Influence of sodium dodecyl sulfate on passivation behavior of 304 stainless steel

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Special Project Title	Influence of sodium dodecyl sulfate on passivation behavior of 304 stainless steel
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Abstract

This special project emphasized on the influence of sodium dodecyl sulfate on the passivation behavior of 304 stainless steel in 1 N H_2SO_4 by using the potentiodynamic polarization technique. The saturated calomel electrode was used as a reference electrode. The platinum mesh was used as a counter electrode. Air was used for circulation of media. The critical micelle concentration (CMC) of SDS in 1 N H_2SO_4 is $8x10^{-4}$ mol/L. The concentration of SDS was used in range below and above the CMC.

The results from the potentiodynamic polarization curve showed that when the concentration of sodium dodecyl sulfate was increased, the corrosion rate was increased, and also the polarization resistance (R_p) was decreased. Therefore, sodium dodecyl sulfate is ineffective to inhibit the corrosion of 304 stainless steel. This can be explained in term of the difficulty of passive film formation due to the interference of SDS during anodic polarization.

Acknowledgement

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Chapter 1

Introduction

1.1 Motivation

Stainless steels are widely used in industry and agriculture because of the hardness, durability and corrosion resistance, which posses better than plain carbon steels. However, in some circumstances, stainless steel is corroded especially in acidity, which lead to deterioration of the properties of stainless steel. In industry when the corrosion occurs, it does not only damage the equipments but also affect to working efficiency, expense, and safety in the plant.

In order to overcome the corrosion problem of stainless steel, several techniques have been applied such as anodic and cathodic protection, coating layer on stainless steel, oxidizing treatment, and the application of inhibitors and inhibiting materials. The use of inhibitor is one of the useful techniques for corrosion prevention in acidic solution. Inhibitors can be separated into 4 kinds: organic inhibitors, inorganic inhibitors, surfactant inhibitors and mixed material inhibitors. The surfactant inhibitors have many advantages, for example low price, low toxic and high capacity.

This research aims to study the passivation behavior of 304 stainless steel in acidic solution with anionic surfactant. Sodium dodecyl sulfate is chosen to be a representative of anionic surfactant in this study. Sodium dodecyl sulfate is widely used as an ingredient in cleaning household production such as detergent, soap, and toothpaste. This study provides more information to understand the influence of sodium dodecyl sulfate on passivation behavior of 304 stainless steel.

1.2 Objective

The purpose of this project is study the effect of sodium dodecyl sulfate on passivation behavior of 304 stainless steel in 1 N sulfuric acid.

1.3 Scope of Study

1.3.1 Determine corrosion rate of 304 stainless steel by using electrochemical polarization technique

1.3.2 Investigate passivation behavior of 304 stainless steel in 1 N sulfuric acid solution with different sodium dodecyl sulfate concentration

Chapter 2
Literature review

2.1 Stainless steel

In Britain, stainless steel was discovered around 1913 by Harry Brearley of Sheffield. He found that steel alloyed with sufficient amount of chromium was not susceptible to attack from etching acids or moisture. This research was applied to develop gun barrels for the military powers of the day.

Figure 1: Harry Brearley [1]

In Sweden, stainless steel development was recognised by "the then-owner of Avesta Jernverk, who financed intensive research into stainless steels and purchased a licence to manufacture them from the British."[1] The first chromium alloy steel was produced in Sweden in 1924 and the first 18-8 (18% chromium, 8% nickel) austenitic grade was introduced in the next year.

Stainless steel is low carbon steel, which contains chromium at 12% or more by weight. This addition of chromium gives the unique stainless property of steel, corrosion resisting property. The chromium content of the steel enables the formation of a rough, adherent, invisible, and corrosion-resisting chromium oxide film on the steel surface. If the surface is subjected to mechanical or chemical damage, the film on surface will present self-healing.

The corrosion resistance and other useful properties are enhanced by increased chromium content and the addition of other elements such as molybdenum, nickel, and nitrogen.

The advantageous properties of stainless steels compared with standard carbon mild steel are:

- Higher corrosion resistance
- Higher cryogenic toughness
- Higher work hardening rate
- Higher strength and hardness
- Higher hot strength
- Higher ductility
- A more attractive appearance
- Lower maintenance

2.1.1 Types of Stainless steels

Stainless steels are classified by their crystalline structure into five basic categories: austenitic, ferritic, duplex, martensitic and precipitation hardening.

2.1.1.1 Austenitic stainless steels

Austenitic stainless steels are the most widely used group of stainless steel. They are generally non-magnetic which contain a minimum of 16% chromium and 6% nickel. They range from basic grades like 304 through to super austenitics such as 904L and 6% Molybdenum grades.

By adding elements such as molybdenum, titanium or copper, the properties of the steel can be modified. These modifications can make the steel suited to high temperature applications or increase corrosion resistance. Most steels become fragile at low temperatures but the nickel in austenitic stainless makes it suited to low temperature or cryogenic applications.

The principal alloying elements are sometimes revealed in the name of the steel. As common name for 304 stainless steel is 18/8, for 18% chromium and 8% nickel.

Type 304 is the most commonly specified austenitic (chromium-nickel class) stainless steel, accounting for more than half of the stainless steel produced in the world. This grade resists general corrosion in architecture, is durable in typical food processing environments, and resists most chemicals.

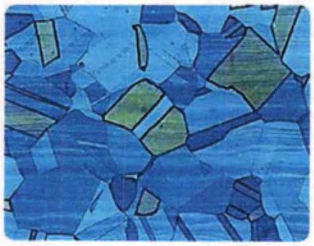


Figure 2: Stainless steel production [1]

Applications for austenitic stainless steels include:

- Kitchen sinks
- Architectural applications such as roofing and cladding
- Roofing and gutters
- Doors and Windows
- Balustrading
- Benches and food preparation areas
- Food processing equipment
- Heat exchangers
- Ovens
- Chemical tanks

The production of stainless steels

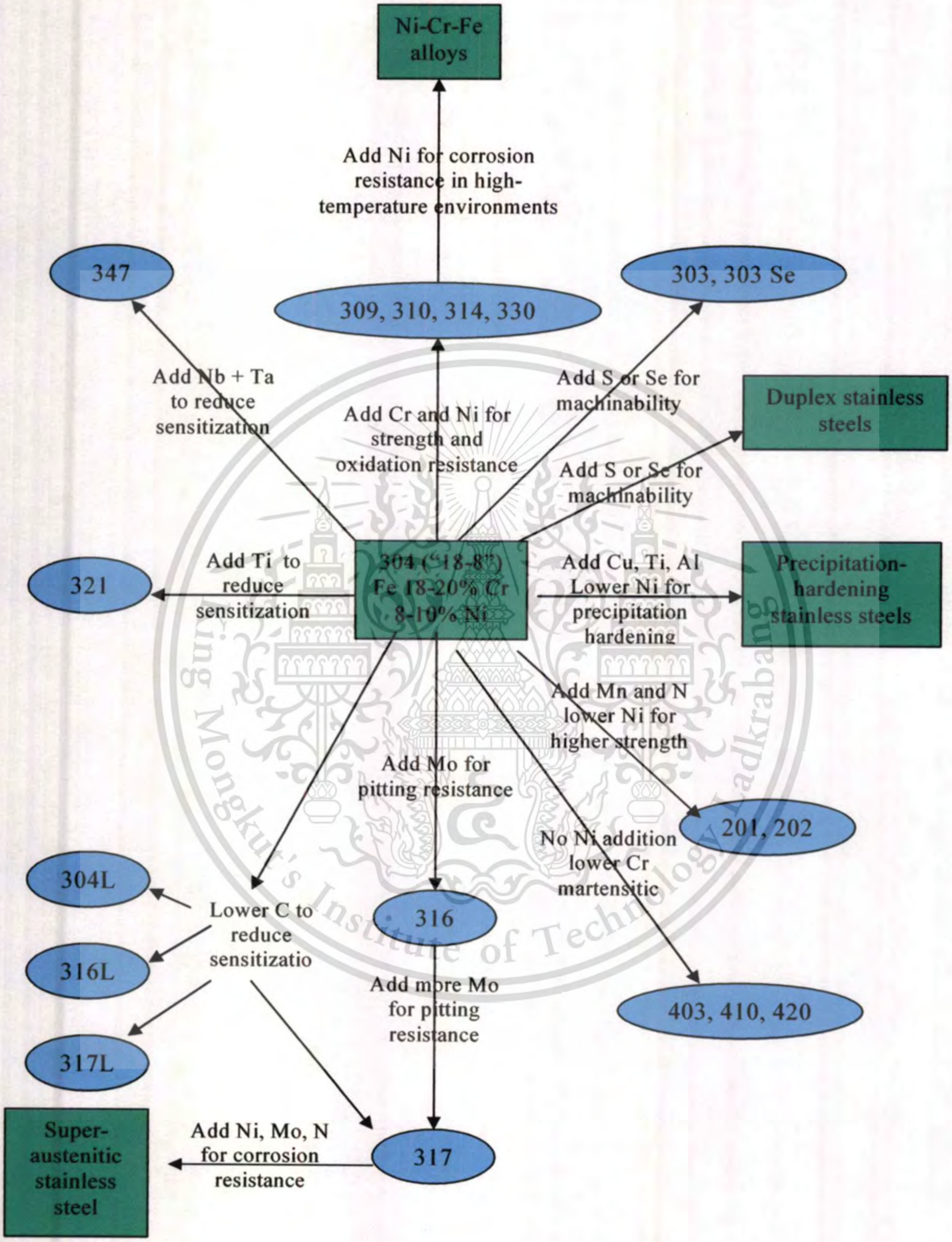


Figure 3: The image shows the microstructure of an austenitic stainless steel [4]

2.1.1.2 Ferritic stainless steels

Ferritic stainless steels include grades like 430 and contain only chromium, 10.5 to 18 percent, as a major alloying element. They are magnetic stainless steels which have moderate corrosion resistance and poor fabrication properties. They are always used in the annealed condition.

Ferritic steels have slightly higher yield strength than austenitic steels, but they have less elongation at fracture. Another characteristic that distinguishes ferritic steel from austenitic material is that ferritic steels have much lower strain hardening.

Ferritic stainless steels are typically used in:

- Vehicle exhausts
- Fuel lines
- Cooking utensils
- Architectural trim
- Domestic appliances

2.1.1.3 Duplex stainless steels

Duplex stainless steels, the two phases present in the microstructure, are intermediate in terms of structure and alloy content between ferritic and austenitic steels, a mixed ferritic/austenitic structure, chromium content varies from 18 to 28% and nickel from 4.5 to 8%.

By having both austenite and ferrite in the microstructure, duplex stainless steels feature properties of both classes. The main austenitic-ferritic steels characteristic difference from austenitic and ferritic steels is that they have a higher yield strength and tensile strength. Duplex grades are resistant to stress corrosion cracking, but not to the same level as ferritic grades. The toughness of duplex grades is superior to that of the ferritic grades but inferior to that of the austenitic grades.

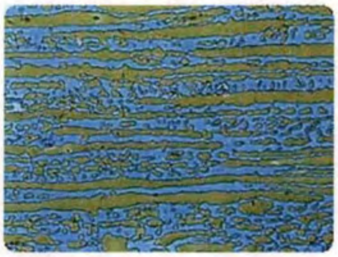


Figure 4: The microstructure shows an image of a duplex stainless steel [1]

Duplex stainless steels typically find application in areas like:

- Heat exchangers
- Marine applications
- Desalination plants
- Food pickling plants
- Off-shore oil & gas installations
- Chemical & petrochemical plant

2.1.1.4 Martensitic stainless steels

Martensitic steels are magnetic which have high carbon and lower chromium content, containing typically 12-18 % chromium, are the distinguishing features of martensitic stainless steels when compared with ferritic stainless. They are hardenable by quenching and tempering. They have the highest strength but also the lowest corrosion resistance of the stainless steels.

Figure 5: Microstructure image of a martensitic stainless steel [1]

Martensitic stainless steels are typically used for:

- Knife blades
- Cutlery
- Surgical instruments
- Fasteners
- Shafts
- Springs

2.1.1.5 Precipitation hardening steels

Precipitation hardening grades contain both chromium and nickel. They develop very high tensile strengths with heat treatment. 630 is the most common precipitation hardening grade which comprises of 17% chromium, 4% nickel, 4% copper and 0.3% niobium.

Precipitation hardening stainless steels are typically used for:

- Pulp and paper industry equipment
- Aerospace applications
- Turbine blades
- Nuclear waste casks
- Mechanical components

2.2 Corrosion

Corrosion is the form change or deterioration of a metal, which effect from the reaction with its environment [5-12].

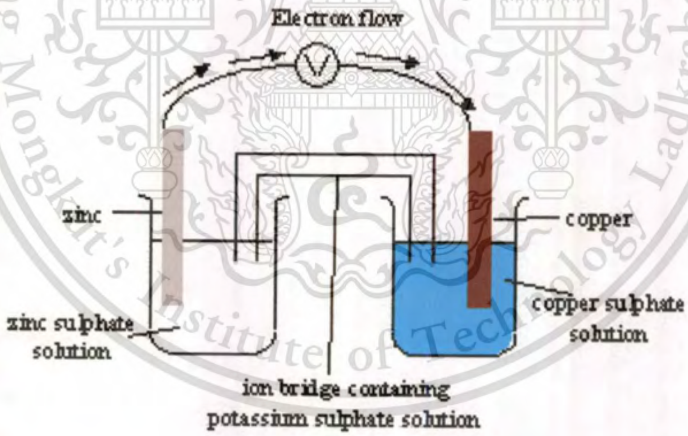


Figure 6: Diagram electrochemical cell of standard zinc and copper half-cell [13]

According to Figure 6, two types of metal in the presence of an electrolyte and an electron conductive path, surface of zinc dissociates to zinc ion and dissolves into solution. On the other side, surface of copper is deposited by copper ion in the solution.

2.2.1 Thermodynamics

Thermodynamics gives the energy changes involved in the electrochemical reactions of corrosion. These energy changes provide the driving force and control the spontaneous direction for a chemical reaction. In consequently, thermodynamics shows how conditions may be adjusted to make corrosion impossible. When corrosion is possible, thermodynamics cannot predict the rate; corrosion may range from fast to very slow. The actual extent or rate of corrosion is governed by kinetic laws.

2.2.1.1 Free Energy [9]

The change in free energy ΔG is a direct measurement of the work capacity or maximum electric energy available from a system. If the change in free energy accompanying the transition of system from one state to another is negative, it indicates a loss in free energy and the spontaneous reaction direction of the system. If the change of free energy is positive, it indicates that the transition represents an increase in energy, and requires that additional energy be added to the system.

The free energy change can be calculated by the following equation:

$$\Delta G = -nFE$$

where: ΔG is the free energy change

n is the number of electrons involved in reaction

F is the Faraday constant

E is equal the cell potential

2.2.1.2 Electrode Potential [14]

From Figure 6, the electric cell is consist of two differ type of electrode are dip into the electrolyte solution. Normally can write in this form

$$Zn/Zn^{2+} // Cu^{2+}/Cu$$

The contact between electrode and electrolyte solution is used / to separate and the contact between solution and solution is used //. In this case M/M^{n+} is called "half-cells." The electrode potential between electrode and electrolyte solution is called "half-cells potential." The electrode potential of electric cell is equal to the summation of each electrode potential and can calculate the any potential electrode that construct from the electrode.

The reaction of half-cells

$$Ox + ne^{-} \rightarrow Red$$

The general form of electrode potential equation is

$$E = E^{0} + (RT/nF)(\ln[Ox][Red])$$

Where R = gas constant (8.314 J/mol·K)

T = Temperature (K)

F = Faraday's constant (96,500 C/mol)

n = number of ion

[Ox] = concentration of oxidation

[Red] = concentration of reduction

E^0 = standard electrode potential

Whenever, the concentration of oxidizing and reducing agent is low. The value of [Ox] and [Red] can be used the normal chemical concentration but if the concentration is high, the reaction is go backward between ion, so the real concentration and chemical concentration is very different. In this case can use activity, which is the concentration after improve, substitute this value into [Ox] and [Red]. The value of activity (a) is the product between concentration and activity coefficient, that is improved or a = mr where a is depend on concentration and temperature.

When the metal are immerse into the electrolyte solution, the electrode potential of half-cell from equation above and assume the activity of electron of solid is equal 1. Then we get

$$M^{n+} + ne^{-} \rightarrow M$$

$$E = E^{0} + (RT/nF) \ln ([M^{n+}]/[M])$$

$$E = E^{0} + (RT/nF) \ln a$$

substitute the value of R and F

$$E = E^{0} + (0.0592/n) \log a$$

The last equation is called "Nernst equation." This equation shows the change of electrode potential of metal when the activity is change. E^0 is the electrode potential when activity is equal 1 and call "standard electrode potential"

The measurement of electrode potential can measure by using one electrode as the standard electrode potential and using this value to compare with some kind of electrode. The standard value is used platinum electrode is saturated with hydrogen gas at pressure 1 atm and dip into the electrode that activity of ion of hydrogen gas is equal 1. This electrode is called "standard hydrogen electrode or SHE." The value of this electrode potential is assumed to equal zero at every temperature level and call "standard electrode potential of hydrogen" that show in the table 1. The electrode potential is above the SHE is positive and the electrode potential below the SHE is negative.

2.2.2 Kinetics

Corrosion is thermodynamically possible for most environment conditions. Thus, it is of primary importance to know how fast corrosion occurs. Chemical kinetics is a study of the rates of such reactions. Corrosion in aqueous systems is governed primarily by electrochemical reactions.

Faraday's Law [5]

Electrochemical reactions either give or receive electrons. Therefore, the rate of electron flow from the reaction is the reaction rate measurement. Electron flow is conveniently measured as current, I, in amperes, where 1-ampere is equal to 1-coulomb of charge (6.2×10^{18} electrons) per second. The proportionality between I and mass loss, m, It is followed to Faraday's Law

$$m = Ita/nF \qquad (1)$$

where *m* is mass loss (g), *F* is *Faraday's* constant (96,500 coulombs/equivalent), *I* is current (A), *n* the number of equivalents exchanged, *a* the atomic weight (g), and *t* the time.

Mostly the measurement of corrosion rate by using the electrochemical method is measured in form of the current. So, from the equation above when calculated in form of time per area the result is corrosion rate (r)

$$r = m/tA = ia/nF \qquad (2)$$

where *i*, defined as current density = I/A (uA/cm^2)

This equation shows proportionality between mass loss per unit area per unit time ($mg/dm^2/day$). The destructive of metal is indicated the violent of corrosion by observe from the corrosion rate. Normally, the corrosion rate is measure in unit of mils per year, mpy

$$mpy = 534W/DAT \qquad (3)$$

where W is weight loss (mg)

D is density of metal sample (g/cm^3)

A is surface area of sample ($inch^2$)

T is test time (Hr)

2.2.3 Polarization [15]

At begin of corrosion, it is proceed for a period of time with constant velocity and electron is continually produce and come around the metal surface and give the potential at this position is more negative. Therefore, the joint between metal and solution is exceed electron for the reduction at cathode due to the reaction is not fast enough to receive the exceed electron. This situation may case to reduce the corrosion call "cathodic polarization" and the potential at this joint is more negative. In the other hand, the electron from the corrosion of metal is not enough to give to the joint between metal surface and solution and effect to the potential at the joint is more positive call "anodic polarization." In this case accelerates the corrosion of the metal to produce more electrons. In consequently, polarization is the change of corrosion rate owing to the donation and acceptance of electron are not related. The potential at the metal surface contact with solution is more positive and tendency to easy and rapidly to corrosion.

So, cathodic polarization is the alteration of reaction rate is controlled the rate of reduction at cathode. And anodic polarization is the change of reaction is controlled the oxidation reaction rate at anode.

Polarization is classified into 2 types:

1. *Activation polarization* [5] refers to an electrochemical process that is controlled by the reaction sequence at the metal-electrolyte interface. This is easily illustrated by considering hydrogen-evolution reaction on zinc during corrosion in acid solution. These steps can also be applied to the reduction of any species on a metal surface. The species must first be adsorbed or attached to the surface before the reaction can proceed. Following this, electron transfer must occur, resulting in a reduction of the species. The speed of reduction of the hydrogen ions will be controlled by the slowest numerous mechanisms have been proposed.

2. *Concentration Polarization* [5] refers to electrochemical reactions that are controlled by the diffusion in the electrolyte. Activation polarization usually is the controlling factor during corrosion in media containing a high concentration of active species. Concentration polarization generally predominates when the concentration of the reducible species is small. In most instances concentration polarization during metal dissolution is usually small and can be neglected; it is only important during reduction reactions.

Normally, concentration polarization and activation polarization is occurred in the same time.

The corrosion behavior of metal can predict from the polarization curve. Some type of metal is immersed in electrolyte solution. Wait for a while, the electrode potential of metal surface contact with the electrolyte solution is convergent to some value call "corrosion potential" or E_{corr}. This value is depending on the ability and velocity of electron exchange of both reactions. Commonly, if the electrode potential at the joint is more than E_{corr}, the corrosion rate or the velocity rate of reaction to give electron is increasing. Therefore, the metal has lower electrode potential is easy to corrode.

2.2.4 Forms of corrosion [5,10]

There are many types of corrosion that can affect metals. There are some basis forms of corrosion list follow:

2.2.4.1 Uniform Corrosion

This form of corrosion is normal form of corrosion. Metal is corroded regularly overall surface of it and the thickness of metal is slowly decrease. Uniform corrosion is the most destructive of metal surface. Then, the retention time of metal is shorter.

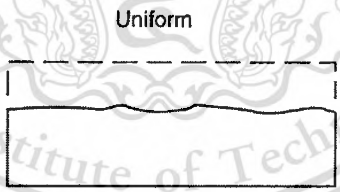


Figure 7: Schematic of uniform corrosion [5]

2.2.4.2 Galvanic Corrosion

This corrosion is an electrochemical action of two different metals. It occurs when dissimilar metals are in contact and immerse in the same electrolyte, then the metal, which has lower electrode potential is easy to corrode. Table 1 is the standard electromotive force, EMF. It shows electrode potential of each kind of metal and used to indicate the difficulty of corrosion mechanism.

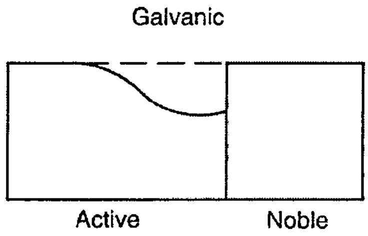


Figure 8: Schematic of galvanic corrosion [5]

2.2.4.3 Crevice Corrosion

Crevice corrosion is occurred in compact area on the metal surface directly contact with corrosion substance. This form of corrosion relate to the amount of solution left in the nook, recess or narrow area, that solution can shut up for along time and don't transfer. So, the concentration of oxygen in water or solution between inside and outside of the narrow area is not equal and it is complete cell of concentration cell of corrosion. The anode is the narrow area, which the metal surfaces are destroyed.

