1. Introduction

Balikpapan is one of the cities that has a reasonably large economy in Indonesia. It has triggered the need to develop an Industrial Estate called the Kawasan Industri Kariangau. Kawasan Industri Kariangau (KIK) is located in the coastal area near Balikpapan in East Kalimantan. The industrial complex is strategically positioned, offering its investors a convenient distribution location for their products. The site has an international container port with 15 ha, designated for the container, general cargo, and bulk and shipping services. In this industrial area, several industrial supporting facilities are planned to be built, one of which is installing a gas pipe located under the ground whose function is to distribute natural gas to companies and housing residents. However, gas pipes buried underground are mostly made of API 5L standard carbon steel, which has a very high risk of damage. One of the pipeline damage is leakage that is caused by corrosion [1].

Corrosion is one of the most critical challenges facing the industry. Mostly, the dangerous corrosion occurs in major industrial plants. There are some direct and indirect consequences of pipeline corrosion, such as safety and financial and environmental damage. Various factors can affect pipeline steel's soil corrosion, such as pH, soil humidity, temperature, soil chemistry, and aeration [2]. Bhattarai (2013) and Noor (2012), on their research, investigated the soil properties such as moisture, pH, resistivity, redox potential, chloride, and sulfide content to the level of corrosion in underground pipes by using three
types of soil. The results showed that the soil moisture level had a very significant effect on the growth of corrosion.

Corrosion damage to gas pipes installed at the Kariangau Industrial Complex needs to be prevented. It is necessary to analyze the environmental effects, especially the soil in the Kariangau industrial area. Therefore, this study investigated the potential factors of soil moisture and pH, which will influence the pipeline's corrosion rate. Hopefully, this analysis can describe the corrosion behavior in the Kariangau Industrial Estate, so it can be one reference to estimate the best material of the pipeline.

2. Methodology

2.1. Materials
The material used in this research is Structural Steel, commonly known as API 5L Grade B. It was brought as a pipe and surface prepared by removing any coating, including in shipping. Half then cut the prepared sample to optimize material usage.

2.2. Overall assessment
The corrosion risk assessment was done at Kariangau Industrial Complex. Corrosion data is taken at 5 locations with an average distance of 1 Km from one site to another, illustrated in figure 1. The starting point is determined based on the location closest to the pier because it is assumed that gas will begin to flow from the area most relative to the riverbank. The conditions of the observed place are described as follows. Location 1 and 5 shows signs of a prepared lot; when this research was conducted, there are no indications of immediate construction on site. But it was clear that the lot was modified by human activity. On the contrary, location 3 has no representation of the effect of human activity. Location 2 and 4, however, indicate some activities being done in those areas.

![Figure 1. Map of corrosion risk assessment locations.](image)

2.3. Corrosion behaviour
Corrosion measurements done in this research are open circuit potential and corrosion rate. Open-circuit potential measures the sample potential versus the Cu/CuSO₄ reference electrode. This potential is then plotted in a pourbaix diagram to check our material's natural form in location. The corrosion rate is measured by calculating the initial mass and final mass of the specimen buried over a certain period. The difference between the last and initial mass over the recorded time will be showing the corrosion
rate data. Corrosion testing using the ASTM G31 standard. Corrosion measurements begin by planting
the specimen in the soil to a depth of approximately 0.5 m. Open circuit potential and corrosion rate
specimens are separated and marked. The open-circuit specimens were tied with copper wire and then
implanted to facilitate measurement. The Corrosion Rate test aims to see the effect of time on soil
aggressivity or material corrosion.

2.4. Soil characterization
Soil characterization testing was done by measuring soil resistivity and soil pH. Soil resistivity was
tested by inserting copper rods and pins. The distance between the copper rod and the two hooks is
arranged not to close together. Cables connect copper, nails, and a resistivity test. Soil pH is the
measurement by taking a 5-gram soil sample and then mixing it with distilled water to become mud,
then measuring the mud with a pH meter.

