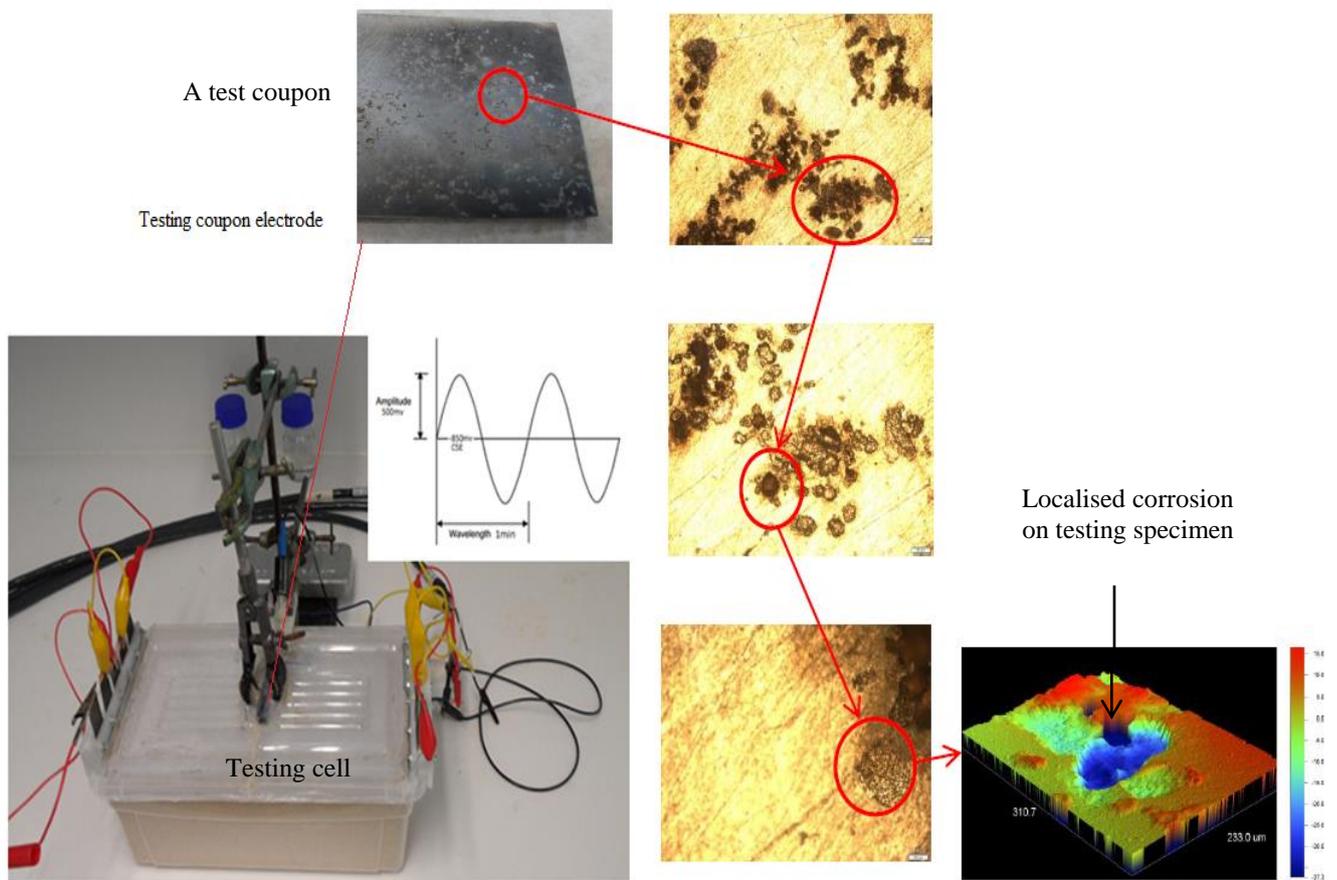


Figure 3. A new sand box electrochemical cell designed and applied to categorise and quantify the level and nature of damage as a result of various modes of CP excursions, and a coupon after 15 days test in the soil sand box electrochemical cell.