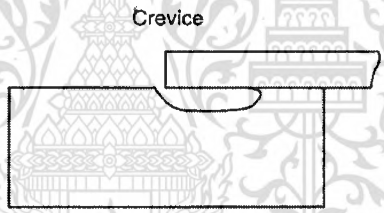


Figure 9: Schematic of crevice corrosion [5]

2.2.4.4 Environmentally Induced Cracking

Brittle fracture of a normally ductile alloy in the presence of an environment that causes minimal uniform corrosion is defined as environmentally induced cracking (EIC).

Table 1 Standard Reduction Potentials [16]

Standard Reduction Potentials at 25°C

Stronger oxidizing agent ↑ / Weaker reducing agent ↓

Reduction Half-Reaction		E° (V)
$F_2(g) + 2e^-$	$\longrightarrow 2F^-(aq)$	2.87
$H_2O_2(aq) + 2H^+(aq) + 2e^-$	$\longrightarrow 2H_2O(l)$	1.78
$MnO_4^-(aq) + 8H^+(aq) + 5e^-$	$\longrightarrow Mn^{2+}(aq) + 4H_2O(l)$	1.51
$Cl_2(g) + 2e^-$	$\longrightarrow 2Cl^-(aq)$	1.36
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^-$	$\longrightarrow 2Cr^{3+}(aq) + 7H_2O(l)$	1.33
$O_2(g) + 4H^+(aq) + 4e^-$	$\longrightarrow 2H_2O(l)$	1.23
$Br_2(l) + 2e^-$	$\longrightarrow 2Br^-(aq)$	1.09
$Ag^+(aq) + e^-$	$\longrightarrow Ag(s)$	0.80
$Fe^{3+}(aq) + e^-$	$\longrightarrow Fe^{2+}(aq)$	0.77
$O_2(g) + 2H^+(aq) + 2e^-$	$\longrightarrow H_2O_2(aq)$	0.70
$I_2(s) + 2e^-$	$\longrightarrow 2I^-(aq)$	0.54
$O_2(g) + 2H_2O(l) + 4e^-$	$\longrightarrow 4OH^-(aq)$	0.40
$Cu^{2+}(aq) + 2e^-$	$\longrightarrow Cu(s)$	0.34
$Sn^{4+}(aq) + 2e^-$	$\longrightarrow Sn^{2+}(aq)$	0.15
$2H^+(aq) + 2e^-$	$\longrightarrow H_2(g)$	0
$Pb^{2+}(aq) + 2e^-$	$\longrightarrow Pb(s)$	−0.13
$Ni^{2+}(aq) + 2e^-$	$\longrightarrow Ni(s)$	−0.26
$Cd^{2+}(aq) + 2e^-$	$\longrightarrow Cd(s)$	−0.40
$Fe^{2+}(aq) + 2e^-$	$\longrightarrow Fe(s)$	−0.45
$Zn^{2+}(aq) + 2e^-$	$\longrightarrow Zn(s)$	−0.76
$2H_2O(l) + 2e^-$	$\longrightarrow H_2(g) + 2OH^-(aq)$	−0.83
$Al^{3+}(aq) + 3e^-$	$\longrightarrow Al(s)$	−1.66
$Mg^{2+}(aq) + 2e^-$	$\longrightarrow Mg(s)$	−2.37
$Na^+(aq) + e^-$	$\longrightarrow Na(s)$	−2.71
$Li^+(aq) + e^-$	$\longrightarrow Li(s)$	−3.04

Weaker oxidizing agent / Stronger reducing agent

Three related but distinct types of failure are included in EIC:

2.2.4.4.1 Stress Corrosion Cracking (SCC)

Stress corrosion cracking occurs when material is received more tensile and compressive stress from specific environmental conditions. The appearance of this corrosion is the fracture and rift of the metal surface.

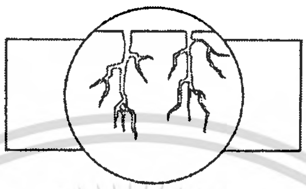


Figure 10: Schematic of stress corrosion cracking [5]

2.2.4.4.2 Corrosion Fatigue Cracking (CFC)

In this case the specimen is always done by tensile and compressive stress from the environment until the metal fracture.

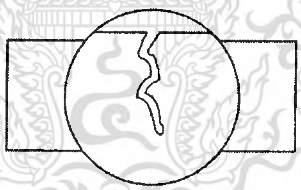


Figure 11: Schematic of corrosion fatigue cracking [5]

2.2.4.4.3 Hydrogen-Induced Cracking (HIC)

Hydrogen induced cracking is caused by the diffusion of hydrogen. The corrosion appearance is the same as stress corrosion.

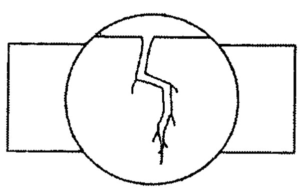


Figure 12: Schematic of hydrogen-induced cracking [5]

2.2.4.5 Hydrogen Damage

Hydrogen damage is occurred from metal adsorb the hydrogen atom from the dissociation of solution. From this type of corrosion is made the metal loss the flexible, so the metal is brittle, swell and break.

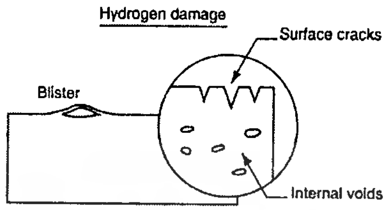


Figure 13: Schematic of hydrogen damage [5]

2.2.4.6 Intergranular Corrosion

The intergranular corrosion is corroded the grain of sample because of lose some element at the edge to resist the corrosion. Stainless steel is one example, which usually occur this form of corrosion.

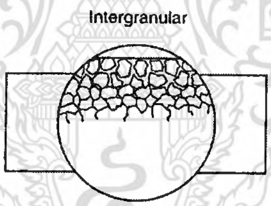


Figure 14: Schematic of intergranular corrosion [5]

2.2.4.7 Dealloying and Dezincification

Dealloying and dezincification is the corrosion of the mixed metal is consisted of more than two type of metal. The metal has lower potential is corroded, for example brass (copper + zinc) which run out of zinc and left only copper, so the color of brass is become red.

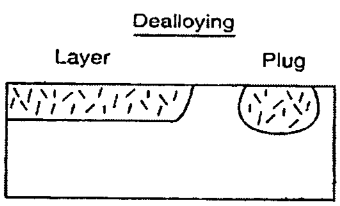


Figure 15: Schematic of dealloying [5]

2.2.4.8 Erosion - Corrosion and Fretting

Erosion corrosion is occurred from the velocity of corrosion substance, which is strike the surface of the sample. Then, the corrosion is immediately occured.

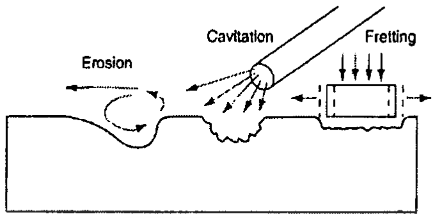


Figure 16: Schematic of erosion-corrosion and fretting [5]

2.2.4.9 Pitting Corrosion

Localized attack in an otherwise resistant surface produced pitting corrosion. The pits may be deep, shallow, or undercut. The stainless steels and nickel alloys with chromium depend on a passive film for corrosion resistance and are especially susceptible to pitting by local breakdown of the film at isolated sites.

Pitting shares the same mechanism with crevice corrosion in stainless steels. The pit is a self-serving crevice that restricts transport between the bulk solution and the acid choloride pit anode.

Pitting is unpredictable, especially in conditions forming deep pits. The rate is variable, depending on uncertain migration of corrodents into and out of the pit. Pits may be initiated by a number of surface discontinuities, including sulfide inclusions, insufficient inhibitor coverage, holidays or scratches in coatings, and deposits of slag, scale, dust, mud, or sand.

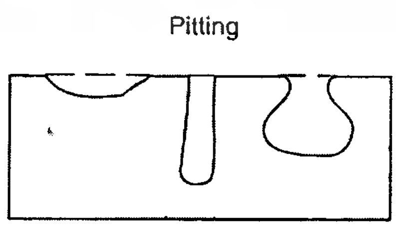


Figure 17: Schematic of pitting corrosion [5]

2.2.4.9.1 Pitting Mechanisms [17]

Pitting can be separated into two different regions, namely *pit initiation* and *pit growth*. The growth mechanism is reasonably well understood, while initiation mechanism is not very clear.

1.) Pit Growth

From a mechanistic point of view, the growth of a pit can be regarded as similar to the corrosion process in a crevice. The exposed surface outside the growing pit is cathodically protected by supporting the reduction of oxygen to hydroxyl ion reaction:

$$O_2 + 2H_2O + 4e^- \rightarrow 4(OH^-)$$

As this cathodically protects the region outside the pit, the metal dissolution region cannot spread laterally across the surface. In addition the large cathodic surface can maintain this reaction and form a large cathode to small anode ratio, which will accelerate the anodic reaction.

Within the pit, which is regarded as a small hemisphere at this stage, the metal dissolution reaction is taking place. This is the general anodic reaction of:

$$M \rightarrow M^{s+} + ze^-$$

However, it is the only reaction within the pit and results in an electrical imbalance again which attracts negatively charge ions, usually chloride ions. The *autocatalytic reaction* to form hydrochloric acid in the pit is initiated and continues:

$$M^{s+}Cl^-_z + zH_2O \rightarrow M(OH)_s + z(H^+Cl^-)$$

Pitting, like crevice corrosion, is an autocatalytic reaction once it is started and the pH decreases while chloride ion concentration increases inside the pit.

2.) Pit Initiation

Pit initiation is not well understood. Pit initiation time can very from very short - days - to very long times- many years. Small changes in conditions can make the difference in whether pits occur or not. There are many mechanisms of pit initiation. These will be reviewed in the following section. At this time it would appear that no one general mechanism is available. The initiation mechanism could be metal specific and history dependent in some cases. In other situations a general type of pit initiation mechanism may be invoked. Most mechanisms involve a breakdown of the passive layer on a metal. The passive layer is thought to be a complicated layer on the surface of a metal. It is a layer, which is 30 to 100 Angstroms thick. As an atom is only about 2 Angstroms in diameter, then a passive layer is only about 15 - 50 atom thick. Experimentally this is very difficult to examine, especially in pitting investigations when the experimentalist does not know which site is going to pit. The passive layer is thought to be a two phases type of structure with the side nearest the metal a crystalline phase while the layer nearest the solution side is thought to be an amorphous mixture of metal ions and hydroxyl ions.

2.2.5 Potentiostat

A potentiostat is an electronic device that controls the potential differences between a working electrode and a reference electrode in a given eletrochemical cell. The voltage change of a working electrode induces electron transfer reaction between solution and the surface of electrode. This electron activity becomes current, which is detected by a voltmeter.

A simple potentiostat consists of two types of circuits: voltage control and current measurement. They connect together with an electrochemical cell that has three electrodes. They are working electrode, reference electrode and auxiliary electrode.

2.3.2.1 Working Electrode

The Working Electrode is a electrode where the control potential is applied and where the current is measured. A sample of the corroding metal is used in the corrosion testing.

2.3.2.2 Reference Electrode

The reference electrode should be a constant electrochemical potential and has no current flows through. It is used in measuring the working electrode potential. The most common reference electrodes are the Saturated Calomel Electrode (SCE) and the Silver/Silver Chloride (Ag/AgCl) electrodes.

2.3.2.3 Auxiliary (Counter) Electrode

The Auxiliary electrode in lab is generally an inert conductor like platinum or graphite to complete the cell circuit. The current flow into the solution via the working electrode leaves the solution via the auxiliary electrode.

Instrument characteristics:

- Both positive and negative potential can be applied in a form of DC ramp.
- Adjustable scan rate
- Adjustable magnify rate of measured current signal
- Analysable many electrochemical techniques

2.3 Surfactants

Surfactants are usually organic compounds that contain both hydrophobic groups (their "tails") and hydrophilic groups (their "heads"). Many surfactants can also assemble in the bulk solution into aggregates that are known as micelles. The concentration at which surfactants begin to form micelles is known as the critical micelle concentration or CMC.

Surfactants are produced from mainly three categories of raw materials:

- Minerals (sodium chloride, limestone, sulphur, oxygen, nitrogen),
- Fossil resources (crude oil, natural gas, coal) and
- Biomass-derived materials (vegetable oils, tallow, corn).

The most important vegetable oils used in surfactant production are palm oil, palm kernel oil and coconut oil.

As represented in Figure18, the production of LAS and SAS are mainly based on fossil feedstocks. In the case of AS, AES and AE are either derived from fossil raw materials (crude oil and natural gas) or oleochemical feedstocks. Soap can be uniquely derived from vegetable oils and tallow. The raw material of APG is small amount of natural gas or starch.

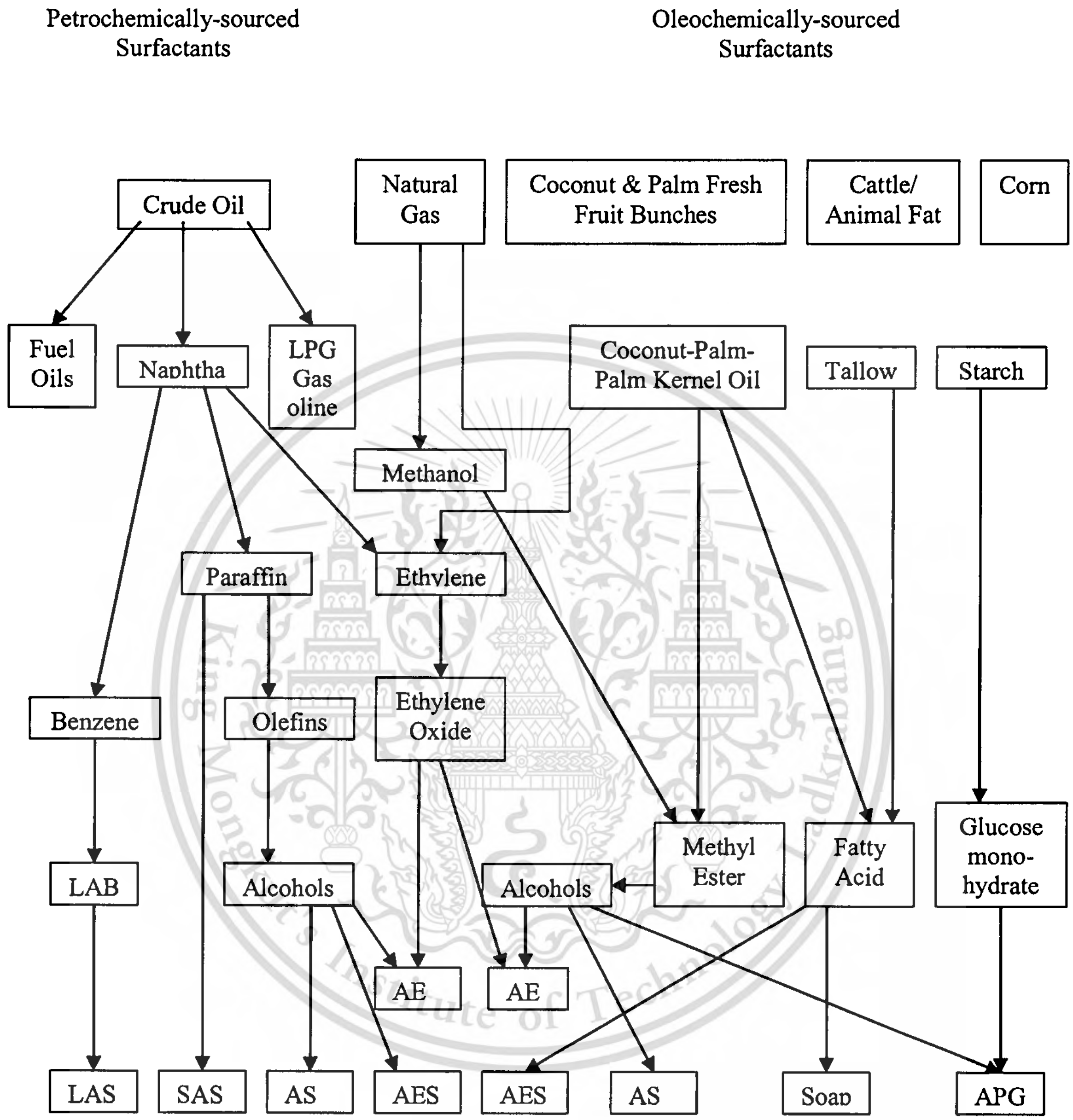


Figure 18: The production of surfactants [25]

AE: Alcohol ethoxylates; AES: Alcohol ethoxy sulphates; APG: Alkyl polyglucosides; AS: Alcohol sulphates; LAS: Linear alkylbenzene sulphonates; LAB: Linear alkylbenzene; LPG: Liquefied petroleum gas; SAS: Secondary alkane sulphonate.

2.3.1 Classification of surfactants

Generally, Surfactants are characterized by their hydrophilic charged group into the following categories :

1. Anionic Surfactants
2. Cationic Surfactants
3. Nonionic Surfactants
4. Amphoteric Surfactants

2.3.1.1 Anionic Surfactants

The hydrophilic portion of anionic surfactants carries a negative charge, in water. The majority are alkyl sulfates, It best for soil suspension The examples of anionic surfactants are a sodium dodecyl sulfate, a sodium alkylbenzenesulfonate, a sodium alkylsulfate and other alkyl sulfate salts

Sodium dodecyl sulfate

Sodium dodecyl sulfate, SDS, is one of the most common surfactants. It can also be called sodium lauryl sulfate, depending on whether it is made from petrochemicals (dodecyl) or plants (lauryl). But they're the same molecule. The molecule has a tail of 12 carbon atoms, attached to a sulfate group, giving the amphiphilic molecule properties required of a detergent.

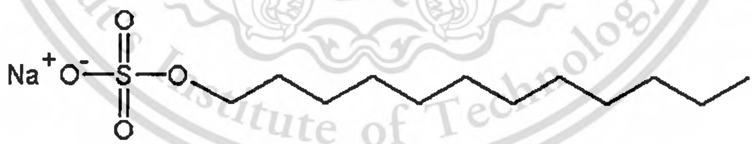


Figure 19: Sodium dodecyl sulfate[24]

Sodium dodecyl sulfate can be used in both industrially produced and home-made cosmetics below:

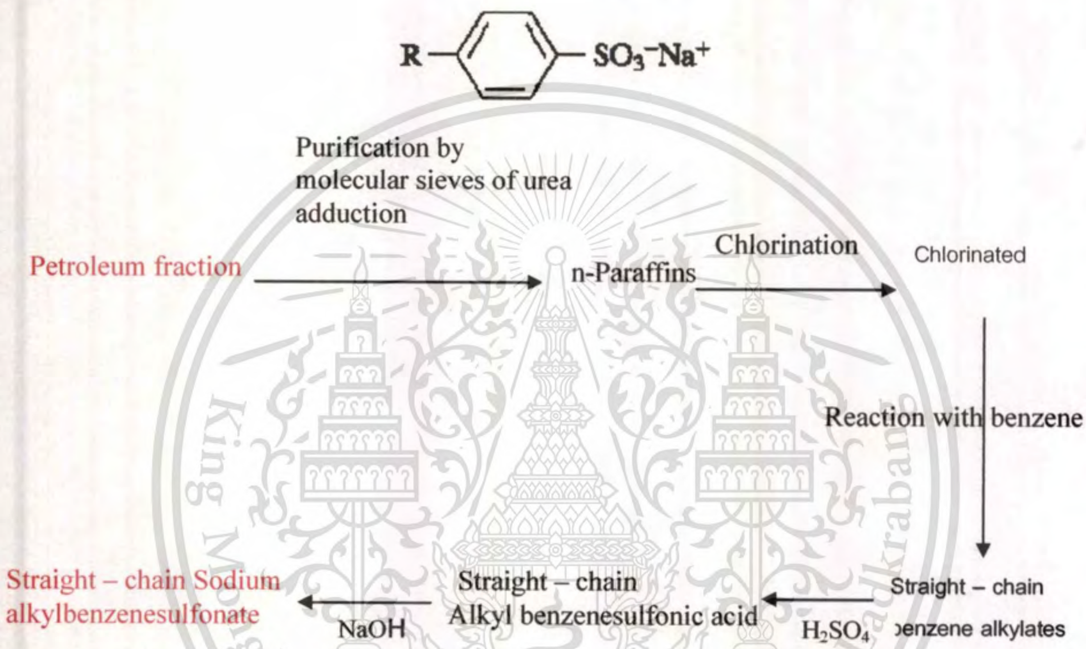
- household product such as toothpastes, shampoos, shaving foam and bubble baths for its thickening effect and its ability to create a lather.
- preparing proteins for polyacrylamide gel electrophoresis, in laboratories

2.3.1.1.1 Anionic production

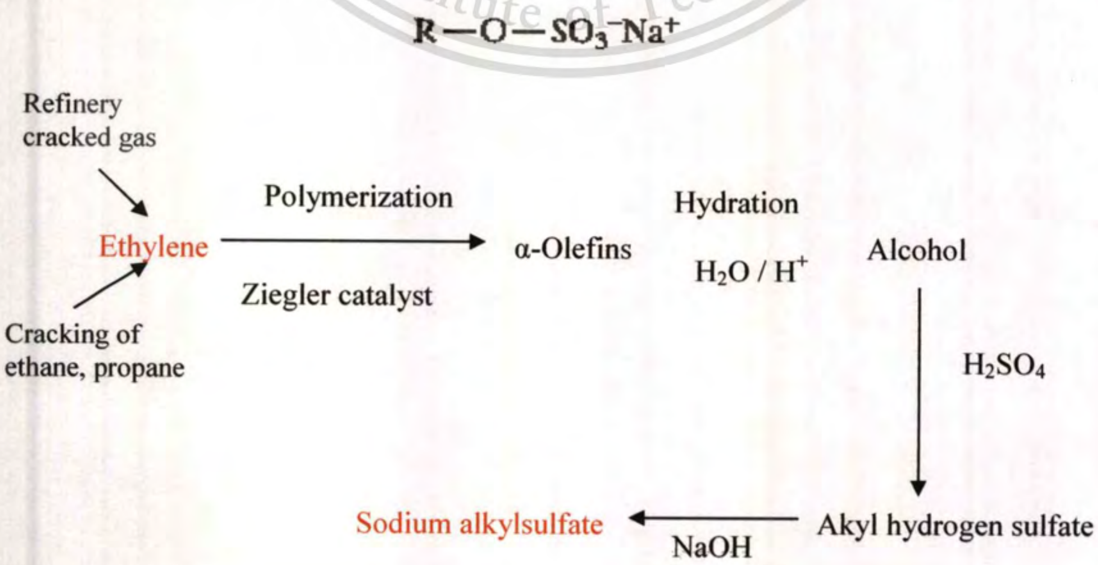
1.) Synthetic Sodium dodecyl sulfate

Sodium dodecyl sulfate is prepared by sulphation, the treatment of an alcohol or phenol with a sulfating agent, of lauryl alcohol (1-dodecanol, dodecyl alcohol, $CH_3(CH_2)_{10}CH_2OH$) to give an alcohol sulfate followed by neutralisation with sodium carbonate.

