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# Corrosion Prevention of Underground Reinjection Pipeline Using Geothermal-powered Impressed Current Cathodic Protection in Lahendong Geothermal Area

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## ABSTRACT

A low pH Brine that flows through carbon steel pipe to the reinjection well will expose a rapid rate of pipe corrosion. Moreover, underground installation of pipe will multiply this corrosion effect and lead in environment pollution and financial losses. This issue could be reduced by applying novel method of corrosion prevention named Geothermal-powered Impressed Current Cathodic Protection (GICCP). This system utilizes a geothermal power source from heat of geothermal pipeline and converts to electric power by using thermoelectric device. Then the electric power is used in GICCP to develop a high potential difference between the surface of pipe to be protected and an anode. It is expected that the implementation of GICCP could inhibit the corrosion rate, extend the remaining life of pipeline, and reduce downtime period as well as the possibility of financial losses in geothermal industry.

## 1. INTRODUCTION

The piping system is one of the most important and most widely used fluid distribution facilities in the industrial world. The fluid that is supplied by the pipe usually has its own characteristics so that it can affect the performance or quality of the pipe itself. The influencing characteristics include fluid temperature, fluid pH, fluid content, etc. One of the effects of the characteristics of an adverse fluid is the occurrence of corrosion which can cause failure in a material.

Corrosion is a natural process that cannot be avoided which can reduce the quality and physical properties of a material. One of the causes of the increase in the corrosion rate of a material is the low pH and the high temperature of the fluid flowing in the material.Corrosion is the electrochemical / chemical interaction process between metal materials and the environment that causes changes in metal properties so that there is a significant weakening of the function of metals, environment and systems. The process of corrosion in metals occurs because of the nature of metals that are easily oxidized both at low temperatures and at high temperatures. [2]

The common methodologies deployed to prevent Corrosion include the use of anodic and cathodic inhibitors, barrier coatings and sacrificial anodic method. However, it has been proven quite extensively in various research studies that the most efficient of these corrosion prevention techniques is Impressed Current Cathodic Protection. This technique involves impressing current over the cathode of the corrosion cell, thereby providing a stream of electrons over the metallic surface. This technique is clearly more preferred than the sacrificial anode system. The voltage differences between anode and cathode are limited in sacrificial anode systems to approximately one volt or less, depending on the anode material and particular environment. Impressed current systems can use larger voltage differences. The larger voltages available with impressed currents allow remote anode locations,producing more efficient current distribution patterns along the protected cathode. These larger voltages are useful in low conductivity environments such as freshwater and concrete. [10]

In this proposed system of Impressed Current Cathodic Protection, output power from the heat of geothermal pipeline is converted into electric power by using thermoelectric device. Then it used to charge and recharge the DC battery source enabling continuous current supply to the iron pipelines employed as the cathode. The subject of corrosion has undergone an irreversible transformation from a state of isolation and obscurity to a recognized discipline of engineering, making it a subject of extreme importance that requires attention. In this era of energy and power crisis, renewable energy sources like geothermal energy exhibit their potential to provide a complete solution to various challenges facing mankind, when used in conjunction with existing protection principles available.[8].

## 2. CORROSION

Corrosion is an electrochemical oxidation reaction that requires an anode, a cathode, an electron pathway and an electrolyte to take place. The complete system comprising these components is called a corrosion cell. The process of corrosion is mostly a nuisance since it leads to the damage of metals and must be prevented from taking place. This is often the case in buried metallic structures such as pipelines, oil storage tanks, oil and gas wells, offshore structures, seagoing ship hulls, marine pilings, water tanks and some chemical equipment. [4]

The anode is generally represented as the negative terminal of the electrolytic cell. In Impressed Current Cathodic Protection method, the positive terminal of the battery is connected to the anode. Zinc has been employed as the anode in this model. Zinc is a good conductor of electricity and enhances low current density current discharge. It also offers low resistance to the electrolyte due its high ratio of surface area to weight. The consumption rate of zinc is about 0.25 Kg/A/Year which makes it a favorable and an economical choice, among the different anode materials available. [10]