### 3. DEVELOPING ELECTROCHEMICAL METHODOLOGIES FOR TESTING AND MONITORING PIPELINE COATING DISBONDMENT AND DEGRADATION

CP excursion towards excessive negative potential could also lead to over-protection and cathodic disbondment of pipeline coatings. Cathodic disbondment is a mode of coating failure that frequently occurs in underground metal structures such as oil and gas pipelines which are protected by organic coatings in conjunction with cathodic protection. It is generally believed that cathodic disbondment of pipeline coatings is due to a strong alkaline environment at the defects in the coating that damages the bonding between coating and metal surface. Traditionally the Direct Current Voltage Gradient (DCVG) is a survey method for detecting defects in the pipeline coating. It is based on the measurement of the potential difference between two reference electrodes placed at a constant distance. It can be performed simultaneously with the Close Interval Potential Surveys (CIPS) hybrid surveys. At the coating holiday locations, due to the lack of a coating acting as a barrier the protective current density increases leading to uneven distribution of current and IR drops. A limitation of these surveys is that they cannot distinguish disbonded coatings from intact coatings. This is due to the fact that in the case of disbonded coatings, the protective current is shielded by the coating film. Developing sensors for monitoring coating degradation, disbondment and local damages is therefore desirable. One of our recent developments is coating assessment based on EIS measurements under CP in a standard three-electrode flat cell (PAR) [19]. As shown in Figure 4, the creation of a small scratch in epoxy coating caused a significant decrease in impedance value (a drop of 2-4 orders of magnitudes). These results indicate that EIS can be carried out under CP potential in highly resistive media and that EIS data could be used to detect coating damage under simulated energy pipeline CP conditions.