2.) Synthetic Sodium alkylbenzenesulfonate



3.) Synthetic Sodium alkylsulfonate



2.3.1.1.2 Application of Anionic Surfactants

Anionic surfactants are used all over the place. They are used in shampoos, in dishwashing detergents and in washing powders. In many industrial and commercial applications, anionic surfactants are no longer used on their own. Typically, they are used in conjunction with nonionic surfactants to provide even greater stability.

2.3.1.2 Cationic Surfactants

Cationic Surfactants carry a positive charge in water and do not react with positively charged water hardness ions. Most of these surfactants are derivatives of ammonia: fatty amine salts (or ammonium salts) were developed as the first cationic surfactants. The examples of cationic surfactants are a trimethylhexadecylammonium chloride, an alkyl pyridinium chloride etc.

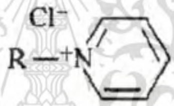


Figure 20: an alkyl pyridinium chloride

Application of Cationic Surfactants

Cationic surfactants are typically used in things like hair-conditioner or clothes rinse. They have good qualities for stabilizing dye and giving a soft feel to wool and silk. Furthermore, they are useful in blends with nonionic surfactants, giving good stability over a range of pH levels. Cationic surfactants are generally more irritating to the skin than nonionic surfactants.

2.3.1.3 Nonionic Surfactants

Nonionic surfactants do not ionize in solution. Lack of charge enables them to avoid water hardness deactivation. The surfactant molecules must have some polar parts to provide the necessary water solubility, the polar part of the molecule consists of three alcohol groups and an ester group. The non-polar part is the usual long hydrocarbon chain. The examples of nonionic surfactants are an alkyl polyethoxylate, an alkyl polyglucosides etc.

$$R\text{-}(CH_2\text{-}CH_2\text{-}O\text{-})_nH$$

Figure 21: an alkyl polyethoxylate

Application of Nonionic Surfactants

Nonionic surfactants are especially good for removing oily dirts by solubilization and emulsification. They are frequently used in some low sudsing detergent powders and in general purpose liquid detergents, typically used in laundry and automatic dishwasher detergent and rinse aids, In addition, nonionic detergents foam less than ionic detergents. Nonionics may be mixed with anionics in some powder or liquid detergents.

2.3.1.4 Amphoteric surfactants

Amphoteric surfactants comprise a long hydrocarbon chain attached to a hydrophile containing both positive and negative charges, which give it the properties of a zwitterion, that are an acid and a base at the same time (like water is). Their structure is complicated. The simplest amphoterics can behave as a cation or anion depending on pH. The surface activity varies widely and depends on the distance between the charged groups. The examples of amphoteric surfactants are Dodecyl betaine, Dodecyl dimethylamine oxide, Cocamidopropyl betaine etc.

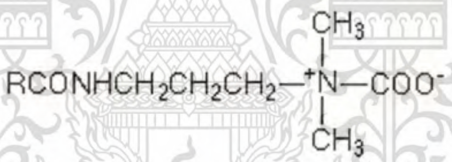


Figure 22: Cocamidopropyl betaine [24]

Application of Amphoteric Surfactants

Amphoteric surfactants are widely used in shampoos, a cocamidopropyl betaine is an example, to stabilize foam and thicken the mixture. Also they are used in personal cleansing and household cleaning products for their mildness.

2.3.2 Tensiometer

Figure 23: Tensiometer [26]

Tensiometer is a measuring instrument for measuring the surface tension of a liquid. There are two methods involve the surface tension measurement:

2.3.3.1 Du Nouy Ring Method

In principle, a platinum-iridium ring is lowered by the tensiometer onto the surface of the test liquid and then driven under the surface so that it is completely wetted. The ring is then progressively raised until contact with the liquid is broken. The maximum force exerted on the ring is measured and this value is used to calculate the surface tension.

2.3.3.2 Wilhelmy Plate Method

In this method, a pre-weighed rectangular roughened platinum plate is lowered by the tensiometer until it totally immersed in and thoroughly wetted by the test liquid whose density has been determined. The plate is then raised until it is only partly immersed and allowed to determine the surface tension of the liquid on the plate.

2.4 Influence of Sodium Dodecyl Sulfate on corrosion behavior of metals

2.4.1 Nickel (Ni)

Rong Guo, Tianqing Liu, and Xun Wei [27] studied the corrosive properties of nickel in SDS/C_2H_5OH/H_2O/HCl and SDS/n-C_4H_9OH/H_2O/HCl by measuring the weight loss, the voltammetry and the impedance. They hang the piece of nickel in the solution of HCl containing the surfactant for 12 h. The electrochemical properties can be determined by using three-electrode system with a potentiostat. In this system, nickel foil was used as working electrode, a large-area nickel foil as the auxiliary electrode and a saturated calomel electrode (SCE) as reference electrode. The scan rate of potential was 60 mV/s. They found the inhibition efficiency of surfactant SDS for nickel increases with increase of SDS concentration. However, concentration of surfactant beyond the CMC, the inhibition efficiency changes with the addition of the surfactant. At the beginning, the corrosion rate of nickel increased up to the maximum and decrease with the increase of alcohol content. The addition of butanol and ethanol can futher increase the corrosion rate of nickel in HCl solution. The order of corrosion rate, the electrochemical corrosion rate constant and the electrochemical exchange current of nickel corrosion in different media are HCl > surfactant + alcohol + HCl > surfactant + HCl > surfactant + alcohol > surfactant.

2.4.2 Copper (Cu)

R. Fuchs-Godec, and V. Doleček [28] studied the effect of sodium dodecylsulfate on copper corrosion in 0.5 M H_2SO_4 + x M SDS. They used electrochemical polarisation measurements. The concentration of SDS was vary below and above CMC (8×10^{-4} M in 0.5 M H_2SO_4). The scan rate was fixed at 5 mV/s and the potential range scanned was from -1.0 to 1.2 V_{SCE}. Before measurement the sample was cathodically polarized at -1.2 V_{SCE} for 10 min. In this experiment, they chose saturated calomel electrode and Pt as reference electrode and counter electrode respectively. They found the SDS was good anodic inhibitor at low anodic overpotentials and the adsorption of the inhibitor follows the Langmuir isotherm. The values of ΔG_{ads} from Langmuir plots are negative, it means the inhibitive action of SDS in 0.5 M H_2SO_4 resulted from the electrostatic adsorption of $C_{12}H_{25}SO_4^-$ ion onto the positively charged copper surface.

A. Lalitha, S. Ramesh, and S. Rajeswari [29] investigated the influence of derivative of 1,2,4 triazole, 3-amino 1,2,4-traizole (ATA), 3-amino 5-mercapto 1,2,4 triazole (AMT) an d 3-amino 5-nethylthio 1,2,4 triazole (AMTT) and ionic surfactants CTAB and SDS on corrosion control of copper in acidic solution by gravimetric and electrochemical methods. They cut the copper specimens of dimension 1.6" × 0.8" × 0.1", polished it by using SiC emery papers (upto 800 grit sized) and final polishing was done using 0.5 μm diamond paste. The samples were degreased ultrasonically using acetone, rinsed with distilled water and dried. After that the specimens were immersed in 300 mL of test solution, that consists of 500 mL of 0.1 M potassium hydrogen phthalate, 467 mL of 0.1 M hydrochloric acid and 33 mL water, in the presence and absence of inhibitors at the temperature 30 ±1 °C for 7 days. The potentiodynamic polarization was used to study the inhibitive action of azole compounds and surfactants. They used SCE as reference electrode and used platinum as counter electrode. The scan rate was fixed at 1 mV/s, before the measurement the electrodes were subjected to cathodic pretreatment at -1.3 V for 60 s and each experiment was repeated at least three times. The results reveal the fact that all of triazoles AMTT shows best inhibition and anionic surfactant SDS protects the surface better than the cationic surfactant CTAB. The polarisation data show that all inhibitors behave as a mixed type synergistic effect.

2.4.3 Aluminium

Tianpei Zhao, Guannan Mu [30] studied the adsorption and corrosion inhibition of the anion surfactants for example Dodecyl Sulphonic Acid Sodium Salt (DSASS), Dodecyl Benzene Sulfonic Acid Sodium Salt (DBSASS) and Sodium Dodecyl Sulfate (SDS) on the aluminium surface in hydrochloric acid solution by using the weight loss method. They used two aluminium sheets of 30 × 40 ×0.1 mm. The samples were immersed in 250 ml 1.0 mol/L hydrochloric acid solution and the reflux condenser was fitted. After 100 min, take it out, wash, dry and weight. This test was repeated three times. Then added the anionic surfactants in various concentration and the aforementioned tests were repeated. Finally the experiments were repeated under the changes of temperature (30-60 °C). The critical micelle concentration (CMC) in hydrochloric acid solution of DSASS, DBSASS and SDS are 9.7×10^{-3}, 1.2×10^{-3}, and 8.7×10^{-3}. The results reveal the adsorption of the anion surfactants DSASS, DBSASS and SDS on the aluminium surface is the main reason to cause the corrosion inhibition. When the concentration of surfactants is close to its CMC, aluminum will obtain its greatest adsorption amount, least weight loss and strongest corrosion resisting property.

2.4.4 Carbon Steel

Susai Rajendran, S. Mary Reenkala, Noreen Anthony, R. Ramaraj [31] have studied the inhibition efficiency (IE) of sodium dodecylsulphate (SDS) in controlling corrosion of carbon steel immersed in the environment for 3 days. The environment is 60 ppm of Cl^- in the absence and presence of Zn^{2+}. It was observed that SDS and Zn^{2+} individually were not good inhibitors.

But their combination shows excellent inhibition efficiency. For example, 100 ppm of SDS has only 10% inhibition efficiency whereas 75 ppm of Zn^{2+} has 45% inhibition efficiency. Interestingly their combination shows 93% inhibition efficiency. This suggests that a synergistic effect exits. The protective film has been analysed by Fourier transform infrared (FTIR) and fluorescence spectra. A suitable mechanism of corrosion inhibition is proposed based on the results obtained from weight-loss method, and FTIR and fluorescence spectra. It is found that in the absence of Zn^{2+}, the protective film consists of Fe^{2+}- SDS complex formed on the anodic sites of the metal surface. In the presence of Zn^{2+}, the protective film consist of Fe^{2+}- SDS complex and $Zn(OH)_2$.

Chapter 3
Experimental

3.1 Reagents

1. Sodium dodecyl sulfate (SDS) (AR grade : Fluka)
2. Potassium chloride (KCl) (Commercial grade : Ajax Finechem)
3. Sulfuric acid (H_2SO_4) (Commercial grade : Carlo erba)
4. Ethanol
5. Distilled water

3.2 Materials and Apparatus

1. Stainless Steel AISI 304
2. Emery paper; grade 320, 600, 1000, 1200
3. Potentiostat
4. Tensiometer
5. Ultrasonic bath
6. Dryer
7. Vial
8. Glassware
9. Lotto red oxide primer
10. Air pump
11. Platinum electrode
12. Saturated calomel electrode
13. Spoon
14. Zip bag
15. Forceps
16. Alligator forceps

3.3 Procedure

Process studies of the influence of sodium dodecyl sulfate on passivation behavior of 304 stainless steel consist of following stages:

3.3.1 Critical micelle concentration (CMC) measurement

The critical micelle concentration (CMC) of SDS surfactant in 1 N H_2SO_4 was evaluated by using tensiometer by surface tension measurement at 25 °C. The various test concentration of SDS in 1 N H_2SO_4 samples are listed in the table 2. The experiment was repeated two times for each concentration.

Table 2: The various test concentration of SDS in 1 N H_2SO_4 samples

[SDS] in 1N H_2SO_4 (mol/dm^3)
5x10^{-5}
1x10^{-4}
6x10^{-4}
1x10^{-3}
5x10^{-3}

3.3.2 Sample Preparation

Cut the 304 stainless steel of dimension 2.0 x 2.5 cm^2. Then polish the sample with emery paper grade 320, 600, 1,000, and 1,200 respectively to eliminate some metal oxides and dirtiness on the surface of specimen. After that, clean the sample with ultrasonic bath by using ethanol and dry it.

3.3.3 Chemical Preparation

3.3.3.1 Preparation of 1 N sulfuric acid

Pipet 27.84 ml of 96% concentratation sulfuric acid into 1,000 ml volumetric flask and fill it up with distilled water.

3.3.3.2 Addition of Sodium dodecyl sulfate (SDS)

Concentration of sodium dodecyl sulfate is shown in the table 3:

Table 3: Addition of Sodium dodecyl sulfate (SDS) into 1 N H_2SO_4

No.	[SDS] in 1 N H_2SO_4 solution	
	mol/dm^3	x CMC
1	2.0×10^{-4}	0.25
2	4.0×10^{-4}	0.5
3	8.0×10^{-4}	1
4	1.6×10^{-3}	2
5	3.2×10^{-3}	4

3.3.3.3 Corrosion Testing

Potentiodynamic polarization measurements employ a three-electrode system. The working electrode was a 304 stainless steel sample, which was immersed in 600 ml of 1 N sulfuric acid in the absence and presence of sodium dodecyl sulfate solution depending on the condition of experiment, with an exposed area of approximately 7.5 cm^2. A saturated calomel electrode (SCE, SHE = SCE + 241 mV) was used as a reference electrode by connecting to Luggin probe. The tip of Lugging probe almost touched the sample. And a platinum plate was used as a counter electrode. The air pump was installed to provide circulation in the solution. The solution was therefore saturated with oxygen. A potentiostat was connected to the PC through an adapter. It was used to determine the polarization curve. Figure 24 shows the experimental set up.

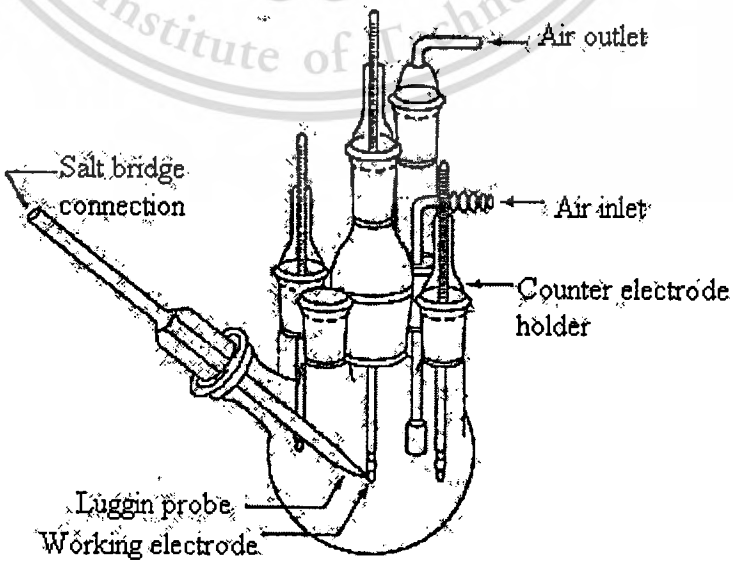


Figure 24: Corrosion testing apparatus [5]

Pretreatment period, after immersion the sample was cathodically polarized to -500 mV for 20 minutes. The potential was changed from -500 to 1,500 mV. The potentiodynamic scan rate during corrosion test was fixed at 600 mV/h. At the end of scanning, the potentiodynamic polarization curve was obtained. Afterward, this curve was arranged in a form of Tafel plot, log current (log i) versus potential (E). The Tafel method was used to obtain the value of corrosion current density (i_{corr}) and Tafel slope, as well as corrosion potential (E_{corr}).

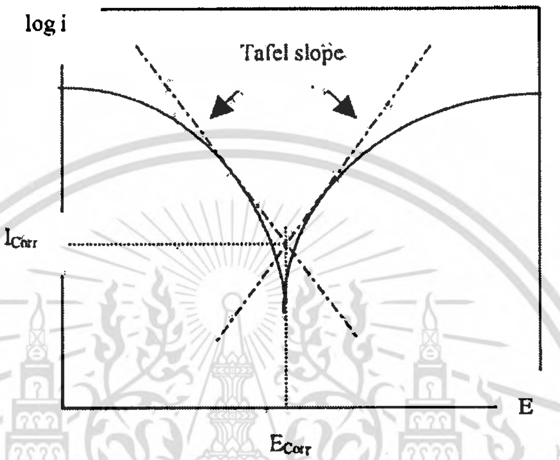


Figure 25: Tafel method of polarization curve [32]

3.4 Data Analysis

3.4.1 The corrosion current density (i_{corr}) indicates the corrosion rate according to Faraday's Law.

$$W = ItM/nF = iAtM/nF$$

where;	W	=	weight loss at instant second time (g)
	I	=	current (A)
	M	=	atomic weight of metal (g/mol)
	n	=	number of electron moles during corrosion
	F	=	Faraday's constant (96,500 C/mol)
	i	=	current density (A/cm^2)
	A	=	average surface area (cm^2)
	t	=	time (s)

3.4.2 Corrosion potential (E_{corr}), and corrosion current density (i_{corr}) of 304 stainless steel in 1 N sulfuric acid with different concentration of sodium dodecyl sulfate were identified from polarization curve.

Chapter 4
Results and Discussion

4.1 Critical micelle concentration (CMC) evaluation

The critical micelle value of SDS surfactant in 1 N H_2SO_4 was determined by surface tension measurements with tensiometer. Surface tension data were obtained and shown in the table 4.

Table 4: the surface tension of each concentration of SDS

[SDS] in 1 N H_2SO_4 (mol/dm^3)		Surface tension (mN/m)		
[SDS]	log [SDS]	1st	2nd	average
$5x10^{-5}$	-4.30	37.289	39.868	38.5785
$1x10^{-4}$	-4.00	30.909	30.817	30.8630
$6x10^{-4}$	-3.22	26.714	27.425	27.0695
$1x10^{-3}$	-3.00	26.052	26.076	26.0640
$5x10^{-3}$	-2.30	26.520	26.586	26.5530

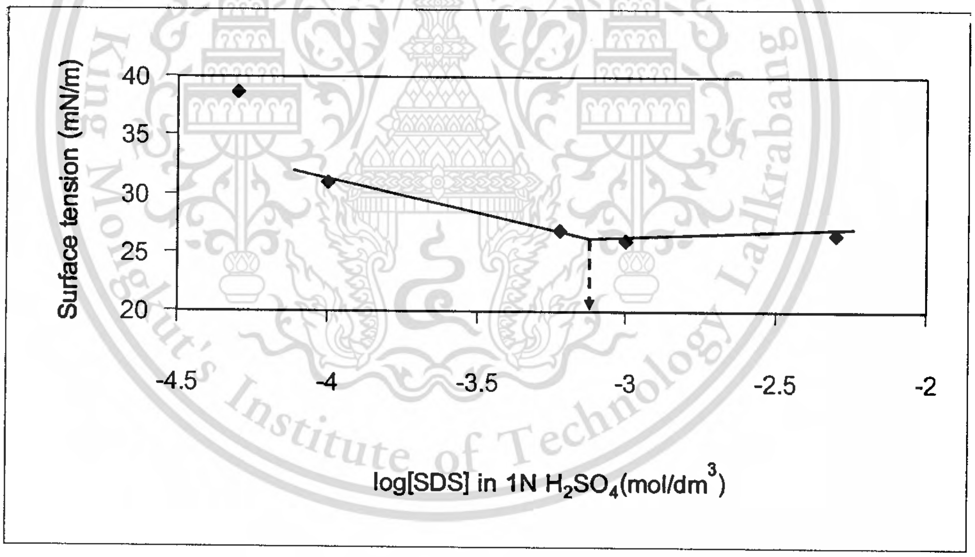


Figure 26: Surface tension of SDS in 1N N H_2SO_4 at 25°C

Figure 26 shows the surface tension of SDS in 1 N H_2SO_4 at 25 °C. A graph of surface tension versus log concentration was produced. The CMC was found as the point at which two lines intersect and the minimum surface tension obtained value is approximately at –3.10 of log [SDS], so the critical micelle concentration (CMC) is $8x10^{-4}$ mol/dm^3 which agrees very well with the literature [28].

4.2 Inhibition test

In order to study the influence of surfactant inhibitor on corrosion of stainless steel in acid solution, corrosion test was carried out by using potentiostat.

Figure 27 shows a polarization curve obtained from 304 stainless steel in 1 N H_2SO_4 solution, which has three regions: active, passive, and transpassive. This is due to the fact that stainless steel can form an oxide film or protective barrier.

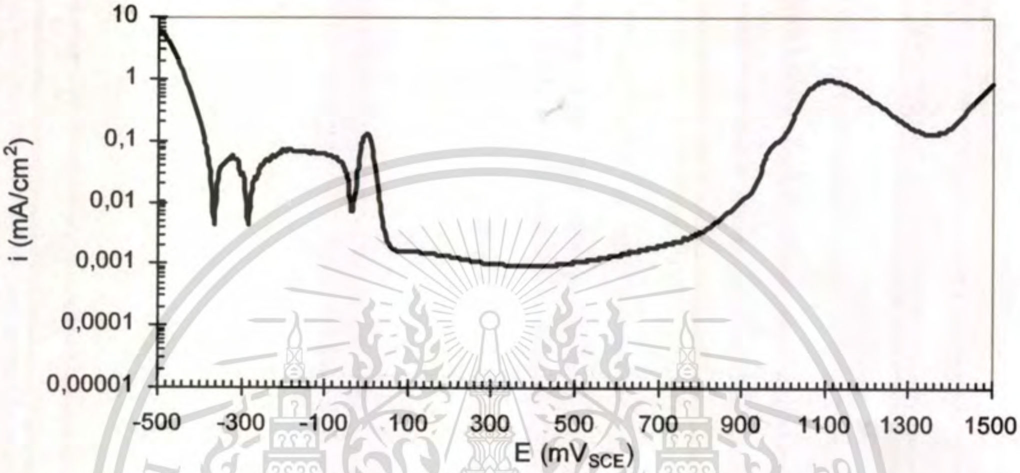


Figure 27: The polarization curves of 304 stainless steel in 1N H_2SO_4

The polarization curves of 304 stainless steel in 1 N H_2SO_4 in absence and presence of various concentration of SDS are shown in Figure 28.