**Table 1: Common Reference Electrodes and Their Potentials and Temperature Coefficients [6]**

| Reference Electrode | Electrolyte Solution | Potential at 25 °C [77 °F] (V/SHE) | Potential at 25 °C [77 °F] (V/CSE] | Temperature Coefficient mV/°C (mV/°F) | Typical Usage |
|---|---|---|---|---|---|
| $Cu/CuSO_4$ (CSE) | Sat. $CuSO_4$ | +0.316[76] | 0 | 0.9 (0.5)[76] | soils, fresh water |
| Ag/AgCl[(A)] (SSC) | 0.6 M NaCl (3 ½%) | +0.256[77] | −0.06 | − 0.33 (0.18)[77] | seawater, brackish[(B)] |
| Ag/AgCl[(C)] (SSC) | Sat. KCl | +0.222[78] | −0.094 | − 0.70 (0.39)[78] | --- |
| Ag/AgCl[(C)] (SSC) | 0.1 N KCl | +0.288[79] | −0.028 | − 0.43 (0.24)[79] | --- |
| Sat. Calomel (SCE) | Sat. KCl | +0.244[10] | −0.072 | − 0.70 (0.39)[10] | water, laboratory |
| Zn (ZRE) | Saline Solution | −0.79 ± 0.1[65] | −1.1 ± 0.1[65] | --- | seawater |
| Zn (ZRE) | Soil | −0.80 ± 0.1[65] | −1.1 ± 0.1[65] | --- | underground |

[(A)]Solid junction.
[(B)]Potential becomes more electropositive with increasing resistivity. See nomograph for correction in waters of varying resistivity in NACE SP0176,[10] or see reference 77.
[(C)]Liquid junction.

The consideration of using zinc as the anode in this cathodic protection system is because zinc is commonly used in underground pipeline system. Zinc has density of 7.1 $g\ m^{-3}$, potential volts of -1.10 $Cu/CuSO_4$, and Amp-hrs of 780 per kg. [1]

**Table 2: Potential required for cathodic protection [1]**

| Metal | Potential ($Cu/CuSO_4$) |
|---|---|
| Steel | -850 mV |
| Steel (sulphate reducing bacteria | -950 mV |
| Copper alloys | -500 to -650 mV |
| Lead | -600 mV |
| Aluminium | -950 to -1200 mV |

The potential required for cathodic protection in this model is -850mV. If it meets these criteria, the pipe will be well protected.

The Cathode is generally represented as the positive terminal of the electrolytic cell. In Impressed Current Cathodic Protection method, the negative terminal of the battery is connected to the cathode. An iron pipe has been employed as the cathode in this model and the objective of deploying this method is to protect the iron pipe from Corrosion. The utility of iron pipelines in transporting commercial liquids over long distances is significant and thereby it is chosen as the cathodic material in this model. [10]

The electrolyte is the electrically conductive solution that enables the flow of electrons and must be present for corrosion to occur. Soil has been utilized as the electrolyte due to its ability to enhance corrosion owing to differences in soil resistivity, oxygen concentrations, moisture content and various ion concentrations. It is a medium that contributes a great deal to the corrosion of underground pipelines when left unprotected. [10]

**Table 3: Current densities required to protect steel [1]**

| Environment | Current density $A\ m^{-2}$ |
|---|---|
| Acidic solutions | 350 - 500 |
| Saline solutions | -.3 - 10 |
| Sea water | 0.05 – 0.15 |
| Saline mud | 0.025 – 0.05 |

## 3. MECHANISM OF CORROSION IN UNDERGROUND PIPELINES

In the case of underground iron pipelines, corrosion is quite significant because corrosion cell components are prevalent inherently and enhance the process of corrosion. These iron pipelines run over long distances without any kind of protection against corrosion. The iron pipelines are subjected to the aggressive action of organic and inorganic anions and the interaction results in the corrosion process. This makes this process an electrochemical or a spontaneous process. [5]

In observing the mechanism of corrosion in iron it is noticed that $Fe^{2+}$ ions are released from the anode by the process of oxidation and $OH^{-}$ ions from the cathode by reduction on the metal surface. The negative and positive ions combine together to form a white precipitate of solid Iron (II) Hydroxide. The various chemical reactions are as follows: [10]