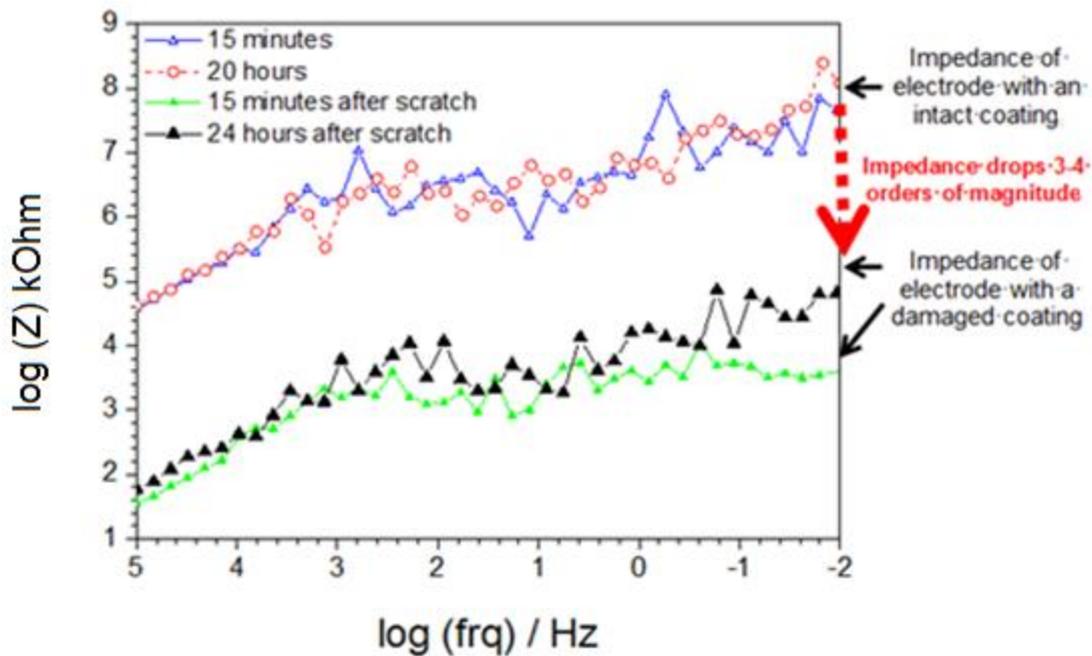


Figure 4. EIS Bode plots collected upon epoxy coated X70 steel specimens (under CP) with and without a scratch. A flat cell, incorporating an Ag/AgCl reference electrode and a titanium mesh counter electrode was used to carry out EIS measurements. Tests were performed in 0.06 wt.% NaCl solution at an applied potential of  $-1200 \text{ mV}_{\text{Ag/AgCl}}$  [19].

EIS has been used for decades for studying the degradation of organic coatings by quantitatively measuring the resistances and capacitances of coated electrodes in an electrochemical cell. For organic coatings, the capacitance measurement is considered to correlate with the water absorption or swelling of the coating, while the polarisation resistance is believed to be related to the rate of corrosion of the metallic substrate beneath the organic coating. The interpretation of experimental EIS data is usually carried out by means of an appropriate equivalent circuit, which compiles system specific elements relevant to the corrosion performance of organic coatings. Many equivalent circuits have been proposed to interpret the impedance behaviour of coated metals. A simple equivalent circuit that is most commonly used to describe a degraded organic coating on a metallic substrate is described by Mansfeld [20]. This circuit is composed of the uncompensated resistance between reference electrode and working electrode ( $R_u$ ) followed by the coating capacitance ( $C_c$ ) in parallel with the coating or pore resistance ( $R_{po}$ ), and finally double layer capacitance ( $C_{dl}$ ) and charge transfer resistance ( $R_{ct}$ ) which represent the elements of electrochemical process at the coating-metal interface.

Currently cathodic disbondment resistance of pipeline coatings is measured using standard laboratory testing such as ASTM G8. Based on this standard method, coated metal with an artificial defect is over-polarized (e.g.  $-1.5 \text{ V}$  vs Cu/CuSO<sub>4</sub> reference electrode) and kept exposed to an electrolyte for a specific duration (usually 28 days). The area of coating disbondment is estimated by visual inspection of the metal surface after mechanically lifting the coating. This method is a destructive technique and cannot be used to perform in-situ measurement of the disbondment of pipeline coatings or to predict the long-term disbondment behavior of coatings. Measuring and monitoring the initiation and growth of cathodic disbondment require *in-situ* techniques that are able to measure and monitor dynamic localised changes of parameters that are associated with the disbondment of coatings. The advent of advanced microscopic and scanning probe techniques, such as the scanning kelvin probe technique, over the past two decades has facilitated substantial research activities aimed at measuring localised coating disbondment occurring at the interface between coating and the metal surface; however these scanning probes are laboratory based techniques. They are often difficult to be applied in practical testing because they require the scanning of a corroding surface by positioning micro-sized sensors extremely close to the surface (e.g.  $100 \mu\text{m}$ ). Moreover, techniques such as scanning kelvin probe and scanning acoustic microscopy have limitations in measuring cathodic disbondment of high thickness pipeline coatings [21,22]. For instance, at typically used frequencies ( $0.1\text{-}1 \text{ GHz}$ ) the scanning acoustic microscopy can only achieve the penetration depth of hitting sound in polymer coatings of approximately  $100 \mu\text{m}$ . Therefore, the application of scanning acoustic microscopy for measuring coatings is limited to low thickness coating systems [23].