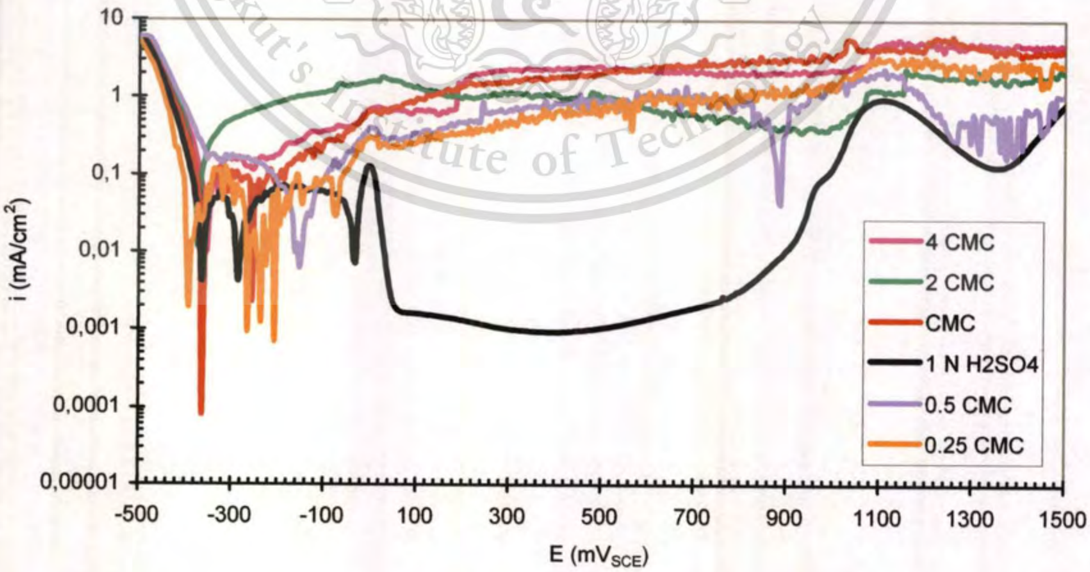


Figure 28: The polarization curves of 304 stainless steel in 1N H_2SO_4 in absence and presence of SDS

It can be seen from Figure 28 that the curves of 304 stainless steel in 1 N H_2SO_4 in presence of SDS do not have the passive region in a consideration range of solution oxidizing power. There are two cases which are low surfactant and high surfactant in acidic solution.

At low amount of SDS as 0.25 CMC, it can be observed from the polarization curve that there are some parts of the curve showed a decrease in current density. This means that stainless steel try to form passive layer but it was not a success. This observation was also found in 0.5 CMC and CMC polarization curves shown in Figure 29. These imply that the stainless steel has a difficulty to form the passive film by SDS.

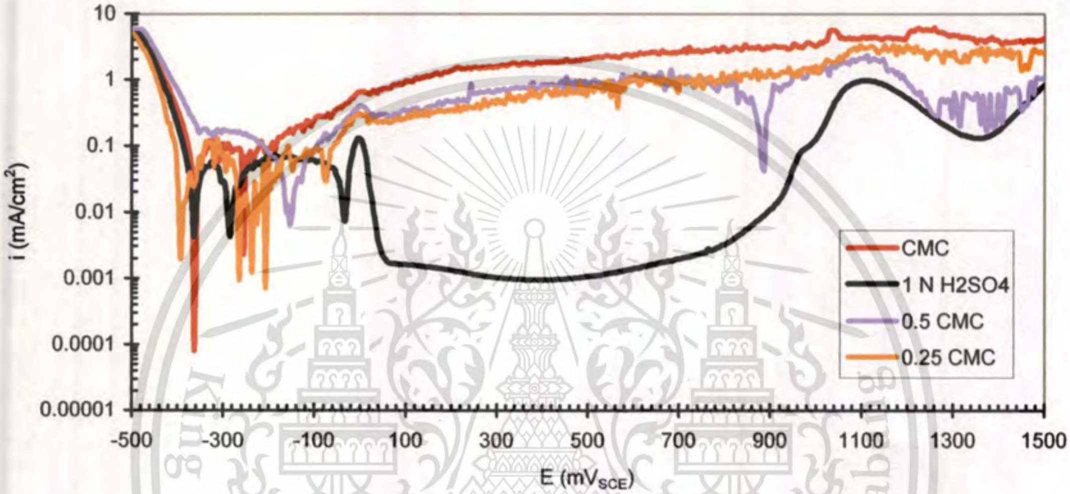


Figure 29: The polarization curves of 304 stainless steel with low amount of SDS

In case of high amount of SDS, 2 CMC and 4 CMC, the passive region can not be observed in these polarization curves as shown in Figure 30. It is clear that there are no passivation with high amount of SDS in the acidic solution.

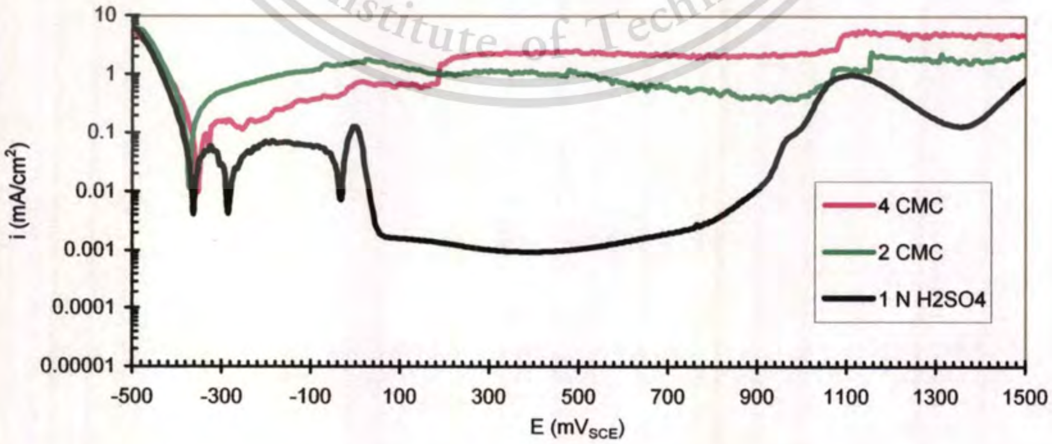


Figure 30: The polarization curves of 304 stainless steel with high amount of SDS

The various electrochemical parameters; cathodic and anodic Tafel slopes (b_a and b_c, respectively), corrosion potential (E_{corr}), corrosion current density (i_{corr}), critical current density (i_{crit}), passivation current density (i_p) and polarization resistance (R_p) were evaluated and calculated from Tafel plots are given in Table 5 and 6.

Table 5: Electrochemical parameters of stainless steel in 1 N H_2SO_4 in absence and presence of SDS

[SDS] in 1 N H_2SO_4 (x CMC)	i_{corr} (mA/cm^2)	E_{corr} (mV_{SCE})	b_c (mV/dec)	b_a (mV/dec)
1 N H_2SO_4	0.010	-360	32	20
0.25	0.013	-387	29	21
0.5	0.017	-140	67	17
1	0.019	-355	47	13
2	0.033	-372	42	28
4	0.047	-351	50	30

The polarization resistance (R_p) was calculated using the following equation:

$$R_p = \frac{b_a b_c}{2.303\, i_{corr}\,(b_a+b_c)}$$

where b_a and b_c are the slopes of anodic and cathodic Tafel lines, respectively. For corrosion rate calculation, the rate was calculated according to Faraday's Law.

Table 6: Electrochemical parameters and corrosion rate of stainless steel in 1 N H_2SO_4 in absence and presence of SDS

[SDS] in 1 N H_2SO_4 (x CMC)	i_{crit} (mA/cm^2)	i_p (mA/cm^2)	R_p ($\Omega\cdot cm^2$)	Corrosion rate mg/cm$^2\cdot$y
1 N H_2SO_4	0.14	0.0010	537.42	90.5
0.25	-	-	406.83	117.6
0.5	-	-	346.34	153.8
1	-	-	232.72	171.9
2	-	-	221.06	298.6
4	-	-	173.22	425.3

From Table 5 and 6, the i_{corr} values and corrosion rate are likely to increase with the concentration of SDS in 1 N H_2SO_4. These data tell that, stainless steel can not be prevented from corrosion by the surfactant.

The polarization resistance value (R_p) decreases as the amount of SDS increases. This result supports the prior comment about the ineffective of SDS as an inhibitor.

For i_{crit} and i_p information, only H_2SO_4 acid solution can lead to these values because stainless steel in acidic solution has passive region.

From all of the obtained data, it reveals that the use of SDS is not effective to inhibit corrosion of 304 stainless steel in 1 N H_2SO_4 as indicated by polarization curves of various amounts of surfactant that do not have passive region.

In fact stainless steels have passive film to prevent further oxidation or corrosion by themselves. In this study, the surface of 304 stainless steel is positively charged during anodic polarization, therefore SDS surfactants can adsorbed their negatively charged head group on stainless steel surface to interfere stainless steel passive film formation in active to passive region by O^{2-} exclusion from oxide layer formation.

From the reason above, it can be defined that SDS surfactant induces the difficulty to stainless steel for passive film formation.

Some of the literature, references were given indicating that SDS was an effective corrosion inhibitor. The references include:

R. Fuchs-Godec, and V. Doleček [28] studied the effect of sodium dodecylsulfate on copper corrosion in 0.5 M H_2SO_4 + x M SDS by using electrochemical polarisation measurements. In this case, it can be explained that copper does not have passive film as stainless steel. During anodic reaction SDS surfactant is adsorbed on the surface to form protective surfactant layer. This reason is also the same in the case of Rong Guo, Tianqing Liu, and Xun Wei [27] who studied the corrosion properties of nickel in SDS/C_2H_5OH/H_2O/HCl and SDS/n-C_4H_9OH/H_2O/HCl by measuring the weight loss.

Another research is from Tianpei Zhao, Guannan Mu.[30] They studied the adsorption and corrosion inhibition of the anion surfactants for example Dodecyl Sulphonic Acid Sodium Salt (DSASS), Dodecyl Benzene Sulfonic Acid Sodium Salt (DBSASS) and Sodium Dodecyl Sulfate (SDS) on the aluminium surface in hydrochloric acid solution by using the weight loss method. The anionic surfactants can easily adsorbed on the aluminum surface with the hydrophilic group to form monomolecular adsorption layer. As the monomolecular adsorption layer effectively isolates the aluminum sheet from contacting with the medium, H^+ can hardly go through the dense surfactant layer. Thus corrosion inhibition is effective without polarization.

Chapter 5
Conclusion

This special project aims to study the influence of sodium dodecyl sulfate on passivation behavior of 304 stainless steel in 1 N of H_2SO_4. The results obtained from potentiodynamic polarization curve reveal the current density (i_{corr}) which refers to an increase in corrosion when the concentration of sodium dodecyl sulfate increases. Polarization resistance (R_p) is decreased when the concentration of sodium dodecyl sulfate is increased. Therefore sodium dodecyl sulfate is unable to inhibit the corrosion of 304 stainless steel. This can be explained that the surface of stainless steel is positively charged during anodic polarization and the surface is covered by negatively charged head group of SDS. Therefore the stainless steel has a difficulty to form passive film by SDS.

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Appendices

Appendix A

Polarization curve data of 304 stainless steel in 1 N H_2SO_4 with various CMC of SDS

1 N H_2SO_4		1 N H_2SO_4 + 0.25 CMC	
Potential (V)	Current (A)	Potential (V)	Current (A)
-0.5000305	-4.138184E-02	-0.5000305	-3.997803E-02
-0.4951477	-4.336548E-02	-0.4951477	-3.637695E-02
-0.4902649	-4.171753E-02	-0.4902649	-0.0328064
-0.4853821	-0.0375061	-0.4853821	-2.905273E-02
-0.4804993	-3.323364E-02	-0.4804993	-2.572632E-02
-0.4756165	-2.947998E-02	-0.4756165	-2.230835E-02
-0.4707336	-2.572327E-02	-0.4707336	-2.007141E-02
-0.4658508	-2.247925E-02	-0.4658508	-1.689453E-02
-0.460968	-1.936645E-02	-0.460968	-1.419067E-02
-0.4560852	-1.655274E-02	-0.4560852	-1.171875E-02
-0.4512024	-1.397705E-02	-0.4512024	-9.54895E-03
-0.4463196	-1.168823E-02	-0.4463196	-7.571411E-03
-0.4414368	-9.631348E-03	-0.4414368	-5.917358E-03
-0.436554	-7.992554E-03	-0.436554	-4.812622E-03
-0.4316711	-6.436157E-03	-0.4316711	-3.463745E-03
-0.4267883	-5.398559E-03	-0.4267883	-2.44751E-03
-0.4219055	-4.425049E-03	-0.4219055	-1.663208E-03
-0.4170227	-3.57666E-03	-0.4170227	-1.626587E-03
-0.4121399	-2.862549E-03	-0.4121399	-1.116943E-03
-0.4072571	-2.230835E-03	-0.4072571	-8.679199E-04
-0.4023743	-1.78833E-03	-0.4023743	-5.871582E-04
-0.3974915	-1.373291E-03	-0.3974915	-6.896973E-05
-0.3926086	-1.062927E-03	-0.3926086	-1.464844E-05
-0.3877258	-7.702637E-04	-0.3877258	-9.674072E-05
-0.382843	-5.731201E-04	-0.382843	1.092529E-04
-0.3779602	-3.704834E-04	-0.3779602	1.596069E-04
-0.3730774	-2.456665E-04	-0.3730774	2.963257E-04
-0.3681946	-9.979248E-05	-0.3681946	1.916199E-04
-0.3633118	3.112793E-05	-0.3633118	1.809998E-04
-0.358429	1.016235E-04	-0.358429	2.298889E-04
-0.3535461	1.748657E-04	-0.3535461	5.032349E-04
-0.3486633	2.675781E-04	-0.3486633	3.362122E-04
-0.3437805	2.969971E-04	-0.3437805	5.926514E-04
-0.3388977	3.569336E-04	-0.3388977	8.94165E-04
-0.3340149	3.590088E-04	-0.3340149	8.447266E-04
-0.3291321	3.693237E-04	-0.3291321	8.816528E-04
-0.3242493	4.430237E-04	-0.3242493	8.157348E-04
-0.3193665	3.620911E-04	-0.3193665	3.506165E-04
-0.3144836	3.626709E-04	-0.3144836	9.515381E-04
-0.3096008	3.408813E-04	-0.3096008	8.081055E-04
-0.304718	2.077637E-04	-0.304718	5.557251E-04
-0.2998352	2.192688E-04	-0.2998352	6.011963E-04
-0.2949524	1.740418E-04	-0.2949524	3.063049E-04
-0.2900696	7.30896E-05	-0.2900696	5.529785E-04

Potential (V)	Current (A)	Potential (V)	Current (A)
-0.2851868	3.149414E-05	-0.2851868	3.92456E-04
-0.280304	-7.626343E-05	-0.280304	4.629517E-04
-0.2754211	-1.237488E-04	-0.2754211	3.245545E-04
-0.2705383	-1.875305E-04	-0.2705383	2.225647E-04
-0.2656555	-1.782532E-04	-0.2656555	-7.049561E-06
-0.2607727	-2.123413E-04	-0.2607727	1.143188E-04
-0.2558899	-2.738037E-04	-0.2558899	9.262085E-05
-0.2510071	-2.929688E-04	-0.2510071	1.399536E-04
-0.2461243	-3.362122E-04	-0.2461243	7.336426E-05
-0.2412415	-3.580322E-04	-0.2412415	5.258179E-05
-0.2363586	-3.338623E-04	-0.2363586	-9.521485E-06
-0.2314758	-3.646851E-04	-0.2314758	2.119751E-04
-0.226593	-4.242249E-04	-0.226593	-4.956055E-05
-0.2217102	-3.962402E-04	-0.2217102	1.325989E-04
-0.2168274	-4.287414E-04	-0.2168274	8.255005E-05
-0.2119446	-4.632873E-04	-0.2119446	3.63678E-04
-0.2070618	-4.78241E-04	-0.2070618	5.279541E-06
-0.202179	-5.303955E-04	-0.202179	4.286804E-04
-0.1972961	-5.056763E-04	-0.1972961	1.638489E-04
-0.1924133	-4.833984E-04	-0.1924133	2.808533E-04
-0.1875305	-5.355835E-04	-0.1875305	2.199097E-04
-0.1826477	-5.282593E-04	-0.1826477	3.746338E-04
-0.1777649	-4.873657E-04	-0.1777649	2.648316E-04
-0.1728821	-5.072022E-04	-0.1728821	4.203186E-04
-0.1679993	-4.992676E-04	-0.1679993	5.551148E-04
-0.1631165	-5.041504E-04	-0.1631165	5.97229E-04
-0.1582336	-5.145264E-04	-0.1582336	7.653809E-04
-0.1533508	-5.0354E-04	-0.1533508	5.422974E-04
-0.148468	-5.169678E-04	-0.148468	3.118591E-04
-0.1435852	-4.940796E-04	-0.1435852	4.339294E-04
-0.1387024	-4.795532E-04	-0.1387024	4.61731E-04
-0.1338196	-4.60144E-04	-0.1338196	4.940796E-04
-0.1289368	-4.837036E-04	-0.1289368	4.916382E-04
-0.124054	-4.622192E-04	-0.124054	5.267334E-04
-0.1191711	-4.634705E-04	-0.1191711	6.756592E-04
-0.1142883	-4.53064E-04	-0.1142883	5.97229E-04
-0.1094055	-4.545898E-04	-0.1094055	5.39856E-04
-0.1045227	-4.573975E-04	-0.1045227	6.35376E-04
-9.963989E-02	-4.506836E-04	-9.963989E-02	6.70166E-04
-9.475708E-02	-4.238281E-04	-9.475708E-02	7.073975E-04
-8.987427E-02	-4.414062E-04	-8.987427E-02	6.219482E-04
-8.499146E-02	-4.424744E-04	-8.499146E-02	6.622315E-04
-8.010864E-02	-4.071655E-04	-8.010864E-02	2.49939E-04
-7.522583E-02	-4.074707E-04	-7.522583E-02	2.189331E-04
-7.034302E-02	-4.037781E-04	-7.034302E-02	3.005066E-04
-6.546021E-02	-3.432922E-04	-6.546021E-02	6.655884E-04
-6.057739E-02	-3.482666E-04	-6.057739E-02	6.973267E-04
-5.569458E-02	-3.3078E-04	-5.569458E-02	8.444214E-04
-5.081177E-02	-2.601623E-04	-5.081177E-02	8.465576E-04

Potential (V)	Current (A)	Potential (V)	Current (A)
-4.592896E-02	-2.138062E-04	-4.592896E-02	9.954834E-04
-4.104614E-02	-1.591492E-04	-4.104614E-02	1.108398E-03
-3.616333E-02	-5.966187E-05	-3.616333E-02	1.259766E-03
-3.128052E-02	5.456543E-05	-3.128052E-02	1.390686E-03
-2.639771E-02	1.947327E-04	-2.639771E-02	1.887207E-03
-2.151489E-02	3.763428E-04	-2.151489E-02	1.578369E-03
-1.663208E-02	5.648804E-04	-1.663208E-02	1.935425E-03
-1.174927E-02	7.492065E-04	-1.174927E-02	2.088318E-03
-6.866455E-03	9.274292E-04	-6.866455E-03	2.205811E-03
-1.983643E-03	9.713745E-04	-1.983643E-03	2.313843E-03
2.89917E-03	9.237671E-04	2.89917E-03	2.250977E-03
7.781982E-03	7.415771E-04	7.781982E-03	2.20398E-03
1.266479E-02	4.995728E-04	1.266479E-02	2.312622E-03
1.754761E-02	2.950134E-04	1.754761E-02	1.687317E-03
2.243042E-02	1.717529E-04	2.243042E-02	1.902771E-03
2.731323E-02	1.068115E-04	2.731323E-02	1.843567E-03
3.219604E-02	6.442261E-05	3.219604E-02	1.893311E-03
3.707886E-02	3.741455E-05	3.707886E-02	1.719055E-03
4.196167E-02	2.502441E-05	4.196167E-02	1.741028E-03
4.684448E-02	1.876831E-05	4.684448E-02	1.789856E-03
5.172729E-02	1.571655E-05	5.172729E-02	1.698608E-03
5.661011E-02	1.397705E-05	5.661011E-02	1.878662E-03
6.149292E-02	1.303101E-05	6.149292E-02	1.699829E-03
6.637573E-02	1.248779E-05	6.637573E-02	1.716003E-03
7.125854E-02	1.235352E-05	7.125854E-02	1.785278E-03
7.614136E-02	1.227112E-05	7.614136E-02	1.969299E-03
8.102417E-02	1.219177E-05	8.102417E-02	1.872864E-03
8.590698E-02	1.214905E-05	8.590698E-02	1.985779E-03
9.078979E-02	1.211243E-05	9.078979E-02	1.886902E-03
9.567261E-02	1.203308E-05	9.567261E-02	1.959534E-03
0.1005554	1.197205E-05	0.1005554	1.973572E-03
0.1054382	1.18927E-05	0.1054382	2.255859E-03
0.110321	1.181946E-05	0.110321	2.066345E-03
0.1152039	1.17096E-05	0.1152039	2.099609E-03
0.1200867	1.16272E-05	0.1200867	2.544251E-03
0.1249695	1.152954E-05	0.1249695	2.146606E-03
0.1298523	1.143188E-05	0.1298523	2.250977E-03
0.1347351	1.135864E-05	0.1347351	2.415772E-03
0.1396179	1.125183E-05	0.1396179	2.200623E-03
0.1445007	1.115417E-05	0.1445007	2.644348E-03
0.1493835	1.10321E-05	0.1493835	2.180176E-03
0.1542664	1.095276E-05	0.1542664	2.49054E-03
0.1591492	1.08551E-05	0.1591492	2.431335E-03
0.164032	1.075439E-05	0.164032	2.480774E-03
0.1689148	1.062927E-05	0.168918	2.485046E-03
0.1737976	1.052246E-05	0.1737976	2.672119E-03
0.1786804	1.040039E-05	0.1786804	2.551575E-03
0.1835632	1.027527E-05	0.1835632	2.503662E-03
0.188446	1.016235E-05	0.188446	2.63031E-03

