Analysis of the Potential of Crust Formation and Corrosiveness in the Way Rilau PDAM Lampung Distribution Network Using the Langelier Saturation Index Method

Anwar¹*, Alexander Sembiring², Agustinus Purna Irawan³
¹Doctoral Student of Civil Engineering, Universitas Tarumanagara
²Master Student of Mechanical Engineering, Universitas Lampung
³Faculty of Engineering, Universitas Tarumanagara

*minakshaka2013@gmail.com

Abstract. Crust formation is a complex problem and always occurs in piping systems, both in oil piping systems, industry, and water distribution. When the crust is formed on the pipe, it will cause the pipe diameter to shrink and inhibit the flow of fluid in the pipe system. If the pipe has a problem, its temperature and pressure will be higher, increasing the possibility of the pipe to break and get damaged. This study aims to determine the formation of PDAM water pipe scale in Bandar Lampung with the Langelier Saturation Index Method. Based on the LSI calculation results, a value of -0.9 is obtained. This indicates that the corrosion rate is high, but there is no visible potential for scale formation. Formation of corrosion in the pipe can cause the pipe wall to thin out thereby increasing the potential for pipe leakage. Due to this, the checking of the pipes is necessary. Potential leakage of pipes will disrupt the distribution system and reduce service levels of PDAM Bandar Lampung City. Increasing the value of LSI in water can increase the pH of each water source. Increasing the pH will cause an increase in the value of LSI so that it is in neutral conditions and the level of corrosivity decreases. In addition, the flow velocity of water needs to be maintained with a minimum speed of 0.3 m/s to prevent the formation of scale on the pipes. Keywords: scale, corrosivity, LSI value.

1. Introduction

The formation of scale is a complex problem and always occurs in piping systems, both in the oil pipeline system, industry, and water distribution [1]. Crust is an inorganic compound that is deposited and forms crystalline deposits on the surface of the substance [2]. When the crust is formed on the pipe, it will cause the pipe diameter to shrink and inhibit the flow of fluid in the pipe system. Because the disruption of fluid flow causes an increase of temperature and pressure, the possibility of the pipe damage gets higher [3]. Corrosion is a result of the chemical reaction of metals in environmental conditions. Corrosion is an electrochemical reaction that is natural and takes place spontaneously, therefore cannot be prevented or stopped altogether. Corrosion can only be controlled or slowed down so that it slows down the damage process. Corrosion is basically a reaction of metal to turn ions on surfaces that come into direct contact with the environment, both water and oxygen. There are two corrosion controls, namely from materials and from the environment [4]. Factors of material include the purity of the material, the microstructure of the material, the elements present in the material and so on. Factors of the environment include the level of air pollution, temperature, humidity and the presence of corrosive chemicals. Corrosive materials consist of acids, bases and salts, both in the form of inorganic and organic compounds. Losses caused by corrosion include reduced efficiency, reduced construction strength and increased maintenance costs [5]. The danger arising from corrosion will damage the tissues in the human body that come into direct contact with the skin.
and will contaminate the respiratory system [6,7,8,9,10]. Research on erosion corrosion by testing composition, hardness testing, microstructure testing, and tensile testing have been carried out. The research focuses on controlling the corrosion rate based on the material or pipe material [11,12]. Based on the background, a study was carried out on the rate of scale formation and the level of corrosivity in the distribution pipelines of PDAM Way Rilau, Bandar Lampung, which was affected by the environment. In this study, the formation of scale and the level of corrosivity in the distribution network of the PDAM "Way Rilau" Bandar Lampung will be studied theoretically by paying attention to corrosive materials, using the Langelier Saturation Index method.

2. Method
Langelier Saturation Index (LSI)
The potential for scale formation and the level of corrosivity in the distribution network can be predicted by calculating the LSI value. Factors that influence the value of LSI include pH, soluble solids (TDS), calcium hardness, alkalinity and temperature of water flowing in the pipeline [13,14,15].

