Pipeline Corrosion Protection Simulation of Cathodic Protection Method Against Electrochemical Potential Distribution

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Abstract. Corrosion protection is very necessary for all steel or other types of metal, especially in buried pipes (underground construction). Direct contact between pipe materials (Carbon steel) can accelerate the corrosion rate. This is the case with the 20 inch pipe project working on the pipe installation. Initially to prevent this type of corrosion was done cathodic protection, but the result of examination was proven that there was a leakage of the potential distribution protection to the ground. Therefore it is necessary to do a distribution protection simulation to get how many anodes (magnesium package) to meet protection needs. The anode distance simulation results on the distribution of potential are carried out with the following variations: distance of every 45 meters, distance of every 30 meters, distance of every 20 meters, and distance of anodes every 15 meters. Based on the simulation results it is found that the anode distance cannot meet the minimum protection (~850 milli volt) except at a distance of 15 meters. Installation of anodes at a distance of 15 meters with each pair of distance of 4.9 meters proved that the simulation results have met the minimum potential for corrosion protection. So that it can be used as a reference for installation of anode spacing for pipe corrosion protection.

1. Introduction
Corrosion is a reduction in the quality of a material generally metal, and a mixture due to the contact between metals and their environment [1]. Various transportation, steel bridges, civil constructions, industrial equipment, factory machinery, and energy generation facilities and equipment often experience corrosion attacks. This also happens as in the piping system in the paper industry which is very important for the production process [2]. Furthermore, it often happens in the buried pipeline. The piping system is underground because the land that is supposed to be used for piping is actually used as a population area so it is not possible to place it on the surface [3]. Therefore various industries that use metal equipment must use corrosion protection systems. Corrosion protection method involves the spread of the electric potential on the surface of the pipe towards the anode. The potential value of this pipe is the benchmark in various standards whether the pipeline has been protected from corrosion or not. This is because the corrosion reaction is the same thing as the potential electrochemical moving reaction which involves electrolyte, anode and cathode elements. However, the installation of corrosion pipeline protection has been installed in the buried pipeline while the
inspection results of potential test. point protection show inadequate values (-450 millivolt) from the protection adequacy range (-850 millivolt to -1050 millivolt). This makes the pipeline area need to be backfilled to reinstall the anode. Therefore, it is very important for engineering evaluation and improvement based on the condition of the project area through numerical modeling simulations to obtain a more accurate and better protection value.

1.1 Reduction and Oxidation Processes
Corrosion is a very detrimental process for all industries in various fields. Corrosion generally occurs gradually and extends as time passes if there is no treatment at all. In the oil and gas drilling industry, this corrosion attack always occurs in equipment, as well as pipes production [4]. Not only this, even corrosion damage is a very important problem because it involves impacts on the surrounding area, as well as very high financial losses. Corrosion damage is especially noted in the damage to oil and gas production construction, which is forty percent of the damage caused by this corrosion attack [5]. The appearance of rust or corrosion starts from the contact namely environment, metal, and potential differences in the material causing a higher displacement of the charge towards the lower. It is this transfer of a higher metal load that results in a period of reduction and quality of material or rust.

Corrosion of a metal material or mixture takes place with various processes after contact with the environment. This is the process of reduction and oxidation. According to [6] states that the beginning of corrosion occurs in metals due to the presence of redox processes (reduction and oxidation). The reduction process that occurs at the anode is a reaction of two elements that bind between electrons. While oxidation is a reaction that in a material frees electrons so that the freed electrons will go to another area to reduce oxygen. In reaction, the redox equation can be written as follows

Fe (s) > Fe^{2+} (aq) + 2e^-                     (1)

The anodic area will then oxidize by releasing the electrons and then flowing from the anodic to the cathodic area. Reduction reaction in the cathodic area shown below

2H^{+} +2e > H_{2}                                   (2)

The cathodic area will accept the electrons so there is no problem in the cathodic area. Whereas in the anodic above the ion electrolyte reacts with hydrolsil when decomposing water into an insoluble process of ferro hydroxide which becomes rust in the anode area [7]. The corrosion reaction is stated in equation below.

- Fe^{2+} +2(OH)>Fe (OH) 2                    (3)

Corrosion is not a kind of animal but its attacks will always scrape the metal. Also corrosion is very divergent with the crack even it can be caused by the corrosion. The rate of corrosion is as a parameter how fast the metal scraped. There some case will ease the corrosion, those are: difference pro exposure to the water or air, difference composition of the corroding material, electrolyte, and contact with dissimilar metal [8]. Higher value of flow rate in millimeter per year show faster scraping of the metal. This parameter also decide how fast the metal will be corroded. So that is way corrosion become the very important topic in every industries which use metal as their complementary.