Potential (V)	Current (A)	Potential (V)	Current (A)
0.1933289	1.004334E-05	0.1933289	2.532043E-03
0.1982117	9.909058E-06	0.1982117	2.695618E-03
0.2030945	9.802246E-06	0 .2030945	2.622986E-03
0.2079773	9.667969E-06	0.2079773	2.582398E-03
0.2128601	9.542847E-06	0.2128601	3.085632E-03
0.2177429	9.402465E-06	0.2177429	2.550049E-03
0.2226257	9.295654E-06	0.2226257	2.703857E-03
0.2275085	9.170532E-06	0.2275085	3.003845E-03
0.2323914	9.04541E-06	0.2323914	2.705078E-03
0.2372742	8.926391E-06	0.2372742	2.986145E-03
0.242157	8.7677E-06	0.242157	2.950439E-03
0.2470398	8.64563E-06	0.2470398	2.87262E-03
0.2519226	8.526611E-06	0.2519226	2.940369E-03
0.2568054	8.401489E-06	0.2568054	3.23761E-03
0.2616882	8.282471E-06	0.2616882	2.810059E-03
0.266571	8.181762E-06	0.266571	3.03833E-03
0.2714539	8.081055E-06	0.2714539	3.813782E-03
0.2763367	7.974243E-06	0.2763367	3.137512E-03
0.2812195	7.904053E-06	0.2812195	3.093567E-03
0.2861023	7.83081E-06	0.2861023	3.441772E-03
0.2909851	7.751465E-06	0.2909851	3.66333E-03
0.2958679	7.687378E-06	0.2958679	3.292541E-03
0.3007507	7.632446E-06	0.3007507	3.790588E-03
0.3056335	7.562256E-06	0.3056335	3.409729E-03
0.3105164	7.498169E-06	0.3105164	3.616028E-03
0.3153992	7.449341E-06	0.3153992	3.282166E-03
0.320282	7.409668E-06	0.320282	3.783874E-03
0.3251648	7.354736E-06	0.3251648	4.578552E-03
0.3300476	7.312012E-06	0.3300476	3.84491E-03
0.3349304	7.278442E-06	0.3349304	4.090881E-03
0.3398132	7.250977E-06	0.3398132	3.689575E-03
0.344696	7.211304E-06	0.344696	4.154358E-03
0.3495789	7.189941E-06	0.3495789	4.284363E-03
0.3544617	7.156372E-06	0.3544617	3.650208E-03
0.3593445	7.138061E-06	0.3593445	3.763428E-03
0.3642273	7.119751E-06	0.3642273	4.34082E-03
0.3691101	7.104492E-06	0.3691101	4.207153E-03
0.3739929	7.073975E-06	0.3739929	5.410767E-03
0.3788757	7.058716E-06	0.3788757	4.329224E-03
0.3837585	7.052612E-06	0.3837585	4.876709E-03
0.3886414	7.046509E-06	0.3886414	4.41864E-03
0.3935242	7.037353E-06	0.3935242	4.100037E-03
0.398407	7.046509E-06	0.398407	4.86145E-03
0.4032898	7.052612E-06	0.4032898	5.053711E-03
0.4081726	7.064819E-06	0.4081726	5.203247E-03
0.4130554	7.067871E-06	0.4130554	5.133057E-03
0.4179382	7.08313E-06	0.4179382	4.510498E-03
0.422821	7.107544E-06	0.422821	4.364319E-03
0.4277039	7.128906E-06	0.4277039	5.554199E-03

Potential (V)	Current (A)	Potential (V)	Current (A)
0.4325867	7.159424E-06	0.4325867	4.502563E-03
0.4374695	7.196045E-06	0.4374695	5.010986E-03
0.4423523	7.214355E-06	0.4423523	4.678345E-03
0.4472351	7.25708E-06	0.4472351	4.632568E-03
0.4521179	7.296753E-06	0.4521179	4.606018E-03
0.4570007	7.342529E-06	0.4570007	5.97229E-03
0.4618835	7.388306E-06	0.4618835	4.922485E-03
0.4667664	7.449341E-06	0.4667664	4.814758E-03
0.4716492	7.507324E-06	0.4716492	4.800415E-03
0.476532	7.562256E-06	0.476532	4.91333E-03
0.4814148	7.635498E-06	0.4814148	6.695556E-03
0.4862976	7.684326E-06	0.4862976	4.700012E-03
0.4911804	7.766724E-06	0.4911804	5.581665E-03
0.4960632	7.83081E-06	0.4960632	4.407044E-03
0.500946	7.919311E-06	0.500946	5.59082E-03
0.5058289	7.992554E-06	0.5058289	6.033325E-03
0.5107117	8.062744E-06	0.5107117	5.050659E-03
0.5155945	8.157349E-06	0.5155945	6.008911E-03
0.5204773	8.242798E-06	0.5204773	5.688476E-03
0.5253601	8.33435E-06	0.5253601	5.917358E-03
0.5302429	8.43811E-06	0.5302429	4.995727E-03
0.5351257	8.541871E-06	0.5351257	7.055664E-03
0.5400085	8.636474E-06	0.5400085	5.587769E-03
0.5448914	8.758545E-06	0.5448914	7.290649E-03
0.5497742	8.874512E-06	0.5497742	4.173279E-03
0.554657	9.008789E-06	0.554657	5.584717E-03
0.5595398	9.127808E-06	0.5595398	6.14624E-03
0.5644226	9.265137E-06	0.5644226	2.896423E-03
0.5693054	9.396363E-06	0.5693054	6.814575E-03
0.5741882	9.539795E-06	0.5741882	5.355835E-03
0.579071	9.68628E-06	0.579071	5.395508E-03
0.5839539	9.835815E-06	0.5839539	7.629395E-03
0.5888367	9.991455E-06	0.5888367	0.0068573
0.5937195	1.015625E-05	0.5937195	7.65686E-03
0.5986023	1.031189E-05	0.5986023	7.705688E-03
0.6034851	1.047669E-05	0.6034851	8.88977E-03
0.6083679	1.066284E-05	0.6083679	6.921387E-03
0.6132507	1.083679E-05	0.6132507	6.222534E-03
0.6181335	1.100769E-05	0.6181335	7.260132E-03
0.6230164	1.11969E-05	0.6230164	8.21228E-03
0.6278992	1.138001E-05	0.6278992	7.290649E-03
0.632782	1.157227E-05	0.632782	7.742309E-03
0.6376648	1.175842E-05	0.6376648	7.769776E-03
0.6425476	1.195679E-05	0.6425476	7.449341E-03
0.6474304	1.21582E-05	0.6474304	6.671143E-03
0.6523132	1.236267E-05	0.6523132	7.598877E-03
0.657196	1.256103E-05	0.657196	6.436157E-03
0.6620789	1.276245E-05	0.6620789	7.434082E-03
0.6669617	1.297302E-05	0.6669617	7.873535E-03

Potential (V)	Current (A)	Potential (V)	Current (A)
0.6718445	1.317749E-05	0.6718445	7.217407E-03
0.6767273	1.338501E-05	0.6767273	7.223511E-03
0.6816101	1.360168E-05	0.6816101	6.506348E-03
0.6864929	1.381226E-05	0.6864929	7.672119E-03
0.6913757	1.403503E-05	0.6913757	6.195068E-03
0.6962585	1.428528E-05	0.6962585	4.895019E-03
0.7011414	1.454468E-05	0.7011414	6.994629E-03
0.7060242	1.475525E-05	0.7060242	8.102417E-03
0.710907	1.499939E-05	0.710907	7.040405E-03
0.7157898	1.525574E-05	0.7157898	6.643677E-03
0.7206726	1.55304E-05	0.7206726	7.171631E-03
0.7255554	1.581116E-05	0.7255554	7.58667E-03
0.7304382	1.611023E-05	0.7304382	7.388306E-03
0.735321	1.64154E-05	0.735321	5.938721E-03
0.7402039	1.674805E-05	0.7402039	7.495117E-03
0.7450867	1.709595E-05	0.7450867	8.69751E-03
0.7499695	1.746216E-05	0.7499695	5.74646E-03
0.7548523	1.787109E-05	0.7548523	6.304932E-03
0.7597351	1.830139E-05	0.7597351	0.0074646
0.7646179	2.044983E-05	0.7646179	7.949829E-03
0.7695007	1.929627E-05	0.7695007	8.190918E-03
0.7743835	1.985779E-05	0.7743835	6.530762E-03
0.7792664	2.045899E-05	0.7792664	6.951904E-03
0.7841492	2.154541E-05	0.7841492	7.507324E-03
0.789032	2.187195E-05	0.789032	6.948852E-03
0.7939148	2.337952E-05	0.7939148	9.567261E-03
0.7987976	2.371216E-05	0.7987976	7.662964E-03
0.8036804	2.465515E-05	0.8036804	7.080078E-03
0.8085632	2.578125E-05	0.8085632	8.59375E-03
0.813446	2.704773E-05	0.813446	8.114624E-03
0.8183289	2.841797E-05	0.8183289	8.068847E-03
0.8232117	2.992248E-05	0.8232117	9.695435E-03
0.8280945	3.15918E-05	0.8280945	7.96814E-03
0.8329773	3.345947E-05	0.8329773	7.235718E-03
0.8378601	3.548279E-05	0.8378601	9.182739E-03
0.8427429	3.759155E-05	0.8427429	8.837891E-03
0.8476257	3.984985E-05	0.8476257	9.344483E-03
0.8525085	4.257202E-05	0.8525085	8.816528E-03
0.8573914	4.544067E-05	0.8573914	8.227539E-03
0.8622742	4.827881E-05	0.8622742	9.286499E-03
0.867157	5.142212E-05	0.867157	1.065674E-02
0.8720398	5.474854E-05	0.8720398	7.650757E-03
0.8769226	5.804443E-05	0.8769226	9.77478E-03
0.8818054	6.21643E-05	0.8818054	8.47168E-03
0.8866882	6.619262E-05	0.8866882	8.728027E-03
0.891571	7.046509E-05	0.891571	8.352662E-03
0.8964539	7.608032E-05	0.8964539	1.046143E-02
0.9013367	8.178711E-05	0.9013367	9.744262E-03
0.9062195	8.685303E-05	0.9062195	8.425904E-03

Potential (V)	Current (A)	Potential (V)	Current (A)
0.9111023	9.521484E-05	0.9111023	8.892822E-03
0.9159851	1.033325E-04	0.9159851	8.682251E-03
0.9208679	1.145935E-04	0.9208679	9.295654E-03
0.9257507	1.28418E-04	0.9257507	9.915161E-03
0.9306335	1.472778E-04	0.9306335	9.661865E-03
0.9355164	1.743469E-04	0.9355164	9.70459E-03
0.9403992	2.107544E-04	0.9403992	1.150208E-02
0.945282	2.633057E-04	0.945282	9.048462E-03
0.9501648	3.322143E-04	0.9501648	9.631348E-03
0.9550476	4.13269E-04	0.9550476	8.456421E-03
0.9599304	4.943848E-04	0.9599304	1.017456E-02
0.9648132	5.664062E-04	0.9648132	9.01184E-03
0.969696	6.207275E-04	0.969696	1.087341E-02
0.9745789	6.619263E-04	0.9745789	1.126404E-02
0.9794617	7.000733E-04	0.9794617	1.103821E-02
0.9843445	7.354736E-04	0.9843445	9.939576E-03
0.9892273	7.830811E-04	0.9892273	1.178284E-02
0.9941101	8.422852E-04	0.9941101	9.686279E-03
0.9989929	9.210205E-04	0.9989929	1.212463E-02
1.003876	1.023865E-03	1.003876	9.683227E-03
1.008759	1.159973E-03	1.008759	1.026917E-02
1.013641	1.333923E-03	1.013641	1.260071E-02
1.018524	1.55426E-03	1.018524	1.323547E-02
1.023407	1.830139E-03	1.023407	1.531372E-02
1.02829	2.165833E-03	1.02829	1.464844E-02
1.033173	2.56073E-03	1.033173	1.401367E-02
1.038055	2.999573E-03	1.038055	0.0138855
1.042938	3.464355E-03	1.042938	1.381531E-02
1.047821	3.934631E-03	1.047821	1.592102E-02
1.052704	4.391174E-03	1.052704	1.693115E-02
1.057587	4.891968E-03	1.057587	1.539001E-02
1.062469	5.288696E-03	1.062469	1.821594E-02
1.067352	5.654907E-03	1.067352	1.800537E-02
1.072235	5.990601E-03	1.072235	2.120972E-02
1.077118	6.283569E-03	1.077118	2.143555E-02
1.082001	6.533814E-03	1.082001	2.354431E-02
1.086884	6.744385E-03	1.086884	0.0217865
1.091766	6.906128E-03	1.091766	2.180176E-02
1.096649	7.028198E-03	1.096649	2.557983E-02
1.101532	7.104492E-03	1.101532	2.325134E-02
1.106415	7.144165E-03	1.106415	2.289429E-02
1.111298	7.144165E-03	1.111298	0.023172
1.11618	7.110596E-03	1.11618	2.405701E-02
1.121063	7.043457E-03	1.121063	2.470093E-02
1.125946	6.948852E-03	1.125946	2.382812E-02
1.130829	6.832886E-03	1.130829	0.0211792
1.135712	6.680298E-03	1.135712	1.960449E-02
1.140594	6.515503E-03	1.140594	2.077332E-02
1.145477	6.329346E-03	1.145477	2.167358E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
1.15036	6.134033E-03	1.15036	2.520752E-02
1.155243	5.923462E-03	1.155243	2.116699E-02
1.160126	5.703735E-03	1.160126	2.142334E-02
1.165009	5.480957E-03	1.165009	2.341003E-02
1.169891	5.252075E-03	1.169891	2.537537E-02
1.174774	5.023194E-03	1.174774	1.841125E-02
1.179657	4.798584E-03	1.179657	2.388611E-02
1.18454	4.57489E-03	1.18454	2.293091E-02
1.189423	4.347229E-03	1.189423	0.0197937
1.194305	4.131164E-03	1.194305	0.0222229
1.199188	3.916931E-03	1.199188	2.565308E-02
1.204071	3.708801E-03	1.204071	2.180176E-02
1.208954	3.513794E-03	1.208954	0.0229126
1.213837	3.321228E-03	1.213837	1.931763E-02
1.218719	3.137817E-03	1.218719	2.420959E-02
1.223602	2.964478E-03	1.223602	2.109375E-02
1.228485	2.798767E-03	1.228485	2.015381E-02
1.233368	2.643433E-03	1.233368	2.145691E-02
1.238251	2.496643E-03	1.238251	1.906128E-02
1.243134	2.356262E-03	1.243134	1.552734E-02
1.248016	2.225342E-03	1.248016	1.986694E-02
1.252899	2.102356E-03	1.252899	1.892395E-02
1.257782	1.986694E-03	1.257782	2.107849E-02
1.262665	1.880798E-03	1.262665	0.0209198
1.267548	1.782532E-03	1.267548	1.867981E-02
1.27243	0.0016922	1.27243	1.798706E-02
1.277313	1.604919E-03	1.277313	1.407776E-02
1.282196	1.525879E-03	1.282196	2.018127E-02
1.287079	1.453552E-03	1.287079	1.802368E-02
1.291962	1.385193E-03	1.291962	1.940002E-02
1.296844	1.325378E-03	1.296844	1.744385E-02
1.301727	1.269226E-03	1.301727	2.061462E-02
1.30661	1.218567E-03	1.30661	1.601257E-02
1.311493	1.172791E-03	1.311493	1.463623E-02
1.316376	1.131592E-03	1.316376	1.432495E-02
1.321259	1.095581E-03	1.321259	1.437073E-02
1.326141	1.064453E-03	1.326141	1.823425E-02
1.331024	1.036072E-03	1.331024	1.439209E-02
1.335907	1.01532E-03	1.335907	0.0164978
1.34079	9.951782E-04	1.34079	2.017212E-02
1.345673	9.84497E-04	1.345673	1.890259E-02
1.350555	9.75647E-04	1.350555	2.116394E-02
1.355438	9.725952E-04	1.355438	1.836548E-02
1.360321	9.753418E-04	1.360321	2.323303E-02
1.365204	9.835815E-04	1.365204	0.0193634
1.370087	9.988403E-04	1.370087	1.455078E-02
1.374969	1.020813E-03	1.374969	2.261963E-02
1.379852	1.051025E-03	1.379852	1.847839E-02
1.384735	1.088257E-03	1.384735	1.894226E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
1.389618	1.13678E-03	1.389618	2.018433E-02
1.394501	1.194153E-03	1.394501	1.785889E-02
1.399384	1.263733E-03	1.399384	2.153931E-02
1.404266	1.34613E-03	1.404266	1.856995E-02
1.409149	1.442261E-03	1.409149	2.261963E-02
1.414032	1.552124E-03	1.414032	1.962891E-02
1.418915	1.675415E-03	1.418915	1.746216E-02
1.423798	1.812744E-03	1.423798	2.196655E-02
1.42868	1.965637E-03	1.42868	1.604004E-02
1.433563	2.131348E-03	1.433563	1.959534E-02
1.438446	2.311401E-03	1.438446	1.898193E-02
1.443329	2.506409E-03	1.443329	1.943054E-02
1.448212	2.714233E-03	1.448212	1.062622E-02
1.453094	2.938538E-03	1.453094	1.082764E-02
1.457977	3.178101E-03	1.457977	1.274109E-02
1.46286	3.434143E-03	1.46286	1.101379E-02
1.467743	3.707886E-03	1.467743	1.407166E-02
1.472626	3.998413E-03	1.472626	2.141724E-02
1.477509	4.30664E-03	1.477509	2.235413E-02
1.482391	4.634094E-03	1.482391	2.055969E-02
1.487274	4.998779E-03	1.487274	1.958618E-02
1.492157	5.349732E-03	1.492157	2.017212E-02
1.49704	5.74646E-03	1.49704	1.907959E-02
1.501923	6.173706E-03	1.501923	1.905518E-02

1 N H_2SO_4 + 0.5 CMC		1 N H_2SO_4 + CMC	
Potential (V)	Current (A)	Potential (V)	Current (A)
-0.5000305	-4.452515E-02	-0.5000305	-4.165649E-02
-0.4951477	-4.483032E-02	-0.4951477	-4.348755E-02
-0.4902649	-0.0447998	-0.4902649	-4.290771E-02
-0.4853821	-0.0446167	-0.4853821	-3.982544E-02
-0.4804993	-4.443359E-02	-0.4804993	-3.585815E-02
-0.4756165	-4.263306E-02	-0.4756165	-3.244019E-02
-0.4707336	-3.818054E-02	-0.4707336	-2.830505E-02
-0.4658508	-3.386841E-02	-0.4658508	-0.0250824
-0.460968	-2.948608E-02	-0.460968	-2.165833E-02
-0.4560852	-2.556152E-02	-0.4560852	-1.859436E-02
-0.4512024	-2.223511E-02	-0.4512024	-1.599121E-02
-0.4463196	-1.966553E-02	-0.4463196	-1.349487E-02
-0.4414368	-1.682129E-02	-0.4414368	-1.137695E-02
-0.436554	-1.470642E-02	-0.436554	-9.689331E-03
-0.4316711	-1.294251E-02	-0.4316711	-8.24585E-03
-0.4267883	-1.118469E-02	-0.4267883	-6.97937E-03
-0.4219055	-9.564209E-03	-0.4219055	-5.917358E-03
-0.4170227	-8.377075E-03	-0.4170227	-5.08728E-03
-0.4121399	-7.354736E-03	-0.4121399	-4.174805E-03
-0.4072571	-6.408691E-03	-0.4072571	-3.52478E-03
-0.4023743	-5.740357E-03	-0.4023743	-2.84729E-03
-0.3974915	-4.968262E-03	-0.3974915	-2.331543E-03
-0.3926086	-4.229737E-03	-0.3926086	-1.904297E-03
-0.3877258	-3.622436E-03	-0.3877258	-1.470947E-03
-0.382843	-3.109741E-03	-0.382843	-1.149292E-03
-0.3779602	-2.685547E-03	-0.3779602	-8.068848E-04
-0.3730774	-2.227783E-03	-0.3730774	-5.566406E-04
-0.3681946	-2.062683E-03	-0.3681946	-2.288818E-04
-0.3633118	-1.765747E-03	-0.3633118	6.103515E-07
-0.358429	-1.488953E-03	-0.358429	8.087158E-05
-0.3535461	-1.202087E-03	-0.3535461	2.972412E-04
-0.3486633	-1.314392E-03	-0.3486633	5.371094E-04
-0.3437805	-1.360779E-03	-0.3437805	5.374146E-04
-0.3388977	-1.358948E-03	-0.3388977	6.390381E-04
-0.3340149	-1.243591E-03	-0.3340149	7.598877E-04
-0.3291321	-1.164246E-03	-0.3291321	9.075928E-04
-0.3242493	-1.184998E-03	-0.3242493	6.912231E-04
-0.3193665	-1.054688E-03	-0.3193665	9.280395E-04
-0.3144836	-1.330566E-03	-0.3144836	7.653809E-04
-0.3096008	-1.307068E-03	-0.3096008	4.397583E-04
-0.304718	-1.194153E-03	-0.304718	7.565308E-04
-0.2998352	-1.351318E-03	-0.2998352	8.248902E-04
-0.2949524	-1.271667E-03	-0.2949524	6.719971E-04
-0.2900696	-1.279907E-03	-0.2900696	8.184814E-04
-0.2851868	-1.237183E-03	-0.2851868	7.174683E-04
-0.280304	-1.226501E-03	-0.280304	6.167602E-04
-0.2754211	-1.246643E-03	-0.2754211	6.781006E-04
-0.2705383	-1.205444E-03	-0.2705383	6.643677E-04

Potential (V)	Current (A)	Potential (V)	Current (A)
-0.2656555	-1.244812E-03	-0.2656555	7.077027E-04
-0.2607727	-1.179199E-03	-0.2607727	5.97229E-04
-0.2558899	-1.119995E-03	-0.2558899	1.739502E-05
-0.2510071	-1.177673E-03	-0.2510071	5.145264E-04
-0.2461243	-1.077881E-03	-0.2461243	4.016113E-04
-0.2412415	-1.055298E-03	-0.2412415	6.332397E-04
-0.2363586	-1.033936E-03	-0.2363586	3.955078E-04
-0.2314758	-9.854126E-04	-0.2314758	5.596924E-04
-0.226593	-9.237671E-04	-0.226593	6.253052E-04
-0.2217102	-8.224488E-04	-0.2217102	7.492065E-04
-0.2168274	-8.520508E-04	-0.2168274	8.877564E-04
-0.2119446	-7.507324E-04	-0.2119446	7.064819E-04
-0.2070618	-7.070923E-04	-0.2070618	5.917358E-04
-0.202179	-6.185913E-04	-0.202179	7.061767E-04
-0.1972961	-5.331421E-04	-0.1972961	6.787109E-04
-0.1924133	-5.181885E-04	-0.1924133	8.529663E-04
-0.1875305	-5.014038E-04	-0.1875305	6.463623E-04
-0.1826477	-4.595947E-04	-0.1826477	9.094238E-04
-0.1777649	-3.701782E-04	-0.1777649	1.014709E-03
-0.1728821	-2.734375E-04	-0.1728821	1.027222E-03
-0.1679993	-2.127075E-04	-0.1679993	1.098022E-03
-0.1631165	-7.598877E-05	-0.1631165	1.195984E-03
-0.1582336	-9.716797E-05	-0.1582336	1.20697E-03
-0.1533508	-4.690552E-05	-0.1533508	1.361084E-03
-0.148468	7.559204E-05	-0.148468	1.174316E-03
-0.1435852	1.591797E-04	-0.1435852	1.333618E-03
-0.1387024	2.146606E-04	-0.1387024	1.493835E-03
-0.1338196	2.43866E-04	-0.1338196	1.470947E-03
-0.1289368	2.159729E-04	-0.1289368	1.552429E-03
-0.124054	3.298645E-04	-0.124054	1.251831E-03
-0.1191711	4.633179E-04	-0.1191711	1.792603E-03
-0.1142883	5.078125E-04	-0.1142883	1.834106E-03
-0.1094055	5.969238E-04	-0.1094055	1.489868E-03
-0.1045227	6.060791E-04	-0.1045227	1.656189E-03
-9.963989E-02	6.866455E-04	-9.963989E-02	1.971741E-03
-9.475708E-02	7.797241E-04	-9.475708E-02	2.07489E-03
-8.987427E-02	9.002686E-04	-8.987427E-02	2.129822E-03
-8.499146E-02	8.795166E-04	-8.499146E-02	2.104797E-03
-8.010864E-02	1.128235E-03	-8.010864E-02	2.094727E-03
-7.522583E-02	1.176453E-03	-7.522583E-02	2.099914E-03
-7.034302E-02	9.423828E-04	-7.034302E-02	2.355347E-03
-6.546021E-02	1.095581E-03	-6.546021E-02	2.045593E-03
-6.057739E-02	1.096191E-03	-6.057739E-02	2.294312E-03
-5.569458E-02	1.261292E-03	-5.569458E-02	2.616577E-03
-5.081177E-02	1.44043E-03	-5.081177E-02	2.70813E-03
-4.592896E-02	1.510315E-03	-4.592896E-02	2.949829E-03
-4.104614E-02	1.51947E-03	-4.104614E-02	2.879028E-03
-3.616333E-02	1.78894E-03	-3.616333E-02	3.200073E-03
-3.128052E-02	1.865234E-03	-3.128052E-02	3.327637E-03