EIS method has also been used for measuring the cathodic disbondment of coatings. Kendig et al. [24] proposed a circuit specifically for a disbonded coating (see Figure 5). They believe once disbonding commences and the coating/metal

interface undergoes hydration and corrosion, cathodic disbonding would proceed from the defect. If the ohmic resistance under the film ( $R_{si}$ ) is relatively large due to a small gap defining the disbondment, then the result may be modeled by a transmission line as shown in Figure 5. Margarit et al. [25] measured EIS of steel electrodes coated with fusion bonded epoxy (500  $\mu\text{m}$ ), low density polyethylene (3000  $\mu\text{m}$ ) and coal tar (3000  $\mu\text{m}$ ) with defects of 6 mm diameter under cathodic protection potential. After exposing the sample to a cathodic potential (-0.85, -1, -1.2 and -1.5 V vs SCE) impedance measurements were performed under the same cathodic potentials. Although the authors asserted that a decrease in the impedance values during exposure time was attributable to the coating disbondment, no quantitative relationship between the delaminated area and the electrochemical parameters was established. Raghunathan [26] in a dissertation reported the results of EIS measurement for prediction of disbondment behavior of fusion bonded epoxy. Steel coated samples with 350  $\mu\text{m}$  thickness and with an artificial defect were kept under a cathodic potential of -3 V versus SCE at 65  $^{\circ}\text{C}$  for 30 days. According to this work, double layer capacitance values derived from EIS data (collected at -1.5 V versus SCE) increased with time during initial days of exposure; however, a drop or plateau behavior was observed afterwards. The in-situ measurement of the cathodic disbondment of thick coatings using EIS under cathodic protection has not been successful to date and no quantitative relationship has been identified between electrochemical parameters and coating disbondment behaviour. In this work EIS was employed to study the cathodic disbondment behavior of a 1000  $\mu\text{m}$  epoxy coating with an artificial defect under an excessive cathodic protection potential.

EIS tests were carried out under applied CP potential conditions. In a typical experiment a sinusoidal potential wave at applied CP potentials (-760 mV or -1200 mV<sub>Ag/AgCl</sub>) with an amplitude of 10 mV was applied to a coated specimen with an artificial defect. Impedance response was measured over frequencies between 10<sup>5</sup> Hz to 10<sup>-2</sup> Hz, recording 10 points per decade of frequency. The most critical step of using EIS is the extraction of useful information from EIS diagrams. An equivalent circuit such as the one shown in Figure 5 is needed to fit the non-ideal EIS plots measured from our experiments in order to extracting useful information related to coating disbondment. By carrying out EIS analysis using the complex equivalent circuit, various parameters including solution resistance ( $R_{\Omega}$ ), double layer capacitance ( $C_{dl}$ ) and polarisation resistance ( $R_p$ ) could be determined. These electrochemical parameters could be correlated to coating disbondment that can be determined based on observation of electrode surface. A typical correlation between electrochemical measurement and coating disbondment observation is shown in Figure 6. Correlation shown in Figure 6 suggests that EIS analysis could provide in-situ information on the processes of cathodic disbondment occurring at the interface of coating and steel pipeline. Therefore EIS has the potential of monitoring coating disbondment in the field. Results from this latest development will be reported elsewhere. It appears in results although the real disbonded area increased even after day 15 (Fig.4), the decrease in EIS parameters showed a plateauing behaviour from day 15 afterwards. Therefore, day 15 EIS lost its sensitivity to measure the changes in resistance values. A further progress in this research is the combined use of the EIS and the array electrode that could provide more detailed spatial and temporal information regarding coating disbondment processes.