1.2 Corrosion protection (cathodic protection)
Various phenomena of corrosion attacks have occurred and have caused many impacts that results various corrosion protection methods appear. Generally corrosion protection that is often used is the impressed current cathodic protection or ICCP. The use of protection methods using the following impressed current has become the most advantageous choice in protection applications for construction, structure, hulls of ships, marine equipment, and marine buildings because it is more economical and easier [9]. Therefore, various industries have long used ICCP as a protection option from corrosion attacks. Although corrosion protection with impressed current is very good and suitable for buildings and marine facilities, it is a common for the use of this method to be used for the protection of pipelines under the surface, or above ground such as onshore pipelines. This ICCP method is intended for corrosion protection by electricity with the help of rectifiers.

the use of Impressed Current Cathodic Protection (ICCP) which can be controlled and re-adjusted by the operator does not need to add anodes as time goes on, and when there is an addition of piping, it
just do adjustments to the rectifier. This indirectly gives a lower cost effect when implementing construction. With the use of corrosion protection type ICCP location or reference anode point attached to the metal surface (pipes, steel structures, sea building facilities, tanks and so on) this can be determined based on the profile of the protected metal itself.

Sacrifice anode is a very active anode material that is used to protect metal surfaces that are less active against corrosion attacks [11]. The anode material in the SACP (Sacrifice Anodic cathodic Protection) system which has more negative electrochemical potential properties than the protected metal is a corroded metal anode that replaces the protected material. The corrosion protection system of the Sacrifice Anode Cathodic Protection type uses packaged anode in which there is a material that has more downward properties in the galvanized potential table and is connected to a connector to the outer surface area of the pipe. So that is way the electrochemical ion will flow from more active material (anode) to the pipe. Even actually there some kind of cathodic anode but the type of magnesium is rottenly used in many projects.

2 Research methodology.

The following methodology is a step, time, and work process taken in conducting research starting from data collection and work processes. The following form of research is in the form of improvement and optimization of the need for protection stresses and the number of anodes to meet the potential protection of the pipeline which will be protected from corrosion attacks. There are several variations that will be done with the distance of each anode so that the area of the pipe area will be obtained which is still not sufficiently protected. Then the results will be used as an analysis material to improve the design of the distance for each anodize. Those process of the research is shown in figure 2 bellow that form start problem and purposes identification, literature study and field study, getting the potential requirement at the pipe location for protection, simulation and having the value of potential distribution.
2.1 description of the research process.
The following methodology is a description of the research process carried out to obtain the corrosion protection anode mounting distance. The first is a literature study carried out to obtain appropriate literature on corrosion protection of sacrificial anode methods, and impressed current. In this study, it has been adapted to the conditions that exist in the field, namely protection using two types (SACP & ICCP). The study was obtained from the literature of library books and e-books, journal references, and previous research. Then the implementation of the field study is information, as well as data obtained when carrying out field studies. The following primary data is the appropriate information, which is applied in the field. for corrosion protection of the pipeline. Some of these data are vendor specifications, client (owner specification), demand for protection time requirements, pipeline isometric images (as calculation of surface area of protection), and the results of testing the protection current. the third is the simulation process to obtain analysis results).

2.2 description of the research process.
The simulation process is an important stage in carrying out research on the problem of spreading the following protection currents. This is because by modeling the distribution of currents on the surface parts of the pipe can be known carefully. Building this simulation process can be done using software and it is very appropriate when you want to explain a system that is very complex and cannot be solved by analytic calculation processes. From this simulation the potential distribution on each pipe location can be solved. There are some criteria that is used to do simulation such as simulation parameters, geometry of the simulations, and the boundary conditions of it.
3 Result and Discussion
Modeling or simulation is a third step of the analysis. It is done after deciding the parameter criteria, and the point that will affect the results. The simulation of this cathodic protection consists of some processes. Those are geometry of modeling, boundary condition, meshing, and computing. Those processes are computed by software Elmer 8.3 (open source analysis software) and the results are displayed by Paraview (open source software).

3.1 Simulation geometry of cathodic protection
Geometry or simulation model is a form of 3D (three dimensional) modeling which is described to do the modeling of the distribution of anode electrochemical potential against pipe material that is protected from corrosion. At the drawing geometry stage the specification of the dimension and the shape of the pipeline become the main data to be used. Simulation modeling the following distribution of corrosion protection stresses in the pipeline is divided into 4 (four) bodies or parts. The section is 1. SACP Anode and ICCP Ground bed, 2. Land of buried pipe area 3. Pipe diameter of 20 inch schedule 40, 4. Pipe sleeve or 24 inch diameter pipe sleeve standard. The following is the dimensional specification used to describe the geometry as a modeling step. Figures 4.1 and 4.2 below are protection geometry of models buried pipe.