LSI values can be calculated using Equation (1)

\[
\text{LSI} = \text{pH} - \text{pHs}
\]  

(1)

where:
LSI: Langelier saturation index
pH: pH measured
pHs: PH the water is saturated

Value of pHs calculated by using equation (2).

\[
\text{pHs} = \text{pK}_2' + \text{pCa}^{2+} - \text{pK}_s' - \log(2[\text{Alk}]) - \log \gamma_m
\]  

(2)

The values of the variables in Equation (2) must be known in advance to get the pHs value. Following are the steps in calculating variables to determine the pH value [13,14,15]. The steps of calculating the value of pK$_2'$ which is the negative value from the constant log K$_2'$ ($-\log K'_2$) are as follows:

Determine of ionic strength in mol per liter (M) in the water using equation:

\[
I(M) = (2.5 \times 10^{-5} \text{ mol/mg}) \times [\text{TDS (mg/L)}]
\]  

(3)

TDS: dissolved solids (mg/L)
a. Determine the value of $\gamma_m$ by using Davies equation:

if $I < 0.5 \text{ M} \rightarrow \log \gamma_m = -AZ^2 \left( \frac{\sqrt{T}}{1+\sqrt{T}} - 0.21 \right)$  

(4)

if $0.5 \text{ M} < I < 1.0 \text{ M} \rightarrow \log \gamma_m = -AZ^2 \left( \frac{\sqrt{T}}{1+\sqrt{T}} \right)$  

(5)

where:
M = Molarity (mol/L)
A = 1.82 $\times$ 10$^6$ (DT)$^{-1.5}$
D = 78.3 (Constanta of dielectric)
T = temperature (K)
Z = ion oxidase value (ion monovalent = 1)
b. Determine the value of pK₂ using equation:

\[ pK_2 = \frac{2.90239}{T} + 0.02379 \ (T) - 6.498 \]  
\[ K_2 = 10^{-pK_2} \]  

(6) (7)

c. Determine the value of \( \gamma_D \) by using equation:

\[ \gamma_D = 10^{0.0379T} \]  
\[ \log \gamma_D = -AZ^2 \left( \frac{\sqrt{I}}{1+\sqrt{I}} \right) \]  

(8) (9)

d. Determine the value of \( K'_2 \) using equation:

\[ K'_2 = \frac{K_2}{\gamma_D} \]  

(10)

e. Determine the value of pK₂' using equation:

\[ pK_2' = \log \frac{1}{K_2'} \]  

(11)

Determine the value of pK₂' which is the negative value of K₂' (−log K₂'). The steps are as follows:

a. Determine the value of pK₅:

\[ pK_5 = 0.01183t + 8.03 \]  
Where: \( t \) = water temperature (°C)

b. Conversion of pK₅ to K₅:

\[ K_5 = 10^{-pK_5} \]  

(12) (13)
c. Using the value of \( \gamma_D \) to calculate of \( K'_5 \):

\[ K'_5 = \frac{K_5}{(\gamma_D)^2} \]  

(14)
d. Determine the value of pK₅':

\[ pK_5' = \log \frac{1}{K_5'} \]  

(15)

Determine the value of pCa²⁺ as follows:

a. Conversion of Ca²⁺ from satuan mg/L to mol/L using equation:

\[ Ca^{2+} (mol/L) = \frac{[Ca^{2+} \text{ in mg/L} \times 10^3]}{40} \]  

(16)
b. Determine of pCa²⁺:

\[ pCa^{2+} = \log \frac{1}{[Ca^{2+} \text{ in mg/L} \times 10^3]} \]  

(17)

Calculate the alkane value in unit of mol / liter, with the following equation:

\[ [ALK] \text{ in mol/L} = \frac{[Ca^{2+} \text{ in mg/L} \times 10^{-3}]}{100} \]  

(18)

The relationship between LSI values with scale formation potential and the level of corrosivity can be seen in Table 1.

| Value of LSI | Indication                    |
|-------------|-------------------------------|
| -2.0 up to -0.5 | High corrosive potential     |
| -0.5 up to 0   | Low corrosive potential; no crust formed |
| 0             | Neutral                       |
| 0 up to 0.5    | Potential for low crust formation; corrosive |
| 0.5 up to 2.0  | High potential for scale formation; not corrosive |
3. Result and Discussion

3.1. Water sample testing data
Based on testing of clean water samples, the results obtained as in Table 2 below.

| Physical testing | Chemical testing |
|------------------|------------------|
| Parameter              | Result of testing | *) Maximum limit | Unit |
| TDS                  | 89.4             | 1500             | mg/l |
| Temperature          | 25.6             | Air temperature (± 3 °C) | °C |
| pH                   | 7.60             | 6.5-9.5          | -    |
| Alkalinity           | 72               | -                | mg/l |
| Total water hardness | 500              | -                | mg/l |
| Water hardness from Mg | -              | -                | mg/l |
| Water hardness from Ca | 11.26           | -                | mg/l |

*) Permenkes No. 492/MENKES/PER/IV/2010

3.2. Calculation value of LSI
The value of pHs refers to formula (2)

\[ \text{pHs} = \text{pK}_2' + \text{pCa}^2+ - \text{pK}_5' - \log(2[\text{Alk}]) - \log \gamma_m \]