Potential (V)	Current (A)	Potential (V)	Current (A)
-2.639771E-02	2.095032E-03	-2.639771E-02	3.452454E-03
-2.151489E-02	2.201538E-03	-2.151489E-02	3.811035E-03
-1.663208E-02	2.472229E-03	-1.663208E-02	4.041138E-03
-1.174927E-02	2.599793E-03	-1.174927E-02	4.346618E-03
-6.866455E-03	2.815247E-03	-6.866455E-03	4.76532E-03
-1.983643E-03	3.091126E-03	-1.983643E-03	4.873047E-03
2.89917E-03	3.006287E-03	2.89917E-03	5.050659E-03
7.781982E-03	2.987976E-03	7.781982E-03	5.010986E-03
1.266479E-02	2.761536E-03	1.266479E-02	4.754944E-03
1.754761E-02	2.492371E-03	1.754761E-02	4.718018E-03
2.243042E-02	2.311096E-03	2.243042E-02	4.603577E-03
2.731323E-02	2.297668E-03	2.731323E-02	5.227661E-03
3.219604E-02	2.085876E-03	3.219604E-02	4.986572E-03
3.707886E-02	2.153625E-03	3.707886E-02	4.82666E-03
4.196167E-02	2.270508E-03	4.196167E-02	5.328369E-03
4.684448E-02	2.254944E-03	4.684448E-02	5.386353E-03
5.172729E-02	2.290344E-03	5.172729E-02	5.581665E-03
5.661011E-02	2.216187E-03	5.661011E-02	5.615234E-03
6.149292E-02	2.161255E-03	6.149292E-02	5.593872E-03
6.637573E-02	2.151489E-03	6.637573E-02	5.776978E-03
7.125854E-02	2.253723E-03	7.125854E-02	6.185913E-03
7.614136E-02	2.338257E-03	7.614136E-02	6.350708E-03
8.102417E-02	2.304687E-03	8.102417E-02	6.356812E-03
8.590698E-02	2.367859E-03	8.590698E-02	6.707764E-03
9.078979E-02	2.54364E-03	9.078979E-02	6.335449E-03
9.567261E-02	2.67395E-03	9.567261E-02	6.762695E-03
0.1005554	2.576294E-03	0.1005554	7.27539E-03
0.1054382	2.626343E-03	0.1054382	7.141113E-03
0.110321	2.669678E-03	0.110321	7.119751E-03
0.1152039	2.826538E-03	0.1152039	7.046509E-03
0.1200867	2.818298E-03	0.1200867	0.0078125
0.1249695	2.847595E-03	0.1249695	8.059693E-03
0.1298523	2.540894E-03	0.1298523	7.870483E-03
0.1347351	2.637024E-03	0.1347351	8.084106E-03
0.1396179	2.567139E-03	0.1396179	8.148193E-03
0.1445007	2.848816E-03	0.1445007	8.523559E-03
0.1493835	3.001404E-03	0.1493835	8.306885E-03
0.1542664	2.973328E-03	0.1542664	8.605957E-03
0.1591492	3.069458E-03	0.1591492	8.834839E-03
0.164032	3.062439E-03	0.164032	9.317016E-03
0.1689148	3.283997E-03	0.1689148	9.451294E-03
0.1737976	3.479004E-03	0.1737976	9.024048E-03
0.1786804	3.214111E-03	0.1786804	9.225463E-03
0.1835632	3.347778E-03	0.1835632	9.698486E-03
0.188446	3.621521E-03	0.188446	9.759521E-03
0.1933289	3.598328E-03	0.1933289	1.007996E-02
0.1982117	3.578796E-03	0.1982117	1.031799E-02
0.2030945	3.614197E-03	0.2030945	1.065063E-02
0.2079773	3.476868E-03	0.2079773	1.112366E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
0.2128601	3.812256E-03	0.2128601	0.0114624
0.2177429	3.760681E-03	0.2177429	1.138916E-02
0.2226257	3.666992E-03	0.2226257	1.101685E-02
0.2275085	3.796997E-03	0.2275085	0.0109375
0.2323914	3.563232E-03	0.2323914	1.122742E-02
0.2372742	3.731384E-03	0.2372742	1.130066E-02
0.242157	6.561279E-03	0.242157	1.095581E-02
0.2470398	4.805908E-03	0.2470398	1.136475E-02
0.2519226	4.795837E-03	0.2519226	0.0117157
0.2568054	4.653015E-03	0.2568054	1.146851E-02
0.2616882	4.953003E-03	0.2616882	1.122742E-02
0.266571	4.845886E-03	0.266571	1.164856E-02
0.2714539	4.937134E-03	0.2714539	0.01138
0.2763367	5.041504E-03	0.2763367	1.174011E-02
0.2812195	5.282593E-03	0.2812195	1.175842E-02
0.2861023	4.905396E-03	0.2861023	1.192627E-02
0.2909851	4.848633E-03	0.2909851	1.152649E-02
0.2958679	4.992676E-03	0.2958679	0.0118042
0.3007507	5.291748E-03	0.3007507	1.158142E-02
0.3056335	5.096436E-03	0.3056335	1.225891E-02
0.3105164	5.307007E-03	0.3105164	1.256409E-02
0.3153992	5.636597E-03	0.3153992	1.239319E-02
0.320282	5.133057E-03	0.320282	1.209412E-02
0.3251648	5.090332E-03	0.3251648	1.265869E-02
0.3300476	5.551147E-03	0.3300476	1.295776E-02
0.3349304	5.551147E-03	0.3349304	1.336365E-02
0.3398132	5.767822E-03	0.3398132	1.322632E-02
0.344696	5.85022E-03	0.344696	1.266479E-02
0.3495789	5.615234E-03	0.3495789	1.260681E-02
0.3544617	5.859375E-03	0.3544617	0.0133606
0.3593445	5.651855E-03	0.3593445	1.305542E-02
0.3642273	5.731201E-03	0.3642273	1.375427E-02
0.3691101	5.709839E-03	0.3691101	0.0131073
0.3739929	6.341553E-03	0.3739929	1.312866E-02
0.3788757	6.80542E-03	0.3788757	1.268921E-02
0.3837585	5.523682E-03	0.3837585	1.306458E-02
0.3886414	5.74646E-03	0.3886414	1.380005E-02
0.3935242	5.880737E-03	0.3935242	1.347046E-02
0.398407	6.399536E-03	0.398407	1.357117E-02
0.4032898	6.320191E-03	0.4032898	0.0138855
0.4081726	6.234741E-03	0.4081726	1.372986E-02
0.4130554	6.265259E-03	0.4130554	1.394043E-02
0.4179382	6.448364E-03	0.4179382	1.375427E-02
0.422821	6.347656E-03	0.422821	1.409607E-02
0.4277039	6.097412E-03	0.4277039	1.377869E-02
0.4325867	5.935669E-03	0.4325867	1.403503E-02
0.4374695	6.866455E-03	0.4374695	1.404114E-02
0.4423523	7.073975E-03	0.4423523	1.414185E-02
0.4472351	5.688476E-03	0.4472351	1.438904E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
0.4521179	8.370971E-03	0.4521179	0.0151825
0.4570007	5.596924E-03	0.4570007	1.456299E-02
0.4618835	6.958008E-03	0.4618835	1.435547E-02
0.4667664	5.419922E-03	0.4667664	1.436768E-02
0.4716492	7.095337E-03	0.4716492	1.493835E-02
0.476532	5.79834E-03	0.476532	1.473389E-02
0.4814148	7.284546E-03	0.4814148	1.442871E-02
0.4862976	6.277466E-03	0.4862976	1.567993E-02
0.4911804	7.070923E-03	0.4911804	1.516724E-02
0.4960632	6.588745E-03	0.4960632	1.546326E-02
0.500946	6.646729E-03	0.500946	1.571045E-02
0.5058289	6.842041E-03	0.5058289	1.581726E-02
0.5107117	7.250977E-03	0.5107117	1.630249E-02
0.5155945	7.492065E-03	0.5155945	1.642456E-02
0.5204773	6.726074E-03	0.5204773	1.669312E-02
0.5253601	7.055664E-03	0.5253601	1.663513E-02
0.5302429	5.981445E-03	0.5302429	1.619873E-02
0.5351257	5.126953E-03	0.5351257	1.690979E-02
0.5400085	6.799316E-03	0.5400085	1.727905E-02
0.5448914	6.866455E-03	0.5448914	1.741943E-02
0.5497742	7.131958E-03	0.5497742	1.686096E-02
0.554657	7.107544E-03	0.554657	0.0165802
0.5595398	5.892945E-03	0.5595398	1.688538E-02
0.5644226	6.393433E-03	0.5644226	1.644592E-02
0.5693054	5.410767E-03	0.5693054	0.0164856
0.5741882	8.911133E-03	0.5741882	1.732788E-02
0.579071	7.434082E-03	0.579071	1.772156E-02
0.5839539	7.632446E-03	0.5839539	1.822205E-02
0.5888367	8.142089E-03	0.5888367	1.765747E-02
0.5937195	8.206177E-03	0.5937195	1.710815E-02
0.5986023	7.266236E-03	0.5986023	1.810913E-02
0.6034851	8.602905E-03	0.6034851	1.771545E-02
0.6083679	8.181763E-03	0.6083679	1.843872E-02
0.6132507	6.893921E-03	0.6132507	1.933594E-02
0.6181335	7.415771E-03	0.6181335	1.862488E-02
0.6230164	9.347534E-03	0.6230164	1.848144E-02
0.6278992	8.294677E-03	0.6278992	1.896667E-02
0.632782	0.0081604	0.632782	1.916199E-02
0.6376648	7.522583E-03	0.6376648	1.994324E-02
0.6425476	8.26416E-03	0.6425476	1.955872E-02
0.6474304	7.818604E-03	0.6474304	1.990051E-02
0.6523132	8.258057E-03	0.6523132	1.873474E-02
0.657196	9.664917E-03	0.657196	1.917725E-02
0.6620789	9.164428E-03	0.6620789	2.070313E-02
0.6669617	5.419922E-03	0.6669617	1.963806E-02
0.6718445	6.088257E-03	0.6718445	1.966553E-02
0.6767273	7.525635E-03	0.6767273	1.907654E-02
0.6816101	1.062317E-02	0.6816101	1.919861E-02
0.6864929	7.672119E-03	0.6864929	1.972046E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
0.6913757	7.757568E-03	0.6913757	1.919861E-02
0.6962585	7.928466E-03	0.6962585	1.985779E-02
0.7011414	8.36792E-03	0.7011414	1.997375E-02
0.7060242	7.962036E-03	0.7060242	2.006226E-02
0.710907	7.821655E-03	0.710907	0.0223175
0.7157898	8.572388E-03	0.7157898	1.945496E-02
0.7206726	8.21228E-03	0.7206726	2.381897E-02
0.7255554	7.238769E-03	0.7255554	2.028809E-02
0.7304382	5.841064E-03	0.7304382	2.093201E-02
0.735321	7.583618E-03	0.735321	2.019348E-02
0.7402039	6.63147E-03	0.7402039	2.130127E-02
0.7450867	8.69751E-03	0.7450867	2.025757E-02
0.7499695	7.019043E-03	0.7499695	1.986999E-02
0.7548523	7.562256E-03	0.7548523	2.063904E-02
0.7597351	7.86438E-03	0.7597351	2.072754E-02
0.7646179	6.707764E-03	0.7646179	2.102661E-02
0.7695007	6.75354E-03	0.7695007	0.0219635
0.7743835	5.841064E-03	0.7743835	2.253113E-02
0.7792664	5.758667E-03	0.7792664	2.298279E-02
0.7841492	5.166626E-03	0.7841492	2.019348E-02
0.789032	6.735229E-03	0.789032	2.153015E-02
0.7939148	6.625366E-03	0.7939148	2.367554E-02
0.7987976	7.138061E-03	0.7987976	2.316284E-02
0.8036804	6.167603E-03	0.8036804	2.025757E-02
0.8085632	7.025146E-03	0.8085632	2.101746E-02
0.813446	6.414795E-03	0.813446	0.0216217
0.8183289	6.472779E-03	0.8183289	2.247315E-02
0.8232117	7.629395E-03	0.8232117	2.359619E-02
0.8280945	3.426514E-03	0.8280945	2.276611E-02
0.8329773	4.780578E-03	0.8329773	2.202759E-02
0.8378601	4.830933E-03	0.8378601	2.167664E-02
0.8427429	4.119873E-03	0.8427429	2.598877E-02
0.8476257	3.679199E-03	0.8476257	2.380676E-02
0.8525085	3.440247E-03	0.8525085	2.287292E-02
0.8573914	4.129944E-03	0.8573914	0.0232605
0.8622742	3.107605E-03	0.8622742	2.307739E-02
0.867157	2.390747E-03	0.867157	2.268982E-02
0.8720398	1.578369E-03	0.8720398	2.420349E-02
0.8769226	1.095276E-03	0.8769226	2.348633E-02
0.8818054	3.75061E-04	0.8818054	2.192993E-02
0.8866882	3.271484E-04	0.8866882	2.249146E-02
0.891571	2.208252E-03	0.891571	2.380981E-02
0.8964539	2.587585E-03	0.8964539	2.294922E-02
0.9013367	3.337097E-03	0.9013367	2.408752E-02
0.9062195	6.219483E-03	0.9062195	2.503357E-02
0.9111023	5.633545E-03	0.9111023	2.454529E-02
0.9159851	5.862427E-03	0.9159851	2.365417E-02
0.9208679	5.099487E-03	0.9208679	2.395019E-02
0.9257507	5.804443E-03	0.9257507	2.388306E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
0.9306335	6.35376E-03	0.9306335	2.392273E-02
0.9355164	6.256104E-03	0.9355164	0.0221283
0.9403992	6.604004E-03	0.9403992	2.242127E-02
0.945282	7.128906E-03	0.945282	2.339783E-02
0.9501648	8.666992E-03	0.9501648	2.677917E-02
0.9550476	8.993531E-03	0.9550476	2.629089E-02
0.9599304	8.560181E-03	0.9599304	0.0236084
0.9648132	1.054688E-02	0.9648132	2.438354E-02
0.969696	8.380127E-03	0.969696	2.341614E-02
0.9745789	8.062745E-03	0.9745789	2.573242E-02
0.9794617	8.355713E-03	0.9794617	2.815552E-02
0.9843445	1.015625E-02	0.9843445	2.787781E-02
0.9892273	0.0116333	0.9892273	2.691955E-02
0.9941101	1.065674E-02	0.9941101	2.544251E-02
0.9989929	1.221924E-02	0.9989929	2.442627E-02
1.003876	9.65271E-03	1.003876	2.568359E-02
1.008759	9.963989E-03	1.008759	2.828674E-02
1.013641	1.064453E-02	1.013641	2.754822E-02
1.018524	1.188049E-02	1.018524	2.982788E-02
1.023407	1.079407E-02	1.023407	3.059387E-02
1.02829	8.752441E-03	1.02829	4.110108E-02
1.033173	1.245728E-02	1.033173	4.294739E-02
1.038055	1.159058E-02	1.038055	4.263916E-02
1.042938	1.168823E-02	1.042938	4.120178E-02
1.047821	1.296692E-02	1.047821	3.691101E-02
1.052704	1.309509E-02	1.052704	3.279419E-02
1.057587	1.455994E-02	1.057587	3.296204E-02
1.062469	1.379395E-02	1.062469	3.158874E-02
1.067352	1.404419E-02	1.067352	3.162231E-02
1.072235	1.317444E-02	1.072235	3.306885E-02
1.077118	1.481628E-02	1.077118	3.198242E-02
1.082001	1.516724E-02	1.082001	3.230286E-02
1.086884	1.411743E-02	1.086884	3.163757E-02
1.091766	1.575012E-02	1.091766	3.215027E-02
1.096649	1.607666E-02	1.096649	3.181152E-02
1.101532	1.608887E-02	1.101532	3.379822E-02
1.106415	1.636963E-02	1.106415	3.343506E-02
1.111298	0.0179657	1.111298	3.280029E-02
1.11618	1.412964E-02	1.11618	3.423157E-02
1.121063	0.0153656	1.121063	3.289185E-02
1.125946	1.581726E-02	1.125946	3.375549E-02
1.130829	1.504517E-02	1.130829	0.0332489
1.135712	1.499634E-02	1.135712	3.227234E-02
1.140594	1.420288E-02	1.140594	3.188477E-02
1.145477	1.561585E-02	1.145477	3.112793E-02
1.15036	1.403809E-02	1.15036	3.279114E-02
1.155243	1.049194E-02	1.155243	3.361511E-02
1.160126	1.044617E-02	1.160126	0.0336853
1.165009	0.0105896	1.165009	3.255005E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
1.169891	1.045837E-02	1.169891	3.215027E-02
1.174774	9.109497E-03	1.174774	3.252869E-02
1.179657	9.796143E-03	1.179657	3.157959E-02
1.18454	7.931518E-03	1.18454	3.211365E-02
1.189423	8.901978E-03	1.189423	3.129273E-02
1.194305	7.720947E-03	1.194305	3.097229E-02
1.199188	7.019043E-03	1.199188	3.470154E-02
1.204071	6.079101E-03	1.204071	4.110108E-02
1.208954	6.030274E-03	1.208954	4.121399E-02
1.213837	4.96521E-03	1.213837	4.180603E-02
1.218719	4.860229E-03	1.218719	4.466858E-02
1.223602	4.552612E-03	1.223602	4.509888E-02
1.228485	4.992676E-03	1.228485	4.435425E-02
1.233368	3.851624E-03	1.233368	4.252014E-02
1.238251	3.912659E-03	1.238251	4.377136E-02
1.243134	3.16803E-03	1.243134	4.360046E-02
1.248016	2.796631E-03	1.248016	4.225769E-02
1.252899	2.428284E-03	1.252899	4.214783E-02
1.257782	2.246399E-03	1.257782	4.705505E-02
1.262665	2.12738E-03	1.262665	4.215393E-02
1.267548	2.145996E-03	1.267548	3.962402E-02
1.27243	3.75885E-03	1.27243	3.995361E-02
1.277313	3.940735E-03	1.277313	3.901367E-02
1.282196	3.461914E-03	1.282196	3.782654E-02
1.287079	3.800659E-03	1.287079	3.627014E-02
1.291962	3.757019E-03	1.291962	3.493958E-02
1.296844	2.059937E-03	1.296844	3.646851E-02
1.301727	4.710388E-03	1.301727	3.565979E-02
1.30661	3.994751E-03	1.30661	3.541565E-02
1.311493	1.92749E-03	1.311493	3.563843E-02
1.316376	1.578674E-03	1.316376	3.337402E-02
1.321259	4.438171E-03	1.321259	3.421936E-02
1.326141	4.712524E-03	1.326141	3.304138E-02
1.331024	4.414673E-03	1.331024	3.339844E-02
1.335907	4.189453E-03	1.335907	3.311462E-02
1.34079	3.925171E-03	1.34079	3.171081E-02
1.345673	3.854065E-03	1.345673	3.153381E-02
1.350555	4.682922E-03	1.350555	2.801514E-02
1.355438	4.143372E-03	1.355438	3.078919E-02
1.360321	1.63147E-03	1.360321	3.057861E-02
1.365204	4.371948E-03	1.365204	3.010559E-02
1.370087	1.471863E-03	1.370087	2.854919E-02
1.374969	1.316528E-03	1.374969	3.150024E-02
1.379852	4.553223E-03	1.379852	0.0312439
1.384735	1.594543E-03	1.384735	3.335571E-02
1.389618	1.40686E-03	1.389618	3.036499E-02
1.394501	1.772461E-03	1.394501	3.052063E-02
1.399384	4.538879E-03	1.399384	2.951965E-02
1.404266	2.522583E-03	1.404266	2.699585E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
1.409149	1.698608E-03	1.409149	2.675781E-02
1.414032	5.535888E-03	1.414032	2.910156E-02
1.418915	5.563355E-03	1.418915	2.767639E-02
1.423798	4.837036E-03	1.423798	2.773132E-02
1.42868	4.879456E-03	1.42868	2.805481E-02
1.433563	5.212402E-03	1.433563	0.0291626
1.438446	5.69458E-03	1.438446	2.836609E-02
1.443329	0.0050354	1.443329	2.998047E-02
1.448212	2.629089E-03	1.448212	2.965088E-02
1.453094	2.806091E-03	1.453094	2.814941E-02
1.457977	3.024292E-03	1.457977	2.946472E-02
1.46286	3.265686E-03	1.46286	3.013611E-02
1.467743	6.506348E-03	1.467743	2.896118E-02
1.472626	7.034302E-03	1.472626	3.065491E-02
1.477509	4.329529E-03	1.477509	2.846985E-02
1.482391	8.041382E-03	1.482391	3.007812E-02
1.487274	8.00476E-03	1.487274	2.967529E-02
1.492157	7.84607E-03	1.492157	2.971497E-02
1.49704	8.062745E-03	1.49704	0.0319519
1.501923	8.273316E-03	1.501923	3.095703E-02