Oxidation half reaction :

$$\mathrm{Fe(s)} \rightarrow Fe^{2+}(aq) + 2e^{-} \tag{1}$$

Reduction half reaction :

$$O_2\ \mathrm{(g)} + 2H_2O\ \mathrm{(l)} + 4e^{-} \rightarrow 4OH^{-} \tag{2}$$

Overall equation :

$$Fe^{2+} + 2OH^{-} \rightarrow FE(OH)_2(s) \tag{3}$$

The rate of anode reaction must equal the rate of cathode reaction in the corrosion cell. The corrosion process is eliminated by inhibiting the occurrence of any one of these reactions from taking place [5]. A soil with lower resistivity is more effective as an electrolyte and a conductive path, facilitating galvanic corrosion. [8]

**Table 4: Soil Resistivity and Corrosivity [8]**

| Field-Measured Soil Resistivity (ohm-cm) | Soil Corrosiveness in Disturbed Soils |
|---|---|
| <1,000 | Severely corrosive |
| 1,000-5,000 | Corrosive |
| 5,000-10,000 | Moderately corrosive |
| >10,000 | Slightly corrosive |

The potential possessed by steel in aerated soil (eg sand) does not differ greatly from steel potential in non-aerated soils (eg clay). However, if there is damage to the cover or pipe lining and contact with different types of soil, there will be potential differences that can cause corrosion currents in the soil. Pipe coating damage in non-aerated (clay) soils, corrosion can occur with a corrosion rate of more than one tenth (0.1) mm per year. [9]

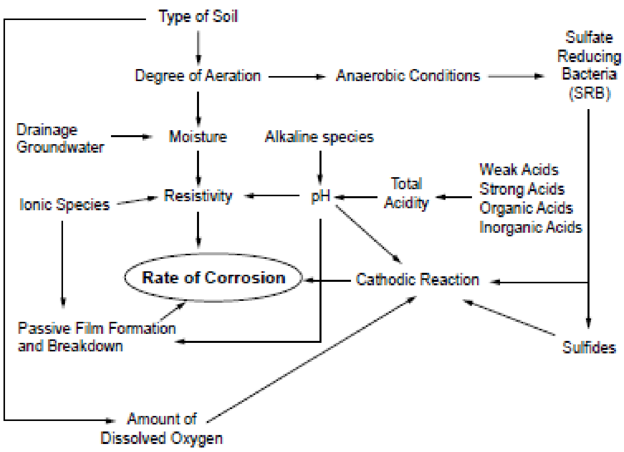


**Figure 1: External Factors that Affecting Soil Corrosion [8]**

## 4. CATHODIC PROTECTION PRINCIPLE

Cathodic protection is an electrical means of mitigating corrosion on buried and submerged structures. Cathodic Protection involves the application of a DC (direct current) onto the surface of a metal structure. Since corrosion only occurs at locations where current discharges from a metal surface, corrosion control may be achieved by applying a net DC current flow onto the entire surface of a structure. In those areas where current collects, corrosion is controlled. [7]

Two types of cathodic protection systems exist. The first type uses galvanic anodes for protection and The second type of system is an impressed current system. For the impressed current cathodic protection system, This system utilize an external power source to develop a high potential difference between the surface to be protected and an anode. A series of anodes installed in the ground are referred to as a groundbed. Impressed current type systems are advantageous because high driving voltages can be developed with an external power supply. [7]

