Effect of Flow Rate and Temperature on Erosion Corrosion Rate of Crude Palm Oil Against Elbow A53 Grade B Carbon Steel Material

Budi Prasojo¹, Hendri Budi Kurniyanto¹, Tarikh Azis R¹, Subagio So’im¹, Asfiem Rahmat Haqin¹

¹ Shipbuilding Institute of Polytechnic Surabaya, Surabaya, Indonesia

budiprasojo1968@gmail.com; budi.hb97@gmail.com; tarikh@ppns.ac.id; bagiosoim@gmail.com; asfiemrahmat@gmail.com

Abstract. In Center Port Nilam there is a construction of storage tanks and pipelines that will be used for the distribution and storage of Crude Palm Oil (CPO). CPO will be transported to the storage tank through a pipeline using carbon steel A53 grade B. In the pipeline there is a pipe bridge as high as 8.6 meters, and under the pipe bridge, there is an elbow that has the potential to erosion corrosion. The experiment is to test the effect of flow rate and temperature to the corrosion-erosion rate of CPO in elbow material of carbon steel A53 grade B. For calculations use the DNV RP O501 standard and for testing using the ASTM G31-72 standard. This research use variation of the fluid speed of 1 ms, 2 m/s, 3 m/s and temperature of 40°C, 50°C, 60°C. From the results using manual calculations for the flow rate of 1 m/s, 2 m/s, 3 m/s erosion corrosion rate successively is 0.0030 mmpy, 0.0440 mmpy, and 0.1946 mm / year. The erosion-corrosion rate successively is 0.0315 mmpy, 0.0450 mmpy and 0.0531 mmpy for flow rate of 1 m/s, erosion corrosion rate of 0.0596 mmpy, 0.0781 mmpy, 0.0950 mmpy for flow rate of 2 m/s and 0.1044 mmpy, 0.1274 mmpy and 0.1497 mmpy for flow rate of 2 m/s for the test results using testing method at a temperature of 40 °C, 50 °C, 60 °C. It can be concluded that the greater flow rate and temperature can lead to greater erosion corrosion rate.

1. Introduction

Erosion corrosion is one thing that can cause failure in a piping system. All production companies or contractors significantly avoid erosion corrosion. The occurrence of erosion-corrosion due to fluid flowing in the order has a corrosive nature, and there is a substantial element in the fluid that flows [1]. There is the construction of storage tanks and pipelines in Central Nilam Port, Surabaya, Indonesia. Storage tanks and pipes will be used to store and transport Crude Palm Oil containing sand [2]. Crude Palm Oil will be transported from ship to storage tank through 8-inch diameter pipeline. At the time of discharge, Crude Palm Oil temperature is maintained between 40°C – 60°C. On the pipeline, there is an 8.6-meter pipe bridge. Under the pipe bridge, there is an elbow that is potentially exposed to erosion corrosion.

Noviadam [4] investigated erosion-corrosion in the pipeline system. It was found the way to analyse the rate of erosion-corrosion on ST 60 steel material using seawater fluid. Investigated about erosion-corrosion in the elbow in the pipeline [3-5]. It was found the way to calculate the rate of erosion on elbow manually concerning standard DNV RP O501 2007/2015. Based on the problem, this research will analyse the effect of flow rate and temperature on crude palm oil erosion rate to A53 grade B carbon
steel elbow. This research will be done by erosion corrosion testing of weight loss method which refers to standard ASTM G31 - 72 and manual calculations referring to DNV standard - RP O501 [6-8].

2. Methods
2.1. Flow diagram
This research is using weight loss method which refers to standard ASTM G31-72, and manual calculation of erosion rate refers to DNV RP O501 2007/2015 standard. This research investigated the rate of Crude Palm Oil erosion (CPO) on elbow using carbon steel material A53 Grade B. The variables used in this erosion corrosion rate testing are velocity of flow rate and temperature, where the rate of flow rate is 1 m/s, 2 m/s, 3 m/s and the test temperature is 40°C, 50°C and 60°C. Also, this research also calculates the erosion-corrosion rate manually referred to DNV RP O501 2007/2015 standard. The speed of the flow rate used for manual calculations is 1 m/s, 2 m/s and 3 m/s. This research method is shown in the flow diagram in Figure 1 below.