1 N H_2SO_4 + 2 CMC		1 N H_2SO_4 + 4 CMC	
Potential (V)	Current (A)	Potential (V)	Current (A)
-0.5000305	-4.165649E-02	-0.5000305	-4.064941E-02
-0.4951477	-4.367065E-02	-0.4951477	-3.842163E-02
-0.4902649	-4.373169E-02	-0.4902649	-3.585815E-02
-0.4853821	-4.354858E-02	-0.4853821	-3.308105E-02
-0.4804993	-0.0428772	-0.4804993	-3.036499E-02
-0.4756165	-4.022217E-02	-0.4756165	-2.770996E-02
-0.4707336	-3.569946E-02	-0.4707336	-2.520142E-02
-0.4658508	-3.180847E-02	-0.4658508	-2.264709E-02
-0.460968	-2.808533E-02	-0.460968	-2.027283E-02
-0.4560852	-2.453003E-02	-0.4560852	-1.805115E-02
-0.4512024	-2.111816E-02	-0.4512024	-1.596985E-02
-0.4463196	-1.800537E-02	-0.4463196	-1.436462E-02
-0.4414368	-1.516724E-02	-0.4414368	-1.272583E-02
-0.436554	-1.277466E-02	-0.436554	-1.124878E-02
-0.4316711	-0.0108429	-0.4316711	-9.899902E-03
-0.4267883	-9.262085E-03	-0.4267883	-8.74939E-03
-0.4219055	-7.742309E-03	-0.4219055	-7.51648E-03
-0.4170227	-6.488037E-03	-0.4170227	-6.292725E-03
-0.4121399	-5.377197E-03	-0.4121399	-5.496216E-03
-0.4072571	-4.345703E-03	-0.4072571	-4.821777E-03
-0.4023743	-3.585815E-03	-0.4023743	-4.074097E-03
-0.3974915	-2.72522E-03	-0.3974915	-3.305054E-03
-0.3926086	-2.005005E-03	-0.3926086	-2.813721E-03
-0.3877258	-1.348877E-03	-0.3877258	-2.325439E-03
-0.382843	-8.392334E-04	-0.382843	-1.843262E-03
-0.3779602	-4.022217E-04	-0.3779602	-1.454773E-03
-0.3730774	8.789063E-05	-0.3730774	-1.101685E-03
-0.3681946	4.98352E-04	-0.3681946	-7.76062E-04
-0.3633118	8.798218E-04	-0.3633118	-4.986572E-04
-0.358429	1.196289E-03	-0.358429	-2.471924E-04
-0.3535461	1.533813E-03	-0.3535461	7.507324E-05
-0.3486633	1.852722E-03	-0.3486633	2.133179E-04
-0.3437805	2.119141E-03	-0.3437805	5.041504E-04
-0.3388977	2.31781E-03	-0.3388977	6.97937E-04
-0.3340149	2.550049E-03	-0.3340149	7.150269E-04
-0.3291321	2.802734E-03	-0.3291321	4.193115E-04
-0.3242493	3.037415E-03	-0.3242493	9.616089E-04
-0.3193665	3.232422E-03	-0.3193665	1.048584E-03
-0.3144836	3.464966E-03	-0.3144836	1.157837E-03
-0.3096008	3.576965E-03	-0.3096008	1.192627E-03
-0.304718	3.710937E-03	-0.304718	1.209412E-03
-0.2998352	3.820801E-03	-0.2998352	1.177063E-03
-0.2949524	3.975525E-03	-0.2949524	1.225586E-03
-0.2900696	4.055786E-03	-0.2900696	1.163635E-03
-0.2851868	4.135132E-03	-0.2851868	1.276245E-03
-0.280304	4.301758E-03	-0.280304	1.209106E-03
-0.2754211	4.405518E-03	-0.2754211	1.09375E-03
-0.2705383	4.627381E-03	-0.2705383	9.814453E-04

Potential (V)	Current (A)	Potential (V)	Current (A)
-0.2656555	4.680481E-03	-0.2656555	9.475708E-04
-0.2607727	4.769287E-03	-0.2607727	9.542847E-04
-0.2558899	4.87854E-03	-0.2558899	8.764648E-04
-0.2510071	5.044556E-03	-0.2510071	9.146118E-04
-0.2461243	5.126953E-03	-0.2461243	1.074524E-03
-0.2412415	5.252075E-03	-0.2412415	1.195373E-03
-0.2363586	5.441284E-03	-0.2363586	1.271667E-03
-0.2314758	5.471802E-03	-0.2314758	1.244202E-03
-0.226593	5.630493E-03	-0.226593	1.187134E-03
-0.2217102	5.853272E-03	-0.2217102	1.222839E-03
-0.2168274	5.862427E-03	-0.2168274	1.239929E-03
-0.2119446	6.109619E-03	-0.2119446	1.231079E-03
-0.2070618	6.188965E-03	-0.2070618	1.325989E-03
-0.202179	6.286621E-03	-0.202179	1.351624E-03
-0.1972961	6.448364E-03	-0.1972961	1.417542E-03
-0.1924133	6.524658E-03	-0.1924133	1.528015E-03
-0.1875305	6.762695E-03	-0.1875305	1.695862E-03
-0.1826477	6.774902E-03	-0.1826477	1.836548E-03
-0.1777649	7.034302E-03	-0.1777649	1.909485E-03
-0.1728821	7.223511E-03	-0.1728821	1.897278E-03
-0.1679993	7.281494E-03	-0.1679993	1.896057E-03
-0.1631165	7.385254E-03	-0.1631165	1.886597E-03
-0.1582336	7.666016E-03	-0.1582336	2.033081E-03
-0.1533508	7.684326E-03	-0.1533508	0.0020401
-0.148468	7.672119E-03	-0.148468	2.133179E-03
-0.1435852	7.873535E-03	-0.1435852	2.233887E-03
-0.1387024	7.971192E-03	-0.1387024	2.420654E-03
-0.1338196	8.056641E-03	-0.1338196	2.565918E-03
-0.1289368	8.081054E-03	-0.1289368	2.693176E-03
-0.124054	8.135987E-03	-0.124054	2.686462E-03
-0.1191711	8.337403E-03	-0.1191711	2.689514E-03
-0.1142883	8.343506E-03	-0.1142883	2.651672E-03
-0.1094055	8.462524E-03	-0.1094055	2.657471E-03
-0.1045227	8.486939E-03	-0.1045227	2.69104E-03
-9.963989E-02	8.569336E-03	-9.963989E-02	2.782898E-03
-9.475708E-02	8.786011E-03	-9.475708E-02	2.833862E-03
-8.987427E-02	8.950805E-03	-8.987427E-02	2.818298E-03
-8.499146E-02	9.09729E-03	-8.499146E-02	2.901306E-03
-8.010864E-02	9.16748E-03	-8.010864E-02	2.919006E-03
-7.522583E-02	1.010132E-02	-7.522583E-02	3.132935E-03
-7.034302E-02	1.101685E-02	-7.034302E-02	3.245544E-03
-6.546021E-02	1.109924E-02	-6.546021E-02	3.146667E-03
-6.057739E-02	1.078796E-02	-6.057739E-02	3.156128E-03
-5.569458E-02	1.046753E-02	-5.569458E-02	3.09082E-03
-5.081177E-02	1.041565E-02	-5.081177E-02	3.08197E-03
-4.592896E-02	1.042175E-02	-4.592896E-02	3.153381E-03
-4.104614E-02	1.091309E-02	-4.104614E-02	3.171387E-03
-3.616333E-02	0.0108551	-3.616333E-02	3.375855E-03
-3.128052E-02	1.083984E-02	-3.128052E-02	3.511352E-03

Potential (V)	Current (A)	Potential (V)	Current (A)
-2.639771E-02	1.100464E-02	-2.639771E-02	3.597717E-03
-2.151489E-02	1.127014E-02	-2.151489E-02	3.934021E-03
-1.663208E-02	1.136475E-02	-1.663208E-02	4.448242E-03
-1.174927E-02	1.159973E-02	-1.174927E-02	4.543457E-03
-6.866455E-03	1.178589E-02	-6.866455E-03	4.986572E-03
-1.983643E-03	1.196594E-02	-1.983643E-03	5.224609E-03
2.89917E-03	1.210632E-02	2.89917E-03	5.429077E-03
7.781982E-03	1.209412E-02	7.781982E-03	5.477905E-03
1.266479E-02	0.012146	1.266479E-02	5.575561E-03
1.754761E-02	1.192627E-02	1.754761E-02	5.541992E-03
2.243042E-02	1.338501E-02	2.243042E-02	5.432129E-03
2.731323E-02	1.360474E-02	2.731323E-02	5.282593E-03
3.219604E-02	1.320496E-02	3.219604E-02	5.249023E-03
3.707886E-02	1.265564E-02	3.707886E-02	5.06897E-03
4.196167E-02	1.256409E-02	4.196167E-02	4.968262E-03
4.684448E-02	1.220093E-02	4.684448E-02	5.090332E-03
5.172729E-02	1.231079E-02	5.172729E-02	5.13916E-03
5.661011E-02	1.210327E-02	5.661011E-02	5.148315E-03
6.149292E-02	1.198425E-02	6.149292E-02	5.08728E-03
6.637573E-02	1.160278E-02	6.637573E-02	5.004883E-03
7.125854E-02	1.109924E-02	7.125854E-02	5.023194E-03
7.614136E-02	1.079102E-02	7.614136E-02	4.944153E-03
8.102417E-02	1.070252E-02	8.102417E-02	4.69513E-03
8.590698E-02	1.061401E-02	8.590698E-02	4.578247E-03
9.078979E-02	1.013184E-02	9.078979E-02	4.663086E-03
9.567261E-02	1.010742E-02	9.567261E-02	5.090332E-03
0.1005554	1.034241E-02	0.1005554	5.151367E-03
0.1054382	9.710694E-03	0.1054382	5.065918E-03
0.110321	9.494019E-03	0.110321	5.093384E-03
0.1152039	9.231567E-03	0.1152039	4.989624E-03
0.1200867	9.100342E-03	0.1200867	4.941711E-03
0.1249695	9.146119E-03	0.1249695	5.187988E-03
0.1298523	9.295654E-03	0.1298523	4.935913E-03
0.1347351	8.865356E-03	0.1347351	5.023194E-03
0.1396179	8.972168E-03	0.1396179	4.750976E-03
0.1445007	8.758545E-03	0.1445007	4.50592E-03
0.1493835	8.450317E-03	0.1493835	4.572754E-03
0.1542664	8.139038E-03	0.1542664	4.910584E-03
0.1591492	7.958984E-03	0.1591492	4.788818E-03
0.164032	7.772827E-03	0.164032	0.0047995
0.1689148	7.843018E-03	0.1689148	5.184936E-03
0.1737976	7.702637E-03	0.1737976	5.157471E-03
0.1786804	7.76062E-03	0.1786804	5.200195E-03
0.1835632	7.775879E-03	0.1835632	5.328369E-03
0.188446	7.821655E-03	0.188446	1.116333E-02
0.1933289	7.415771E-03	0.1933289	1.122131E-02
0.1982117	7.302857E-03	0.1982117	1.146545E-02
0.2030945	7.830811E-03	0.2030945	1.235046E-02
0.2079773	7.635498E-03	0.2079773	1.301575E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
0.2128601	7.546997E-03	0.2128601	1.342773E-02
0.2177429	7.357788E-03	0.2177429	1.443481E-02
0.2226257	7.250977E-03	0.2226257	1.459351E-02
0.2275085	7.501221E-03	0.2275085	1.511536E-02
0.2323914	7.473755E-03	0.2323914	1.480103E-02
0.2372742	7.635498E-03	0.2372742	1.506958E-02
0.242157	7.913208E-03	0.242157	1.537781E-02
0.2470398	8.026123E-03	0.2470398	1.525574E-02
0.2519226	7.794189E-03	0.2519226	1.567993E-02
0.2568054	7.989502E-03	0.2568054	1.602783E-02
0.2616882	8.062745E-03	0.2616882	1.592407E-02
0.266571	8.624268E-03	0.266571	0.0164978
0.2714539	8.105469E-03	0.2714539	1.647339E-02
0.2763367	8.285522E-03	0.2763367	1.655274E-02
0.2812195	8.224487E-03	0.2812195	1.660461E-02
0.2861023	8.624268E-03	0.2861023	1.685181E-02
0.2909851	8.474732E-03	0.2909851	1.685791E-02
0.2958679	8.251953E-03	0.2958679	1.714478E-02
0.3007507	8.69751E-03	0.3007507	1.739197E-02
0.3056335	8.599853E-03	0.3056335	1.693115E-02
0.3105164	8.428955E-03	0.3105164	1.705933E-02
0.3153992	8.441162E-03	0.3153992	1.709289E-02
0.320282	8.54187E-03	0.320282	1.705322E-02
0.3251648	8.514404E-03	0.3251648	1.641541E-02
0.3300476	8.236694E-03	0.3300476	1.723328E-02
0.3349304	8.502197E-03	0.3349304	1.772156E-02
0.3398132	8.139038E-03	0.3398132	0.0177948
0.344696	7.662964E-03	0.344696	0.0172699
0.3495789	7.623291E-03	0.3495789	1.738281E-02
0.3544617	8.181763E-03	0.3544617	1.719971E-02
0.3593445	8.020019E-03	0.3593445	1.745911E-02
0.3642273	8.343506E-03	0.3642273	1.719971E-02
0.3691101	7.901001E-03	0.3691101	1.687012E-02
0.3739929	7.946777E-03	0.3739929	1.756897E-02
0.3788757	8.300781E-03	0.3788757	1.789246E-02
0.3837585	8.12378E-03	0.3837585	1.746216E-02
0.3886414	8.099365E-03	0.3886414	1.731567E-02
0.3935242	8.551026E-03	0.3935242	1.704407E-02
0.398407	8.258057E-03	0.398407	1.725464E-02
0.4032898	8.187866E-03	0.4032898	1.810608E-02
0.4081726	7.60498E-03	0.4081726	1.766052E-02
0.4130554	7.366943E-03	0.4130554	0.0175293
0.4179382	7.492065E-03	0.4179382	1.776123E-02
0.422821	7.446289E-03	0.422821	1.797485E-02
0.4277039	7.290649E-03	0.4277039	1.800232E-02
0.4325867	7.546997E-03	0.4325867	1.775208E-02
0.4374695	7.312012E-03	0.4374695	1.763306E-02
0.4423523	7.647705E-03	0.4423523	1.781311E-02
0.4472351	7.531738E-03	0.4472351	1.842957E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
0.4521179	7.553101E-03	0.4521179	0.0186676
0.4570007	7.180786E-03	0.4570007	1.835022E-02
0.4618835	7.116699E-03	0.4618835	1.845093E-02
0.4667664	7.241821E-03	0.4667664	1.829224E-02
0.4716492	7.226563E-03	0.4716492	1.855774E-02
0.476532	8.850098E-03	0.476532	1.844788E-02
0.4814148	8.834839E-03	0.4814148	1.809082E-02
0.4862976	8.215332E-03	0.4862976	1.871948E-02
0.4911804	8.517456E-03	0.4911804	1.908569E-02
0.4960632	7.836914E-03	0.4960632	1.903992E-02
0.500946	7.598877E-03	0.500946	1.868591E-02
0.5058289	7.830811E-03	0.5058289	1.738586E-02
0.5107117	7.409668E-03	0.5107117	1.726685E-02
0.5155945	7.723999E-03	0.5155945	1.724548E-02
0.5204773	7.476807E-03	0.5204773	1.728821E-02
0.5253601	7.452392E-03	0.5253601	0.0176239
0.5302429	7.177734E-03	0.5302429	1.864624E-02
0.5351257	7.241821E-03	0.5351257	1.740112E-02
0.5400085	6.826782E-03	0.5400085	1.803894E-02
0.5448914	6.237793E-03	0.5448914	1.811523E-02
0.5497742	6.329346E-03	0.5497742	1.722412E-02
0.554657	6.472779E-03	0.554657	1.744385E-02
0.5595398	6.433106E-03	0.5595398	0.017099
0.5644226	6.173706E-03	0.5644226	1.708069E-02
0.5693054	6.149292E-03	0.5693054	1.699524E-02
0.5741882	5.334473E-03	0.5741882	1.678467E-02
0.579071	5.892945E-03	0.579071	1.665039E-02
0.5839539	6.100464E-03	0.5839539	1.760559E-02
0.5888367	5.603028E-03	0.5888367	1.781921E-02
0.5937195	5.551147E-03	0.5937195	0.0175415
0.5986023	5.459595E-03	0.5986023	1.723328E-02
0.6034851	5.517578E-03	0.6034851	1.700439E-02
0.6083679	5.19104E-03	0.6083679	0.0174408
0.6132507	5.075073E-03	0.6132507	1.700439E-02
0.6181335	5.264282E-03	0.6181335	1.598816E-02
0.6230164	4.897461E-03	0.6230164	1.698303E-02
0.6278992	4.927063E-03	0.6278992	1.652222E-02
0.632782	4.509277E-03	0.632782	0.015979
0.6376648	5.053711E-03	0.6376648	1.724243E-02
0.6425476	4.918518E-03	0.6425476	1.599426E-02
0.6474304	4.714966E-03	0.6474304	1.674805E-02
0.6523132	4.014282E-03	0.6523132	1.622009E-02
0.657196	4.835205E-03	0.657196	0.0160614
0.6620789	5.044556E-03	0.6620789	1.654053E-02
0.6669617	4.783325E-03	0.6669617	1.624451E-02
0.6718445	4.676208E-03	0.6718445	1.730957E-02
0.6767273	4.590759E-03	0.6767273	1.697693E-02
0.6816101	5.014038E-03	0.6816101	1.600647E-02
0.6864929	4.642944E-03	0.6864929	1.625366E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
0.6913757	4.667969E-03	0.6913757	1.670227E-02
0.6962585	4.667969E-03	0.6962585	1.679382E-02
0.7011414	4.656677E-03	0.7011414	1.550903E-02
0.7060242	4.200744E-03	0.7060242	1.604309E-02
0.710907	4.283447E-03	0.710907	1.649475E-02
0.7157898	4.038391E-03	0.7157898	1.654968E-02
0.7206726	4.226685E-03	0.7206726	0.0161438
0.7255554	4.455871E-03	0.7255554	1.570129E-02
0.7304382	4.494324E-03	0.7304382	1.614075E-02
0.735321	4.237671E-03	0.735321	0.0158783
0.7402039	4.453125E-03	0.7402039	1.528931E-02
0.7450867	3.807068E-03	0.7450867	1.538696E-02
0.7499695	3.817444E-03	0.7499695	1.480713E-02
0.7548523	4.061279E-03	0.7548523	1.641846E-02
0.7597351	4.150696E-03	0.7597351	1.586609E-02
0.7646179	4.302368E-03	0.7646179	1.470642E-02
0.7695007	4.382019E-03	0.7695007	1.602783E-02
0.7743835	4.34021E-03	0.7743835	0.0153717
0.7792664	4.278259E-03	0.7792664	1.496582E-02
0.7841492	4.114685E-03	0.7841492	0 .0158905
0.789032	4.068604E-03	0.789032	1.678772E-02
0.7939148	0.0037854	0.7939148	1.548462E-02
0.7987976	4.233398E-03	0.7987976	1.576538E-02
0.8036804	3.917236E-03	0.8036804	1.636963E-02
0.8085632	3.749695E-03	0.8085632	1.539917E-02
0.813446	3.346558E-03	0.813446	1.515198E-02
0.8183289	3.401489E-03	0.8183289	0.0155304
0.8232117	3.621216E-03	0.8232117	1.601562E-02
0.8280945	3.941956E-03	0.8280945	1.659241E-02
0.8329773	4.059143E-03	0.8329773	1.487427E-02
0.8378601	3.965454E-03	0.8378601	1.539001E-02
0.8427429	3.49823E-03	0.8427429	1.572876E-02
0.8476257	3.543091E-03	0.8476257	1.561585E-02
0.8525085	3.214722E-03	0.8525085	1.541443E-02
0.8573914	3.224182E-03	0.8573914	1.595764E-02
0.8622742	3.056946E-03	0.8622742	1.522827E-02
0.867157	3.005371E-03	0.867157	1.612549E-02
0.8720398	0.003237	0.8720398	1.630249E-02
0.8769226	3.043213E-03	0.8769226	1.564941E-02
0.8818054	2.999268E-03	0.8818054	1.594238E-02
0.8866882	3.037109E-03	0.8866882	1.625366E-02
0.891571	3.267212E-03	0.891571	1.593628E-02
0.8964539	3.175354E-03	0.8964539	1.559143E-02
0.9013367	3.111267E-03	0.9013367	1.582947E-02
0.9062195	2.987366E-03	0.9062195	1.548157E-02
0.9111023	3.182678E-03	0.9111023	1.569519E-02
0.9159851	3.163452E-03	0.9159851	0.0167572
0.9208679	3.02063E-03	0.9208679	1.610413E-02
0.9257507	2.893982E-03	0.9257507	1.588745E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
0.9306335	2.733459E-03	0.9306335	1.629639E-02
0.9355164	2.846374E-03	0.9355164	1.714783E-02
0.9403992	3.04657E-03	0.9403992	1.684875E-02
0.945282	3.14148E-03	0.945282	1.554565E-02
0.9501648	3.220825E-03	0.9501648	1.616821E-02
0.9550476	3.195496E-03	0.9550476	1.551208E-02
0.9599304	3.109741E-03	0.9599304	0.0164093
0.9648132	2.957459E-03	0.9648132	1.643982E-02
0.969696	2.928162E-03	0.969696	1.645508E-02
0.9745789	2.963562E-03	0.9745789	1.636658E-02
0.9794617	2.896118E-03	0.9794617	1.665955E-02
0.9843445	2.911987E-03	0.9843445	1.665344E-02
0.9892273	2.90863E-03	0.9892273	1.705628E-02
0.9941101	3.246765E-03	0.9941101	1.747131E-02
0.9989929	3.276977E-03	0.9989929	1.765442E-02
1.003876	3.29834E-03	1.003876	1.680298E-02
1.008759	3.417053E-03	1.008759	1.768799E-02
1.013641	3.339233E-03	1.013641	1.698914E-02
1.018524	3.876648E-03	1.018524	1.711121E-02
1.023407	3.876038E-03	1.023407	1.734009E-02
1.02829	3.934021E-03	1.02829	1.720886E-02
1.033173	4.544678E-03	1.033173	1.794739E-02
1.038055	4.691162E-03	1.038055	1.815186E-02
1.042938	4.874878E-03	1.042938	1.966553E-02
1.047821	4.980469E-03	1.047821	1.897278E-02
1.052704	5.371094E-03	1.052704	1.850281E-02
1.057587	5.502319E-03	1.057587	1.955872E-02
1.062469	5.92041E-03	1.062469	1.959229E-02
1.067352	6.610108E-03	1.067352	2.010803E-02
1.072235	8.908081E-03	1.072235	2.034302E-02
1.077118	9.262085E-03	1.077118	2.061462E-02
1.082001	9.631348E-03	1.082001	2.528686E-02
1.086884	9.500122E-03	1.086884	3.279419E-02
1.091766	9.649659E-03	1.091766	3.494263E-02
1.096649	9.509278E-03	1.096649	3.665771E-02
1.101532	9.552002E-03	1.101532	3.622437E-02
1.106415	9.320068E-03	1.106415	3.822327E-02
1.111298	8.88977E-03	1.111298	3.853149E-02
1.11618	9.179687E-03	1.11618	3.952942E-02
1.121063	9.378051E-03	1.121063	3.635864E-02
1.125946	8.874511E-03	1.125946	0.0412384
1.130829	8.773804E-03	1.130829	3.910523E-02
1.135712	8.963013E-03	1.135712	3.825989E-02
1.140594	9.295654E-03	1.140594	4.265442E-02
1.145477	9.09729E-03	1.145477	0.041922
1.15036	8.87146E-03	1.15036	3.826904E-02
1.155243	1.775818E-02	1.155243	3.734436E-02
1.160126	1.618652E-02	1.160126	4.067383E-02
1.165009	1.578064E-02	1.165009	3.917541E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
1.169891	1.531982E-02	1.169891	3.795471E-02
1.174774	1.594238E-02	1.174774	0.0360199
1.179657	1.622925E-02	1.179657	3.732605E-02
1.18454	1.547852E-02	1.18454	0.038797
1.189423	1.506653E-02	1.189423	4.015198E-02
1.194305	1.488647E-02	1.194305	3.856506E-02
1.199188	1.488953E-02	1.199188	3.828735E-02
1.204071	1.508789E-02	1.204071	3.833008E-02
1.208954	1.491394E-02	1.208954	3.752136E-02
1.213837	1.482544E-02	1.213837	3.783875E-02
1.218719	0.0144165	1.218719	3.988647E-02
1.223602	1.394959E-02	1.223602	3.398437E-02
1.228485	1.384888E-02	1.228485	3.702087E-02
1.233368	1.351624E-02	1.233368	3.512573E-02
1.238251	1.423035E-02	1.238251	3.033447E-02
1.243134	1.414185E-02	1.243134	3.575439E-02
1.248016	1.380005E-02	1.248016	3.679199E-02
1.252899	1.379089E-02	1.252899	3.668213E-02
1.257782	1.415405E-02	1.257782	0.0365387
1.262665	1.364441E-02	1.262665	3.529663E-02
1.267548	0.0138031	1.267548	3.439941E-02
1.27243	1.408081E-02	1.27243	3.232117E-02
1.277313	1.394348E-02	1.277313	3.709717E-02
1.282196	1.428223E-02	1.282196	3.269043E-02
1.287079	0.0132843	1.287079	3.460388E-02
1.291962	1.252441E-02	1.291962	3.594666E-02
1.296844	0.0130188	1.296844	3.857422E-02
1.301727	1.299133E-02	1.301727	3.760681E-02
1.30661	1.265869E-02	1.30661	3.609009E-02
1.311493	1.669312E-02	1.311493	3.479614E-02
1.316376	1.445618E-02	1.316376	3.867187E-02
1.321259	1.401062E-02	1.321259	3.578186E-02
1.326141	1.352539E-02	1.326141	3.702087E-02
1.331024	1.448364E-02	1.331024	3.580933E-02
1.335907	0.0144165	1.335907	3.768616E-02
1.34079	0.0132843	1.34079	0.0364502
1.345673	1.235352E-02	1.345673	3.592224E-02
1.350555	1.196289E-02	1.350555	3.695374E-02
1.355438	1.315613E-02	1.355438	0.0364563
1.360321	1.325378E-02	1.360321	3.576355E-02
1.365204	1.360474E-02	1.365204	3.401489E-02
1.370087	0.0119873	1.370087	3.466797E-02
1.374969	1.164551E-02	1.374969	3.578186E-02
1.379852	1.156311E-02	1.379852	0.0341156
1.384735	1.333923E-02	1.384735	3.237915E-02
1.389618	1.357727E-02	1.389618	3.587646E-02
1.394501	1.347961E-02	1.394501	3.814087E-02
1.399384	1.241455E-02	1.399384	3.735352E-02
1.404266	1.208496E-02	1.404266	3.606873E-02