To find the value of a variable in the calculation of pHs, the following steps are carried out:

a. Determine ionic strength (I) by using formula (3)

\[
I(\text{M}) = (2.5 \times 10^{-5} \text{ mol/mg}) \times [\text{TDS} \text{ (mg/L)}] \\
= (2.5 \times 10^{-5} \text{ mol/mg}) \times [89.4 \text{ (mg/L)}] = 2.235 \times 10^{-3} \text{ M}
\]

b. Determine the value of \( \gamma_m \), by using formula (4) because value of I < 5

\[
I < 0.5 \text{ M} \rightarrow \log \gamma_m = -AZ^2\left(\frac{\sqrt{I}}{1+\sqrt{I}}\right) - 0.2I
\]

\[
A = 1.82 \times 10^6 \text{ (DT)^{-1.5}} \\
= 1.82 \times 10^6 (78.3 \times (25.6 + 273))^{-1.5} = 0.509
\]

\[
\log \gamma_m = -AZ^2\left(\frac{\sqrt{I}}{1+\sqrt{I}}\right) - 0.2I
\]

\[
= -0.509 \times 1^2\left(\frac{2.235^{-10^{-3}}}{1+\sqrt{2.235^{-10^{-3}}}}\right) - 0.2 \times 2.235 \times 10^{-3} = 0.0227
\]

c. Calculation of \( \text{pK}_2 \) by using formula (6)

\[
\text{pK}_2 = \frac{290.39}{T} + 0.02379 \text{ (T)} - 6.498 \\
= \frac{2902.39}{(25.6+273)} + 0.02379 (25.6 + 273) - 6.498 = 10.32
\]

\[
\text{K}_2 = 10^{-\text{pK}_2} = 10^{-10.32} = 2.1 \times 10^{10}
\]

d. Calculation of \( \gamma_D \) by using formula (8)

\[
\gamma_D = 10^{\log \gamma_D} \\
\log \gamma_D = -AZ^2\left(\frac{\sqrt{I}}{1+\sqrt{I}}\right) = -0.509 \times 1^2\left(\frac{2.235^{-10^{-3}}}{1+\sqrt{2.235^{-10^{-3}}}}\right) = -0.0229
\]

\[
\gamma_D = 10^{-0.0229} = 0.948
\]

e. Calculation of \( \text{K}_2' \) by using formula (10)
\[ K'_{2} = \frac{K_{2}}{\gamma_{D}} = \frac{2.1 \times 10^{10}}{0.948} = 2.21 \times 10^{10} \]

f. Calculation of \( pK'_{2} \) by using formula (11)
\[ pK'_{2} = \log \frac{1}{K'_{2}} = \log \frac{1}{2.21 \times 10^{10}} = -10.34 \]

Calculation of \( pK'_{s} \) which is the negative value of Constanta \( K'_{s} \) (\( -\log K'_{s} \)), by using formulas (12) up to (15).

a. Calculation of \( pK_{s} \) by using formula (12):
\[ pK_{s} = 0.01183t + 8.03 = 0.01183 \times 25.6 + 8.03 = 8.33 \]

b. Conversion of \( pK_{s} \) to \( K_{s} \) by using formula (13)
\[ K_{s} = 10^{-pK_{s}} = 10^{-8.33} = 4.67 \times 10^{-9} \]

c. Calculation of \( K'_{s} \) using the value of \( \gamma_{D} \) (14)
\[ K'_{s} = \frac{K_{s}}{(\gamma_{D})^{2}} = \frac{4.67 \times 10^{-9}}{0.948^{2}} = 5.204 \times 10^{-9} \]

d. Calculation of \( pK'_{s} \) by using formula (15)
\[ pK'_{s} = \log \frac{1}{K'_{s}} = \log \frac{1}{5.204 \times 10^{-9}} = 8.283 \]

Calculation of \( pCa^{2+} \) by using formulas (16) and (17)

a. Conversion calculation of \( Ca^{2+} \) by using formula (16)
\[ Ca^{2+} (\text{mol/L}) = \frac{\text{[Ca}^{2+} \text{in mg/L]} \times 10^{3}}{40} = \frac{11.26 \text{mg/L} \times 10^{3}}{40} = 0.000282 \text{ mol/L} \]

b. Calculation of \( pCa^{2+} \) by using formula (17)
\[ pCa^{2+} = \log \frac{1}{0.000282 \text{ mol/L}} = 3.55 \]