![Flow diagram of this research](image)

Figure 1. Flow diagram of this research

2.2. Calculation formula
2.2.1. Erosion rate
Base on DNV RP O501, to calculate the erosion rate on elbow required the following steps.
- **Calculation for the characteristic impact angle (α)**
  \[
  \alpha = \arctan \left( \frac{1}{\sqrt{2} \cdot R \text{ curvature}} \right)
  \]  
  (1)
  
  Where:
  - \( \alpha \) = Impact Angle (°)
  - \( R \text{ curvature} \) = radius of curvature (-)

- **Calculation for the dimensionless parameter group (A)**
  \[
  A = \frac{\rho_m \cdot \tan(\alpha) \cdot U_p \cdot \Omega \cdot D}{\rho_p - \rho_m}
  \]  
  (2)
Where:
\( \text{A} = \) Dimensionless Parameter Group (-)
\( \rho_m = \) Fluid Mixture Density (kg/m\(^3\))
\( \alpha = \) Impact Angle (°)
\( \text{ID} = \) Inside Diameter (m)
\( \rho_p = \) Particle Density (kg/m\(^3\))
\( \mu_m = \) Fluid Mixture Viscosity (kg/m.s)
\( U_p = \) Impact Particle Velocity (m/s)

- **Determination the value of critical particle diameter**

\[
\gamma_c = \frac{\rho_m}{\rho_p \cdot [1.88 \cdot \ln(A) \cdot -6.04]} \quad \gamma_c < 0.1
\]  

Where:
\( \gamma_c = \) Critical Particle Diameter (-)
\( \rho_m = \) Fluid Mixture Density (kg/m\(^3\))
\( \rho_p = \) Particle Density (kg/m\(^3\))
\( A = \) The Dimensionless Parameter Group

- **Calculation for the particle size correction function \((G)\)**

\[
G = \begin{cases} 
\frac{\gamma}{\gamma_c} & \gamma < \gamma_c \\
1 & \gamma \geq \gamma_c
\end{cases}
\]  

Where,
\( G = \) The Particle Size Correction (-)
\( \gamma_c = \) Critical Particle Diameter (-)
\( \gamma = \) \( \frac{dp}{ID} \) (-)

- **Calculation for the characteristic pipe bend area exposed to erosion**

\[
A_t = \frac{\pi}{4 \cdot \sin(\alpha)}
\]  

Where,
\( A_t = \) Area Exposed to Erosion (m\(^2\))
\( \text{ID} = \) Pipe Inside Diameter (m)
\( \alpha = \) Impact angle (°)

- **Determination the value of the function \( F(\alpha) \) by using the angle \((\alpha)\)**

![Figure 2. Function \( F(\alpha) \) by using the angle \((\alpha)\)](image)

- **Calculate erosion rate**

\[
EL = \frac{K_{F(\alpha)} \sin(\alpha) U_p^n}{\rho_t A_t} \cdot G \cdot C_1 \cdot GF \cdot \tilde{m}_p \cdot C_{unit}
\]  

\[ (6) \]
Where:
EL = Erosion Rate (mmpy)
K = Material Constant [(m/s)^n]
α = Impact Angle (°)
U_p = Impact Particle Velocity (m/s)
n = Velocity Exponent
ρ_t = Density Material (kg/m^3)
A_t = Area Exposed to Erosion (m^2)
G = The Particle Size Correction (-)
C1 = Model/Geometry Factor (-)
GF = Geometry Factor (-)
ṁ = Mass Flow Particle (kg/s)
C_unit = Unit Conversion Factor (-)

2.2.2. Weight loss testing method

Based on ASTM G31 – 72, to obtain the erosion-corrosion rate using the following formula below

\[ Cr = \frac{KW}{DA.T} \]  

Where,
Cr = Corrosion Rate (mmpy)
K = Constant (8,76 x 10^4)
W = Weight Loss (gram)
D = Material Density (gram/cm^3)
A = Area (cm^2)
T = Time Exposure (hours)

3. Results

3.1. Erosion corrosion rate by manual calculation

The manual calculation of erosion-corrosion rate base on DNV RP O501. From the calculation of erosion-corrosion rate, that each flow rate velocity has different erosion rate values, it can be seen the effect of flow rate velocity to the rate of erosion of carbon steel material A53 Gr B in Figure 2. From the results obtained, it can be concluded that the higher of flow rate, can cause greater the rate of erosion.

![Figure 3. Results of the erosion-corrosion rate by manual calculation](image)

3.2. Erosion corrosion by the testing method

The method used in corrosion test is weight loss which refers to ASTM G31-72 standard. This test uses a variation of flow rate velocity and temperature. The velocity of flow rate used is 1 m/s, 2m/s, 3m/s and the temperature used is 40°C, 50°C, and 60°C. The following corrosion test results are shown in Table 1.
Table 1. Result of erosion corrosion rate based on ASTM G 31-72