Potential (V)	Current (A)	Potential (V)	Current (A)
1.409149	1.274719E-02	1.409149	3.568726E-02
1.414032	1.282043E-02	1.414032	3.548889E-02
1.418915	1.281738E-02	1.418915	3.607788E-02
1.423798	0.0129303	1.423798	3.562622E-02
1.42868	1.288757E-02	1.42868	3.507385E-02
1.433563	1.425781E-02	1.433563	3.385925E-02
1.438446	1.389465E-02	1.438446	3.641968E-02
1.443329	1.422424E-02	1.443329	3.126526E-02
1.448212	1.429749E-02	1.448212	0.0355011
1.453094	1.360779E-02	1.453094	3.533325E-02
1.457977	1.325684E-02	1.457977	3.518677E-02
1.46286	1.399536E-02	1.46286	3.636169E-02
1.467743	1.453552E-02	1.467743	3.569641E-02
1.472626	1.527405E-02	1.472626	3.643494E-02
1.477509	1.472473E-02	1.477509	3.552551E-02
1.482391	1.439819E-02	1.482391	3.444824E-02
1.487274	1.625671E-02	1.487274	3.519592E-02
1.492157	0.0168457	1.492157	3.635559E-02
1.49704	1.594238E-02	1.49704	3.510437E-02
1.501923	1.639099E-02	1.501923	3.327942E-02

Appendix B

Polarization curves of 304 stainless steel in 1 N H_2SO_4 with various CMC of SDS

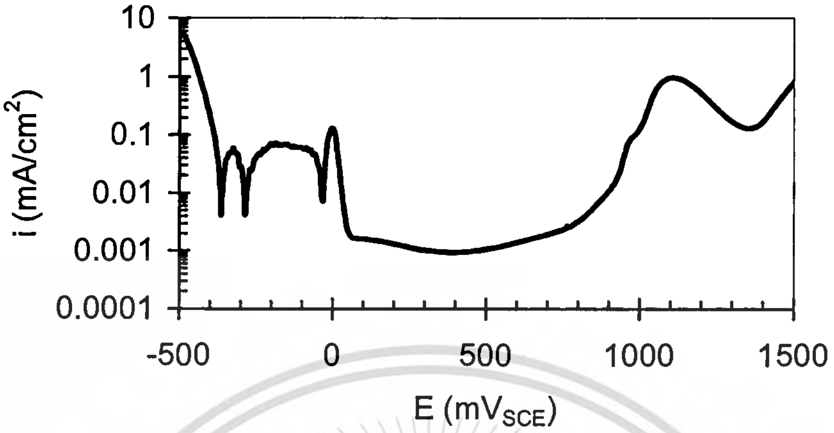

Figure B1: polarization curve of 304 stainless steel in 1N H_2SO_4

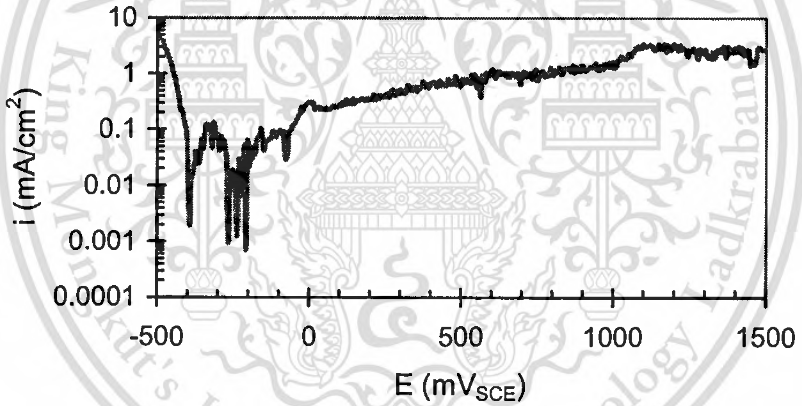

Figure B2: Polarization curve of 304 stainless steel in 1N H_2SO_4+ 0.25CMC of SDS

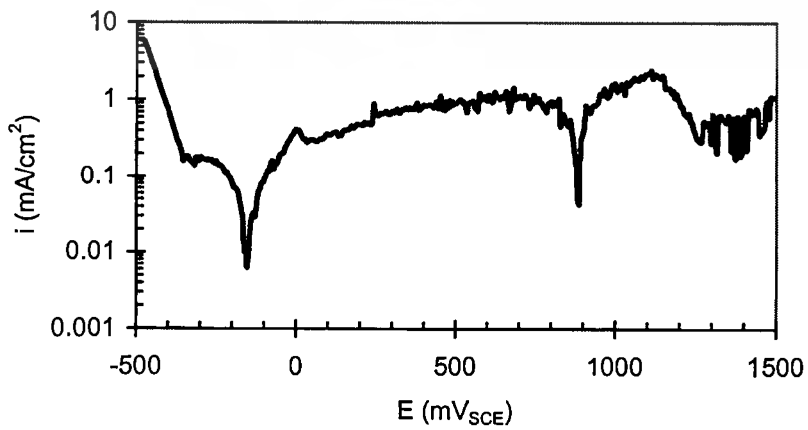

Figure B3: Polarization curve of 304 stainless steel in 1N H_2SO_4+ 0.5CMC of SDS

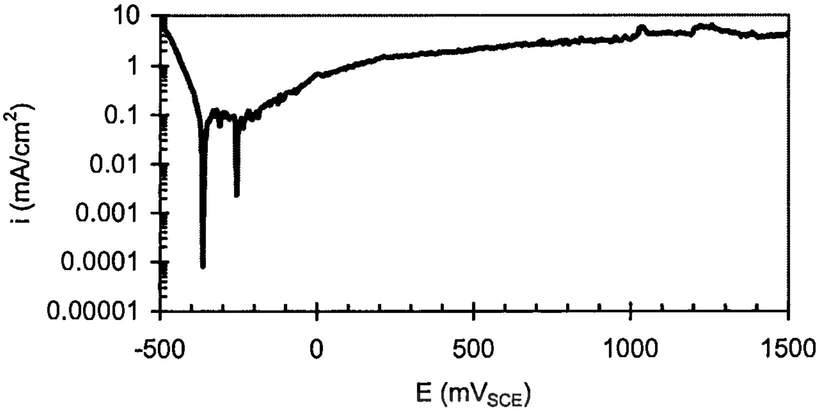

Figure B4: Polarization curve of 304 stainless steel in 1N H_2SO_4+ CMC of SDS

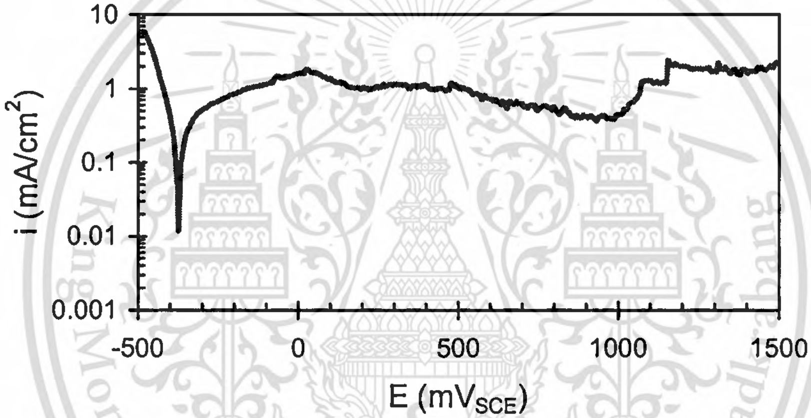

Figure B5: Polarization curve of 304 stainless steel in 1N H_2SO_4+ 2CMC of SDS

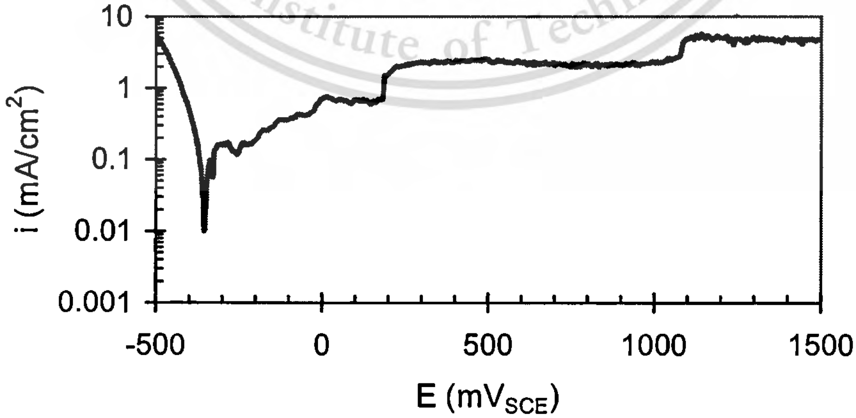

Figure B6: Polarization curve of 304 stainless steel in 1N H_2SO_4+ 4CMC of SDS

Appendix C

Anodic and cathodic slopes of 304 stainless steel in 1 N H_2SO_4 with various CMC of SDS

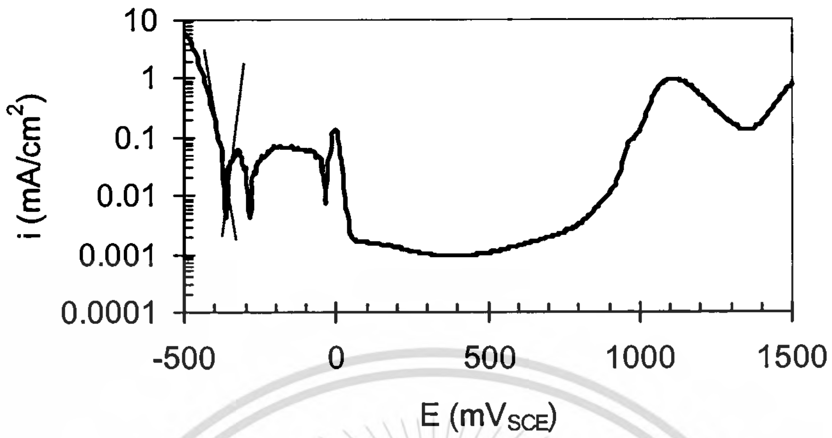

Figure C1: Anodic and cathodic slopes of 304 stainless steel in 1N H_2SO_4

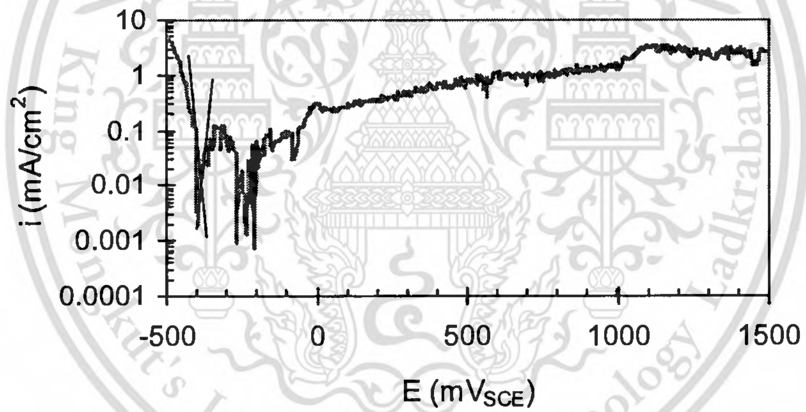

Figure C2: Anodic and cathodic slopes of 304 stainless steel in 1N H_2SO_4+ 0.25CMC of SDS

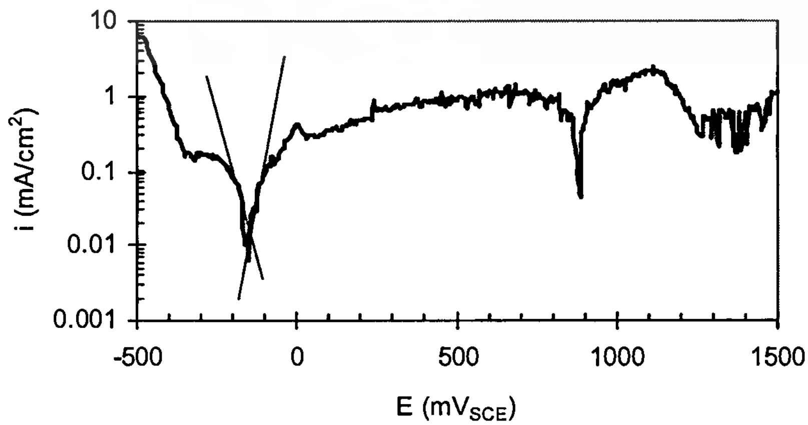

Figure C3: Anodic and cathodic slopes of 304 stainless steel in 1N H_2SO_4+ 0.5CMC of SDS

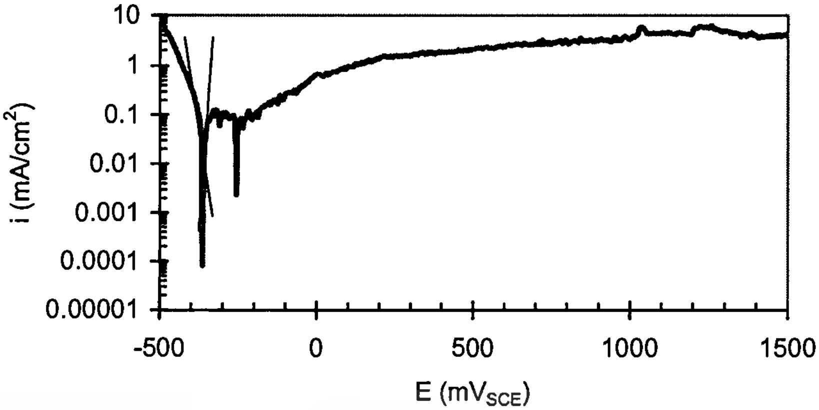

Figure C4: Anodic and cathodic slopes of 304 stainless steel in 1N H_2SO_4+ CMC of SDS

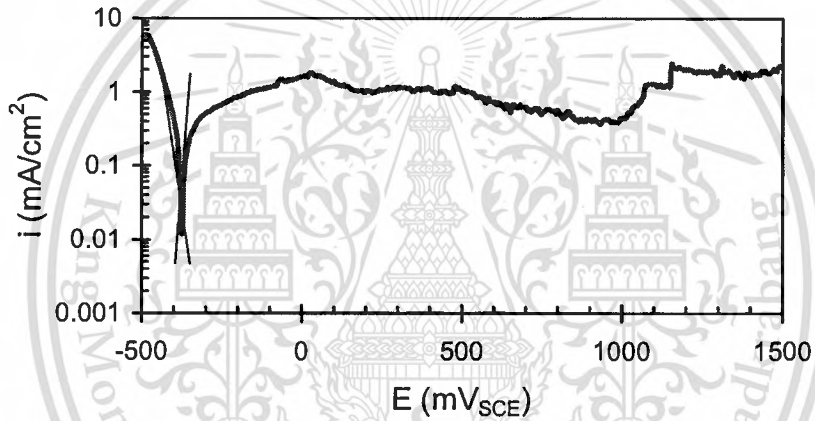

Figure C5: Anodic and cathodic slopes of 304 stainless steel in 1N H_2SO_4+ 2CMC of SDS

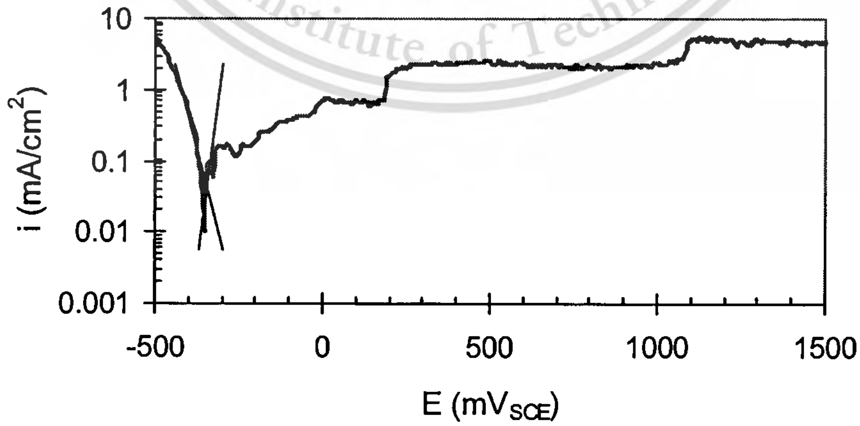

Figure C6: Anodic and cathodic slopes of 304 stainless steel in 1N H_2SO_4+ 4CMC of SDS

Appendix D

Calculation

1. Atomic weight of stainless steel

Stainless steel = 8%Ni + 18%Cr + 74%Fe

Atomic mass: Ni = 58.6934

Cr = 51.9960

Fe = 55.847

Atomic weight of stainless steel = 0.08(58.6934) + 0.18(51.9960) + 0.74(55.847)

= 55.38 g/mol

2. Corrosion rate

According to Faraday's Law

$$W = \frac{iAtM}{nF}$$

where;

W	=	weight loss at instant second time (g)
M	=	atomic weight of metal (g/mol)
i	=	current density (A/cm^2)
n	=	number of electron moles during corrosion
F	=	Faraday's constant (96,500 C/mol or 96,500 A•s/mol)
A	=	average surface area (cm^2)
t	=	time

For 304 stainless steel in 1 N H_2SO_4 in absence of SDS,

From table 3, the value of i_{corr} of 304 stainless steel in 1 N H_2SO_4 in absence of SDS is 0.010 mA/ cm^2.

$$\frac{W}{At} = \frac{0.010\ \text{mA}}{\text{cm}^2} \cdot \frac{1}{2} \cdot \frac{55.38\ \text{g}}{\text{mol}} \cdot \frac{\text{mol}}{9{,}6500\ \text{A•s}}$$

$$= \frac{2.87\text{x}10^{-6}\ \text{mg}}{\text{cm}^2\text{•s}} \cdot \frac{60\ \text{s}}{1\ \text{min}} \cdot \frac{60\ \text{min}}{1\ \text{hr}} \cdot \frac{24\ \text{hr}}{1\ \text{day}} \cdot \frac{365\ \text{day}}{1\ \text{y}}$$

$$= \underline{90.5}\ \text{mg / cm}^2\text{•y}$$

The same calculation method can be used for 304 stainless steel in 1 N H_2SO_4 in presence of 0.25CMC, 0.5CMC, CMC, 2CMC, and 4CMC of SDS.

3. The polarization resistance, R_p

From following equation

$$R_p = \frac{b_a b_c}{2.303\, i_{corr}\,(b_a + b_c)}$$

where; b_a = the slopes of anodic Tafel lines

b_c = the slopes of cathodic Tafel lines

For 304 stainless steel in 1 N H_2SO_4 in absence of SDS,

From table 3, the values of b_a and b_c of 304 stainless steel in 1 N H_2SO_4 in absence of SDS are 20 and 32, respectively.

$$R_p = \frac{20\text{ mV}}{\text{decade}} \cdot \frac{32\text{ mV}}{\text{decade}} \cdot \frac{1}{2.303} \cdot \frac{\text{cm}^2}{0.010\text{ mA}} \cdot \frac{\text{decade}}{(20+32)\text{ mV}}$$

$$= \underline{537.42}\ \Omega\cdot\text{cm}^2$$

The same calculation method can be used for 304 stainless steel in 1 N H_2SO_4 in presence of 0.25CMC, 0.5CMC, CMC, 2CMC, and 4CMC of SDS.

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