Calculation of alkalinity value in \( \text{mol/liter, by using formula (18)} \)
\[ [\text{ALK}] \text{ in mol/L} = \frac{11.26 \text{ in mg/L]} \times 10^{-3}}{100} = 0.0001126 \text{ mol/L} \]

Calculation of LSI value:
\[ \text{pHs} = pK'_{2} + pCa^{2+} - pK'_{s} - \log(2\text{[Alk]}) - \log \gamma_{m} \]
\[ = -10.34 + 3.55 - 8.283 - \log(2 \times 0.0001126) - \log 0.0227 = 8.5 \]
\[ \text{LSI} = 7.6 - 8.5 = -0.9 \]

Besides doing LSI calculations manually, it can be done using the LSI Calculator which can be accessed on the website. LSI Calculator is standardized and has a better level of accuracy than manual calculations. The water data input process at the PDAM Way Rilau source can be seen in Figure 1, and the LSI calculation results can be seen in Figure 2.
4. Conclusion
The calculation of LSI value is carried out on the water source used by the PDAM "Way Rilau" Bandar Lampung. From LSI calculation, the LSI value of -0.9 is obtained. This indicates that the corrosion rate is high, but the potential for scale formation is not visible. Based on Table 1, the formation of rust on the pipe can cause the pipe wall to thin, thereby increasing the potential for pipe leakage. Due to this, checking the condition of the pipe is necessary. Potential leakage of pipes will disrupt the distribution system and reduce service levels of PDAM Bandar Lampung City. Increasing the LSI value in water can be done by increasing the pH in each water source. Increasing the pH value will cause an increase in the value of LSI so that the LSI value can be in neutral conditions and the level of corrosivity decreases. In addition, the flow velocity of water needs to be maintained with a minimum speed of 0.3 m/s to prevent the formation of scale on the pipes [15,16,17].

5. References
[1] Suyono, T., Pranoto, W.A., Irawan, A.P., 2017 IOP Conference Series: Materials Science and Engineering, vol. 508, no. 012035.
[2] Kemmer, F. N., 1979 *The Nalco Water Hand Book* (New York: Mc. Graw Hill Book Co).
[3] Patton, C., 1981 *Oilfield Water System 2.ed* (Oklahoma: Cambell Petroleum Series).
[4] Irawan, A.P., Halim, H., Kurniawan, H. 2017 *IOP Conference Series: Materials Science and Engineering*, vol. 237 (2017). pp. 1-8.
[5] Irawan, A.P., Utama, D.W., Affandi, E., Suteja, H., 2019 *IOP Conference Series: Materials Science and Engineering*, vol. 508, no. 012054.
[6] Kumala, R., 2011 *Mengenal Korosi dan Akibatnya, Serta Cara Pencegahannya dalam Kehidupan Sehari-hari* (Jakarta: Gramedia Pustaka Utama).
[7] Irawan, A.P., Halim, A., Kurniawan, H., 2017 *IOP Conference Series: Materials Science and Engineering* 237-1-012006
[8] Irawan, A.P., Adianto, Sukania, I.W., 2018 *IOP Conference Series: Materials Science and Engineering* 420-1-012015
[9] Irawan, A.P., 2018 *IOP Conference Series: Materials Science and Engineering* 420-1-012060
[10] Irawan, A.P., Soemardi, T.P., Widjajalaksmi, K., Reksoprodjo, A.H.S., 2010 *International Conference APHCI Ergofuture 2010* pp. 37-43. (Denpasar Bali Indonesia)
[11] Sukarto, Teguh, R., 2017 *Final Project*. (Surabaya: Institut Teknologi Sepuluh November).
[12] Sulistiyono, W., 2014 *Jurnal Teknik Mesin* 2-4.
[13] Saefudin, Sundono, 2015 *Jurnal Metalurgi* 5-1.
[14] Benefield, L., Judkins, J., Weand, B., 1982 *Process Chemical for Water and Wastewater Treatment* (New Jersey: Prentice-Hall, Inc. Englewood Cliffs).
[15] Hafid, Muhammad, 2019 *Hasil Pemeriksaan Kualitas Air* (Bandar Lampung: Laboratorium PDA Way Rilau).
[16] Lenntech, B.V., 2019 *Langelier Saturation Index Calculator*. https://www.lenntech.com/calculators/angelier/index/angelier.html
[17] Peraturan Menteri Pekerjaan Umum Nomor No. 18/PRT/M/2007 *Penyelenggaraan Pengembangan Penyediaan Air Minum Jilid Pengelolaan* (Jakarta: Departemen Pekerjaan Umum, Direktorat Pengembangan Air Minum, Ditjen Cipta Karya).