3.2 Simulation parameters
The parameter of this simulation or modeling analysis is described at the table 1. The modeling is done inside of soil boundary and involve geometry of pipeline and packaged anode. The dimension of soil geometry for length x width x height is 90 meter x 2 meter x 4 meter. The distance of each combination anode is varied to get better potential distribution for cathodic protection. On Figure 3 show geometry simulation parameter.

Figure 3. The simulation parameters of corrosion protection modeling on the cathodic type protection (side view).

Figure 3 above describes how the geometry is drawn in the geometry software. The pipe is shaped with having an internal diameter. The thickness of the pipe is 15.09 millimeter. The soil geometry’s dimension length x width x height is 90 meters x 2 meters x 4 meters. Those dimension will ease the people who want to simulate it again in the analysis software.
Table 1 Parameter simulation criteria of cathodic protection.

| No | Description                  | Number | Unit   |
|----|------------------------------|--------|--------|
| 1  | Soil depth                   | 4      | meter  |
| 2  | Inside pipe diameter         | 0.477  | meter  |
| 3  | Outside pipe diameter        | 0.508  | meter  |
| 4  | Pipe length                  | 90     | meter  |
| 5  | Distance of anode to the pipe (Y axis) | 0.5   | meter  |
| 6  | Distance of each couple anode| 15     | meter  |
| 7  | Length of anode              | 0.7    | meter  |
| 8  | Diameter of anode packaged   | 0.16   | meter  |

3.3 Meshing for cathodic protection simulation
The next stage of analysis on pipeline protection with this type of cathodic protection is "Meshing", which is divided by the geometry of the area around the 20 inch pipe into a number of pieces or nodes and can then be analyzed for the spread of corrosion protection potential. In flow modeling, passing 3D objects (three dimensions) has a classification with several stages of grouping types. The grouping carried out on the analysis include: first is Grouping on each side of the face area of the distribution of protection analyzed will form the body in the Elmer simulation, secondly is Volume grouping in each part of the modeling will form a boundary which is then given boundary conditions.

3.4 Boundary condition for cathodic protection simulation
Boundary condition is a condition parameter given in numerical modeling simulations. In the corrosion protection modeling, the following cathodic types are given several parameters. That is namely: The value of the sacrifice anode anode voltage according to vendor specifications is 7.2 volts. The value of the voltage given by the ICCP rectifier is according to vendor specifications of 48 volts. The potential difference value on the ground is 0 volts, and uses a static current conduction solver. After setting the boundary conditions above, a solver process is then performed using the static current conduction module to perform an iterative calculation. This solver require us to do electric conductivities of each material. Such as the electric conductivities of the soil parameter, the electric conductivities of pipe and the electric conductivities of the coating. The value of electric conductivities can be determined by dividing 1 by the electric conductivities of each material.

3.5 Results of Cathodic Protection Simulation
Corrosion protection of the following cathodic protection method is corrosion protection in a pipeline that is in a 90 m (ninety meter) land over a 36 m (thirty six meter) main crossway. This makes the pipeline using a pipe casing. In research using design calculations for protection needs and the following software simulation requires the results of construction engineering simulations carried out based on the data that has been obtained. So after setting the modeling with variations in modeling the spreading of corrosion protection stresses on the distance of the anode laying and each combination of the ICCP-SACP. The results of the simulation of corrosion protection modeling on the cathodic type protection from the review software paraview are shown in the Figure 2 Corrosion protection of the following.
Those cathodic protection method is corrosion protection for a 90 m pipeline (ninety meter) land over a 36 m (thirty six meters) main high cross way. This makes the pipeline using a pipe casing. In research using design calculations for the protection of the following software simulation requires that the data be carried out based on the data that has been obtained. So after setting the modeling with the variations in modeling the spread of corrosion protection potential on the distance of the method of setting and each combination of the ICCP-SACP. The results of the simulation of corrosion protection modeling on the cathodic type of protection from the review software review are shown in the Figure bellow. The results of modeling are shown in Figure 3 graph of the potential value of corrosion protection spread per anode.

Corrosion protection above is carried out at the anode distance every 15 meters (fifteen meters) with each pair of distance 0.7 meters (zero point seven meters), 1.4 meters (one point four), 2.8 meters (two point eight meters), 4.2 meters (four point two meters), 4.9 meters (four point nine meters) and 5.6 meters (five point meters) six meters). From the results of the modeling it was found that the pipeline could be protected against corrosion. It is evident that the potential spread value experienced by the pipeline at that distance has entered the potential protection limit (min -850 millivolt).

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