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

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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)

$$\text{LSI} = \text{pH} - \text{pH}_s \quad (1)$$

where:

LSI: Langelier saturation index

pH: pH measured

pH_s: PH the water is saturated

Value of pH_s calculated by using equation (2).

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

The values of the variables in Equation (2) must be known in advance to get the pH_s 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:

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

TDS: dissolved solids (mg/L)

a. Determine the value of γ_m by using Davies equation:

$$\text{if } I < 0.5 \text{ M} \rightarrow \log \gamma_m = -AZ^2 \left(\frac{\sqrt{I}}{1+\sqrt{I}} - 0.2I \right) \quad (4)$$

$$\text{if } 0.5 \text{ M} < I < 1.0 \text{ M} \rightarrow \log \gamma_m = -AZ^2 \left(\frac{\sqrt{I}}{1+\sqrt{I}} \right) \quad (5)$$

where:

M = Molarity (mol/L)

A = $1.82 \times 10^6 (\text{DT})^{-1.5}$

D = 78.3 (Constanta of dielectric)

T = temperature (K)

Z = ion oxidase value (ion monovalent = 1)

- b. Determine the value of pK_2 using equation:

$$pK_2 = \frac{2.902,39}{T} + 0.02379 (T) - 6.498 \quad (6)$$

$$K_2 = 10^{-pK_2} \quad (7)$$

- c. Determine the value of γ_D by using equation:

$$\gamma_D = 10^{\log \gamma_D} \quad (8)$$

$$\log \gamma_D = -AZ^2 \left(\frac{\sqrt{I}}{1+\sqrt{I}} \right) \quad (9)$$

- d. Determine the value of K'_2 using equation:

$$K'_2 = \frac{K_2}{\gamma_D} \quad (10)$$

- e. Determine the value of pK'_2 using equation:

$$pK'_2 = \log \frac{1}{K'_2} \quad (11)$$

Determine the value of pK'_s which is the negative value of K'_s ($-\log K'_s$). The steps are as follows:

- a. Determine the value of pK_s :

$$pK_s = 0.01183t + 8.03 \quad (12)$$

Where: t = water temperature ($^{\circ}\text{C}$)

- b. Conversion of pK_s to K_s :

$$K_s = 10^{-pK_s} \quad (13)$$

- c. Using the value of γ_D to calculate of K'_s :

$$K'_s = \frac{K_s}{(\gamma_D)^2} \quad (14)$$

- d. Determine the value of pK'_s :

$$pK'_s = \log \frac{1}{K'_s} \quad (15)$$

Determine the value of pCa^{2+} as follows:

- a. Conversion of Ca^{2+} from satuan mg/L to mol/L using equation:

$$Ca^{2+}(\text{mol/L}) = \frac{[Ca^{2+} \text{ in mg/L}] \times 10^3}{40} \quad (16)$$

- b. Determine of pCa^{2+} :

$$pCa^{2+} = \log \frac{1}{[Ca^{2+} \text{ in mg/L}] \times 10^3} \quad (17)$$

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

$$[ALK] \text{ in mol/L} = \frac{[Ca^{2+} \text{ in mg/L}] \times 10^{-3}}{100} \quad (18)$$

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

Table 1. LSI value and potential of crust formation and corrosiveness [14,15,16]

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.

Table 2. Result of testing [14,15,16]

No.	Parameter	Result of testing	*) Maximum limit	Unit
Physical testing				
1	TDS	89.4	1500	mg/l
2	Temperature	25.6	Air temperature (+/- 3 °C)	°C
Chemical testing				
1	pH	7.60	6.5-9.5	-
2	Alkalinity	72	-	mg/l
3	Total water hardness		500	mg/l
4	Water hardness from Mg		-	mg/l
5	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)

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

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

Determine pK'_2 by using formulas (3) until (11)

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

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

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

$$\begin{aligned} I < 0.5 \text{ M} &\rightarrow \log \gamma_m = -AZ^2 \left(\frac{\sqrt{I}}{1+\sqrt{I}} - 0.2I \right) \\ A &= 1.82 \times 10^6 (\text{DT})^{-1.5} \\ &= 1.82 \times 10^6 (78.3 \times (25.6 + 273))^{-1.5} = 0.509 \\ \log \gamma_m &= -AZ^2 \left(\frac{\sqrt{I}}{1+\sqrt{I}} - 0.2I \right) \\ &= -0.509 \times 1^2 \left(\frac{\sqrt{2.235 \times 10^{-3}}}{1+\sqrt{2.235 \times 10^{-3}}} - 0.2 \times 2.235 \times 10^{-3} \right) = 0.0227 \end{aligned}$$

c. Calculation of pK_2 by using formula (6)

$$\begin{aligned} \text{pK}_2 &= \frac{290.39}{T} + 0.02379 (T) - 6.498 \\ &= \frac{2,902.39}{(25.6+273)} + 0.02379 (25.6 + 273) - 6.498 = 10.32 \\ K_2 &= 10^{-\text{pK}_2} = 10^{-10.32} = 2.1 \times 10^{-10} \end{aligned}$$

d. Calculation of γ_D by using formula (8)

$$\begin{aligned} \gamma_D &= 10^{\log \gamma_D} \\ \log \gamma_D &= -AZ^2 \left(\frac{\sqrt{I}}{1+\sqrt{I}} \right) = -0.509 \times 1^2 \left(\frac{\sqrt{2.235 \times 10^{-3}}}{1+\sqrt{2.235 \times 10^{-3}}} \right) = -0.0229 \\ \gamma_D &= 10^{-0.0229} = 0.948 \end{aligned}$$

e. Calculation of 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 γ_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)

$$Ca^{2+}(\text{mol/L}) = \frac{[Ca^{2+} \text{ in } \text{mg/L}] \times 10^3}{40} = \frac{11.26 \text{ mg/L} \times 10^3}{40} = 0.000282 \text{ mol/L}$$

- 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 mol/liter, by using formula (18)

$$[ALK] \text{ in } \text{mol/L} = \frac{[11.26 \text{ in } \text{mg/L}] \times 10^{-3}}{100} = 0.0001126 \text{ mol/L}$$

Calculation of LSI value:

$$\begin{aligned} pH_s &= pK'_2 + pCa^{2+} - pK'_s - \log(2[Alk]) - \log \gamma_m \\ &= -10.34 + 3.55 - 8.283 - \log(2 \times 0.0001126) - \log 0.0227 = 8.5 \end{aligned}$$

$$LSI = 7.6 - 8.5 = -0.9$$

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.

Langelier Saturation Index Calculator

This calculator helps you determine the scaling potential of the water by using the Langelier Saturation Index.

Give the values of your water analysis. All the fields with * are required.

Table 1: Input table

pH

Conductivity / TDS

[Ca²⁺]

[HCO₃⁻]

Water temperature

If you do not have a water analysis you can use the values in table 2. Click on a button at the bottom of table 2

Table 2 : Additional data

	pH = 7.7	8	8.6	
TDS =	20	34483	273	mg/l
[Ca ²⁺] =	5	400	49	mg/l
[HCO ₃ ⁻] =	10	140	121	mg/l
T =	20	20	20	degree C

Figure 1. LSI calculator of Leentech [15,16]

Table 3: Results Langelier Saturation Index

pH_s

LSI

Indication based on Langelier (1936)

Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to

Indication based on improved Langelier by Carrier (1965)

Serious corrosion.

The Langelier Saturation Index formula is $LSI = pH - pH_s$

For an explanation of the formula click [here](#).

Figure 2. The Result of LSI value [15,16]

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].

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