| Flow Rate (M/S) | Temperature (Celsius) | Specimen | W1 (g) | W2 (g) | ΔW (g) | A (cm²) | CR (mmpy) | CR (mmpy) |
|-----------------|-----------------------|----------|--------|--------|--------|---------|-----------|-----------|
|                 |                       |          |        |        |        |         |           |           |
| 1 m/s           |                       |          |        |        |        |         |           |           |
| 40              |                       | A1       | 49.0666| 49.0624| 0.0042 | 30.974  | 0.0315    | 0.0315    |
| 40              |                       | A2       | 52.1152| 52.1106| 0.0046 | 33.809  | 0.0316    | 0.0316    |
| 40              |                       | A3       | 51.6551| 51.6506| 0.0045 | 33.209  | 0.0315    | 0.0315    |
| 50              |                       | B1       | 50.8292| 50.8230| 0.0062 | 33.764  | 0.0426    | 0.0455    |
| 50              |                       | B2       | 51.7867| 51.7803| 0.0064 | 32.679  | 0.0455    | 0.0455    |
| 50              |                       | B3       | 50.6658| 50.6591| 0.0067 | 33.209  | 0.0468    | 0.0468    |
| 60              |                       | C1       | 50.2644| 50.2569| 0.0075 | 32.099  | 0.0542    | 0.0542    |
| 60              |                       | C2       | 49.2396| 49.2310| 0.0086 | 33.209  | 0.0598    | 0.0598    |
| 60              |                       | C3       | 48.3933| 48.3857| 0.0076 | 32.099  | 0.0562    | 0.0562    |
| 2 m/s           |                       |          |        |        |        |         |           |           |
| 40              |                       | D1       | 51.2488| 51.2357| 0.0091 | 34.319  | 0.0614    | 0.0576    |
| 40              |                       | D2       | 51.1802| 51.1719| 0.0083 | 34.939  | 0.0551    | 0.0551    |
| 40              |                       | D3       | 50.4658| 50.4575| 0.0083 | 34.319  | 0.0563    | 0.0563    |
| 50              |                       | E1       | 47.4521| 47.4416| 0.0105 | 32.099  | 0.0756    | 0.0759    |
| 50              |                       | E2       | 49.6780| 49.6679| 0.0101 | 32.654  | 0.0716    | 0.0716    |
| 50              |                       | E3       | 49.2330| 49.2215| 0.0115 | 33.209  | 0.0805    | 0.0805    |
| 60              |                       | F1       | 49.3783| 49.3652| 0.0131 | 32.654  | 0.0934    | 0.0926    |
| 60              |                       | F2       | 50.2092| 50.1955| 0.0137 | 33.209  | 0.0958    | 0.0958    |
| 60              |                       | F3       | 51.2686| 51.2557| 0.0129 | 33.834  | 0.0885    | 0.0885    |
| 3 m/s           |                       |          |        |        |        |         |           |           |
| 40              |                       | G1       | 51.4288| 51.4122| 0.0166 | 33.764  | 0.1142    | 0.1044    |
| 40              |                       | G2       | 53.2954| 53.2804| 0.0150 | 35.559  | 0.0979    | 0.1011    |
| 40              |                       | G3       | 48.6913| 48.6771| 0.0142 | 32.609  | 0.1011    | 0.1011    |
| 50              |                       | H1       | 48.3124| 48.2938| 0.0186 | 33.209  | 0.1300    | 0.1276    |
| 50              |                       | H2       | 51.6048| 51.5853| 0.0195 | 34.319  | 0.1319    | 0.1319    |
| 50              |                       | H3       | 47.5486| 47.5322| 0.0164 | 31.519  | 0.1208    | 0.1208    |
| 60              |                       | I1       | 50.5969| 50.5729| 0.0240 | 34.409  | 0.1619    | 0.1497    |
| 60              |                       | I2       | 47.1310| 47.1125| 0.0185 | 31.519  | 0.1363    | 0.1510    |
| 60              |                       | I3       | 47.4284| 47.4079| 0.0205 | 31.519  | 0.1510    | 0.1510    |

Figure 4. Effect of flow rate velocity and temperature to the erosion-corrosion rate

From the calculation of erosion rate, that the effect of flow rate velocity and temperature has different erosion rate values. From the table above, it can be seen the impact of flow rate velocity and temperature to the rate of erosion of carbon steel material A53 Gr B shown in graphical form in Figure 3. From the results obtained, it can be concluded that the higher of flow rate, can cause greater the rate of erosion. Moreover, also the higher of temperature can cause greater the rate of erosion.
4. Results

Based on result and analysis, it can be concluded that the higher velocity of flow rate can cause the higher value of the erosion-corrosion rate. From the results of manual calculations, the lowest erosion corrosion rate is found at a velocity 1 m/s in the amount of 0.003 mmpy, while the highest is at a velocity of 3 m/s of 0.1946 mmpy. From the test results obtained the lowest erosion corrosion rate at the fluid flow rate of 1 m/s at temperature 40°C with a value of 0.0315 mmpy while the highest value is at the fluid flow rate of 3 m/s at temperature 60°C with a value of 0.1497 mmpy. Increasing the flow rate of fluid in the pipe will increase the erosion-corrosion rate and if the fluid temperature increase, the corrosion rate will be increased.

5. References

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