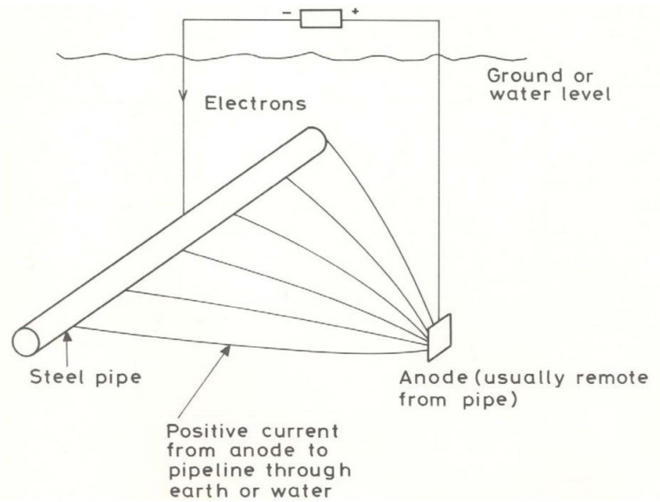


***Figure 2 :*** **Impressed Current Cathodic Protection principle [7]**

Impressed current systems typically use a power source known as a rectifier. The rectifier converts ac power to dc power and provides adjustability to the system. The current output may be increased by increasing the voltage. A transformer is used to adjust the output voltage of the rectifier. This is accomplished by adjusting tap bars on the front panel of the unit. A rectifying element, such as a diode bridge circuit, is used to convert AC power to DC power (ripple). [7]

## 5. DESIGNING GEOTHERMAL-POWERED IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM

Geothermal-powered Impressed Current Cathodic Protection system will be used primarily in underground/buried pipeline where the electrolyte resistivity is high and is more economically feasible compared to ordinary sacrificial anodic protection systems. The proposed Geothermal-powered Impressed Current Cathodic Protection experimental set-up consists of a typical electrochemical cell wherein the pipeline acts as the cathode and zinc acts as the anode. Soil is deployed as the electrolyte to ensure current passage. The driving force for this set-up is a 12volts, 20 amperehour lead acid battery, which is charged by the thermoelectric setup. The generated output voltage from the thermoelectric system is regulated adequately using LM723 voltage regulator. The LM723 voltage regulator also ensures the battery is prevented from overcharging. Geothermal-powered Impressed Current Cathodic Protection is preferred over sacrificial anode method as it ensures low capital investment is incurred for protection of underground/buried pipeline.

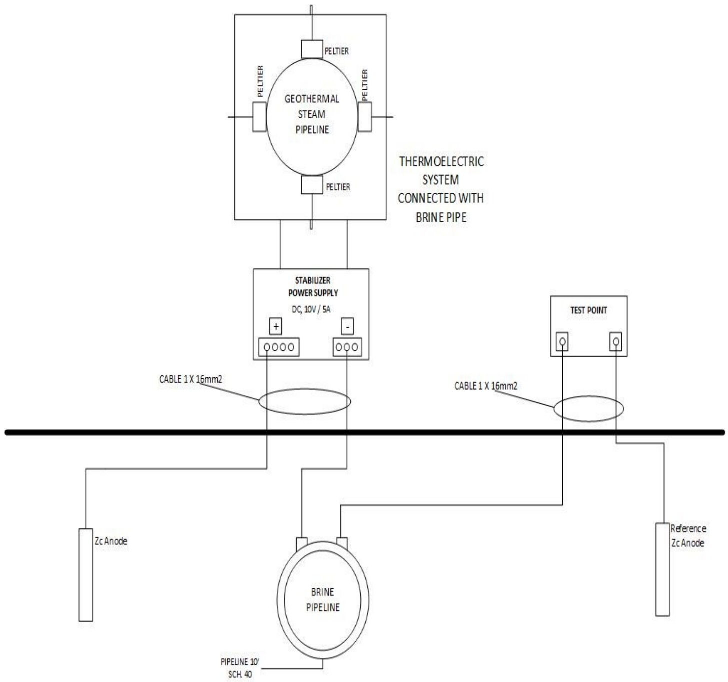


**Figure 3: Design of Geothermal-powered Impressed Current Cathodic Protection**

Geothermal-powered Impressed Current Cathodic Protection has a clear edge over other methods of corrosion prevention. It makes it possible to adjust the current and voltage, with an ability to provide an unlimited current output. [10] This technique can be adopted over a wide range of resistive environments and works quite well on undergroun/buried pipeline which are typically employed in most of the geothermal industrial sectors.