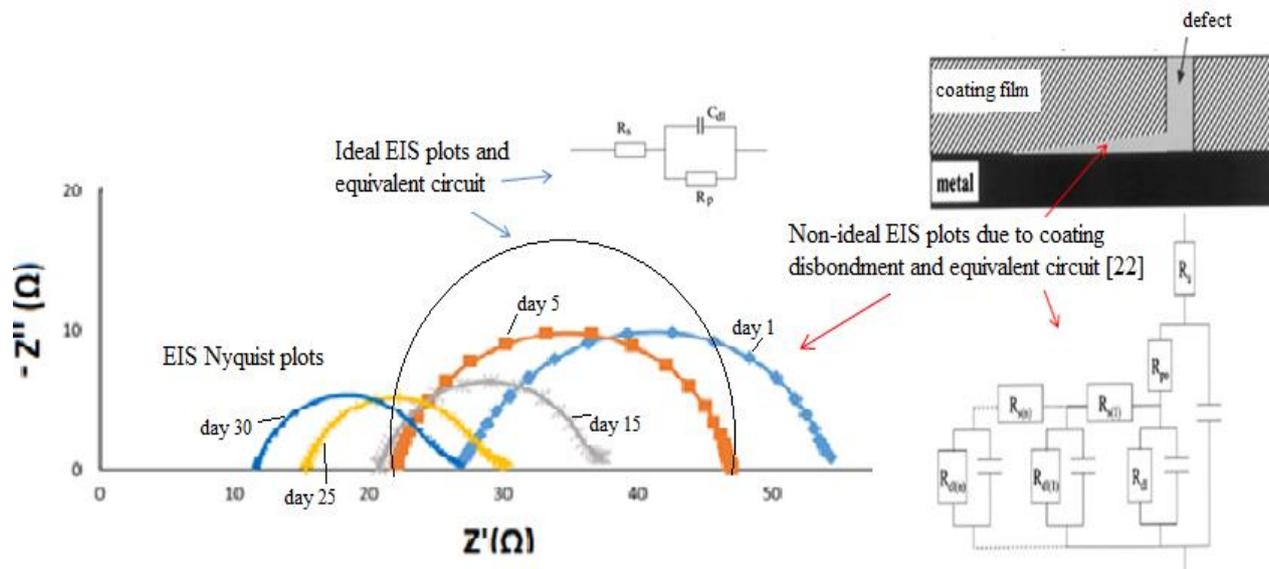


Figure 5. A complex equivalent circuit proposed to fit the ‘non-ideal’ EIS plots measured from electrode with a disbonded coating [22], and a typical set of EIS data obtained after different periods of cathodic disbondment testing using a flat cell, incorporating an Ag/AgCl reference electrode and a titanium mesh counter electrode.

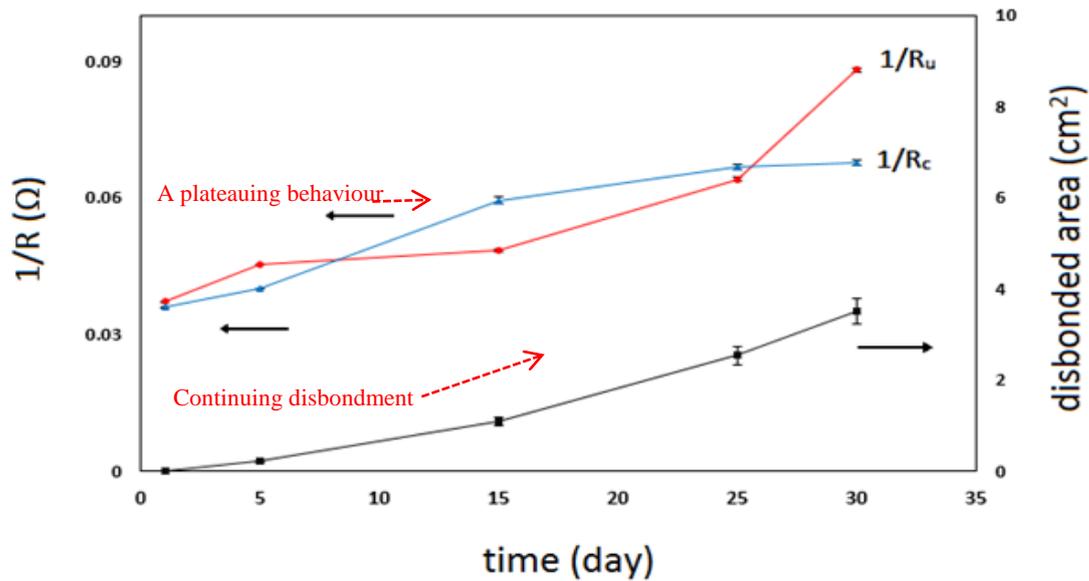


Figure 6. Correlation between charge transfer and uncompensated resistances and disbonded area against time for coated steel during 30 days exposure under  $-1.4 \text{ V}_{\text{Ag}/\text{AgCl}}$  CP potential.