3. Results and discussion

3.1. Corrosion behaviour
Corrosion potential and corrosion rate could lead us to learn the behavior of corrosion in specific
conditions. In this research, the corrosion potential and corrosion rate measurement are shown in table
1 and table 2, respectively.

| Location Code | Corrosion Potential (mV) | pH (avg) | Status |
|---------------|--------------------------|---------|--------|
| A             | -580.8                   | 4.82    | Active |
| B             | -631.2                   | 6.15    | Active |
| C             | -629.9                   | 6.18    | Active |
| D             | -603.5                   | 6.15    | Active |
| E             | -559.5                   | 5.99    | Active |

| Location Code | Corrosion Rate (mpy) | Soil Aggressivity | Material Corrodibility |
|---------------|----------------------|-------------------|-----------------------|
| A             | 8.27 14.85 0.42 17.87| Increased         | Increased             |
| B             | 11.09 5.92 2.93 19.53| Decreased         | Increased             |
| C             | 10.30 9.66 18.20 15.13| Decreased         | Decreased             |
| D             | 4.06 6.51 18.71 6.38 | Increased         | Decreased             |
| E             | 3.28 8.43 17.10 10.35| Increased         | Decreased             |

We can see that in all locations, the corrosion potential at given pH the materials will corrode as the
stable condition of steel under said conditions is active or in the form of Fe^{2+} I on. It means corrosion is
spontaneously happening for every steel structure installed underground and tells us that extra
precaution to corrosion is needed when engineers start designing systems underground in KIK [5]. The
Table shows that behavior change over time for both soil aggressiveness and material corrodibility. The
data imply that locations that are in minimum contact with human activity have decreased corrosion
activity for soil aggression. However, material corrodibility does not show the same behavior [6].
Material corrodibility is affected by the distance between the locations of the riverbank. Location 1 and
2 are close by and thus show identical behavior. On the contrary, locations 3, 4, and 5 are further from
the riverbank.
These behaviors lead us to believe that KIK’s continuous development will lead to an increase in soil aggressivity. The fact that ongoing development will bring more human activity to the location brings us to conclude that corrosion behavior will change over time [6].

3.2. Soil resistivity
Soil resistivity contributes to the rate at which corrosion reactions happen [7]. The measurement result is shown in Table. The data shows which location is more active than the other. This data also shows us that locations that are already affected by human activity are more corrosive than the other. The classification based on soil resistivity is made and displayed in Table 3.

| Location Code | Soil Resistivity (Ohm.m) | Classification   |
|---------------|--------------------------|------------------|
| A             | 19.26                    | Corrosive        |
| B             | 989.18                   | Low Corrosivity  |
| C             | 324.71                   | Low Corrosivity  |
| D             | 564.82                   | Low Corrosivity  |
| E             | 37.12                    | Corrosive        |

3.3. Other factors
Many factors are contributing to the behavior of corrosion in soil systems [8]. In this research, soil humidity and acidity were observed for a month. The result shows dynamic fluctuations in soil humidity (figure 2 left) and continuous acidity (figure 2 right). Instability in both cases means that the soil condition will change in regards to time. As stated in the introduction, KIK is still under development, and the construction from many companies continues. It will also contribute to the change in the environment, especially the soil condition. The soil observed either for the native soil or the imported soil to cover the unstable native ground was not exposed to any activity during the research period, not counting the climate or natural occurrence. Even so, the fluctuation in data can be seen clearly.

The differences in acidity were not too significant in all locations showing relatively balanced acidity or neutral condition. However, location 1 and location 5 tend to be more acid than locations 2, 3, and 4. From the location characteristics, we can learn that the new location has neutral acidity than locations 1 and 5, modified by heavy equipment and other human activities. On the other hand, the humidity data shows a relatively constant movement. It could imply that the change in humidity was identical in all locations if we compared to the data from soil resistivity and its condition. It does not show a correlation.
at all. This condition leads us to conclude that humidity's change does not directly affect the resistivity [9]. The constant movement in humidity value implies that humidity change happens uniformly for every location in KIK areas.

4. Conclusions
Considering the analysis and data provided by this research, we conclude that KIK has a relatively low soil corrosion rate when this research is conducted. It means that the risk of buried steel structures installed in this establishment is low. However, this should not be underestimated because the development of industrial buildings and establishments could increase the corrosion aggressivity in surrounding areas. It is recommended to use this article wisely as a basis for corrosion study and prevention. For intricate engineering design, authors encourage engineers to make their measurements for actual and updated data following the change in the surrounding area.

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