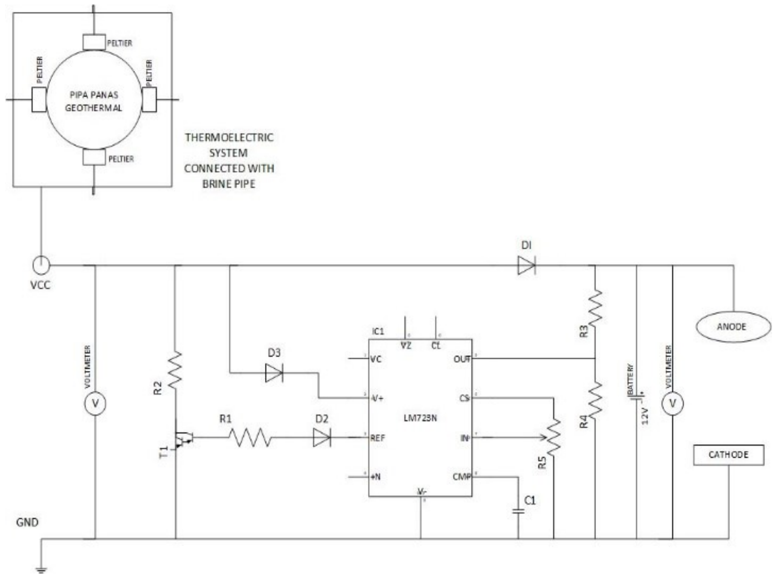


**Figure 4: Schematic Diagram of Geothermal-powered Impressed Current Cathodic Protection System**

Material used for this system

- Reducing Volt LM723 Adjustable DC to AC Voltage : 2ea
- Thermal Adhesive Tape 3M Double Side 9448A : 2ea
- Heatsink 40x40x11 mm : 40ea
- Peltier Thermoelectric Module SP1848-27145 : 40ea
- DC-DC Boost Converter Digital 400W : 1ea
- Dual Display voltmeter digital : 5ea
- Zinc Anode WW B9 (8.3 Kg) : 2ea

The voltage generated from the thermoelectric system is utilized as power source of this system and to charge the battery to its maximum level. By employing the LM723 regulator, current and voltage are sensed using the current meter and voltage meter. The output voltage of the battery is given back to the inverting input of the voltage regulator to obtain a constant output voltage on -850mV. Capacitor C1 is used for frequency compensation and also to bypass high frequency noises. Thermoelectric system will charges the battery and also supplies current to the pipeline all day long. In this system, battery is used as a backup energy storage and as the stabilizer when the output current from the thermoelectric system is unstable.

### 6. CALCULATION

The pipe that want to be protected is 10 inch SCH 40 carbon steel pipe and have 1500m length. To calculate the surface area to be protected :

$$SA = \pi \text{ x } OD \text{ x } L \qquad (1)\ [11]$$

Where, OD = outside diameter of pipe (m)

L = length of pipe (m)

$\pi$ = 3.14519

SA = Area to be protected ($m^2$)

Based on this equation, the size of the area to be protected is about 1285.83 $m^2$

### 6.1 Electrical Current Requirement

$$I = [\frac{SA \text{ x } CD \text{ x } CB}{1000}] \text{ x } (1+SF_1) \qquad (2)\ [11]$$

Where,

$I_t$ = the total current needed to protect the pipe(A)

SA = surface area to be protected ($m^2$)

CD = current density in ambient temperature ($mA/m^2$)

CB = The damage of protected layer

$SF_1$ = Safety factor

Based on this equation, the total current needed to protect the pipe is 3214.375 mA

Geothermal pipe temperature is about 125° celcius, and the ambient temperature is 25° Celcius. Then with temperature difference about 100°Celcius, peltier SP1848-27145SA can produce around 4.8V and 669mA. For supplying the Geothermal-powered Impressed Current Cathodic Protection system, it needs = 3214.375 mA/669mA =4,8= ~5 peltier.

The voltage need 9.5/4.8 = 1,97=~2

Then total peltier needs 5x2 = 10 peltier

## 7. CONCLUSION

Based on the obtained discussion and literature review

1. The utilization of heat from geothermal steam pipeline as a source of electrical energy for the impressed current cathodic protection system is a new breakthrough in the process of corrosion prevention that can be applied to underground/buried pipeline system.
2. The success of applying this impressed current cathodic protection can be achieved by maintaining the stability of the energy source which is equal to 10V / 5A and maintaining the potential difference of the anode and cathode by more negative than -850 mV.

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