#### 4. CONCLUDING REMARKS

Technological difficulty is believed to be the primary reason for the slow progress in understanding CP-excursion induced pipeline corrosion and coating disbondment. Our new approaches to quantifying the influence of electrical interference signals on CP and steel corrosion include the use of newly designed electrochemical corrosion cells. A novel electrochemical cell has been developed by employing an electrolyte that mimics the high resistivity of soil and an ion selective and conducting membrane that separates the electrolytes in the anodic and cathodic zones. Our new approaches to monitoring cathodic disbondment of coatings include the use of electrochemical impedance spectroscopy. Preliminary results have shown that this new methodology is able to simulate the conductivity, pH and CP excursion conditions expected over a bare pipeline surface. It also enables better control and reproducibility of testing conditions and parameters, and in-situ observation of corrosion processes and patterns. EIS has been proposed as a method for measuring and monitoring coating disbondment under cathodic protection. Preliminary results from this work suggest that EIS is a potential technique for in-situ measurement of cathodic disbondment of pipeline coatings, although EIS appears to lose its sensitivity with the extension of cathodic disbondment test.

#### 5. ACKNOWLEDGMENTS

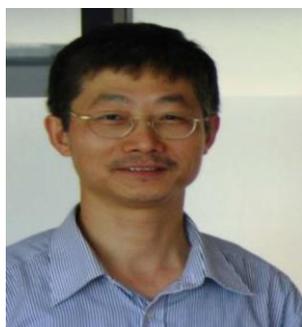
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## 7. AUTHOR DETAILS



Mike Yongjun Tan is a Professor in Applied Electrochemistry and Corrosion Technologies at Deakin University in Australia. He is also a Research Program Leader of the Energy Pipelines Cooperative Research Centre. Dr Tan's principal teaching and research interests are in corrosion science and engineering and their applications for enhancing the reliability and durability of civil and industrial infrastructures. He contributed to electrochemical methods for corrosion testing, monitoring and prediction and corrosion inhibitor and anti-corrosion coating research. He is the author of some 150 publications and a book entitled 'Heterogeneous Electrode Processes and Localized Corrosion' (2012 John Wiley & Sons).



Ying Huo is currently a PhD student at Deakin University in Australia. He graduated from Ji Lin University in China, with a Bachelor degree in Construction Management. In 2012 he attained a Master of Professional Water Engineering from Deakin University. Ying's final year experiment was entitled 'Effects of high salt concentration and residue on copper and aluminium corrosion' and the results were published as a journal article. Ying's PhD work examines the effects of electrical interference signals and the environment on the effectiveness of cathodic protection (CP). The aim of this project is to conduct a fundamental study of stray current and environmental influences on CP efficiency. The results of this study is expected to help improving the Australian pipeline industry CP standard.



Fariba Mahdavi graduated from the University of Karshan in Iran and worked on anti-corrosion coatings for 6 years before studying for a Master degree at the University Putra Malaysia. She is currently a PhD student at Deakin University in Australia. Fari's PhD research is on electrochemical research on the disbondment of protective organic coatings to avoid limitations in traditional methods of evaluating cathodic disbondment of pipeline coatings by means of advanced electrochemical methods.



Professor Maria Forsyth completed her PhD in January 1990 at Monash University and moved to Northwestern University to take up a Fulbright Fellowship in the area of solid electrolytes for lithium batteries. On her return to Melbourne she worked at DSTO for a year before joining the Department of Materials Engineering as a Lecturer in 1993. In 2001 she was awarded an ARC Professorial Fellowship and is currently the Chair in Electromaterials and Corrosion Sciences at Deakin University, within the Institute for Technology Research and Innovation (ITRI). She is co-author of over 280 refereed journal papers, has delivered over twenty invited talks in the last 5 years and has over 7000 citations at present