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A Review of Corrosion Assessment Model and Parameters of Drinking Water Distribution Pipelines

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Abstract

Corrosion assessment is an important aspect in asset and facilities management. Generally the purpose of corrosion assessment is to assure the activities of the management will be effective and efficient. Lack of corrosion assessment can be decrease the function and reduce the life cycle of assets and facilities caused by corrosion. Corrosion is an electrochemical or chemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties. Even though most of the dangers from corrosion occurs in major industrial plant, corrosion also has a great impact on the drinking water industry. In drinking water distribution pipelines, corrosion damage cause the leakages of distribution pipelines and around 30% of water supplied to consumers is lost. Most of the leakages of drinking water distribution pipelines are initiated by lack of corrosion assessment and poor maintenance because the pipes are usually located underground. To overcome this problem, an effective corrosion assessment method is imperative to get the accurate information about the condition of the pipelines. This will ensure better decisions for repair or replacement of the pipelines before they fail. This review paper describes the corrosion assessment model and the major parameters considered for drinking water distribution pipelines.

Keywords: Asset and facilities management; corrosion-assessment; corrosion-parameters; drinking water; distribution pipelines

■1.0 INTRODUCTION

The shortage of drinking water supply has become a global issue today, because more than one billion people do not have access to safe drinking water [1]. Access to drinking water means that the source is less than 1 kilometer away from its place of use and that it is possible to reliably obtain at least 20 liters per member of a household per day and the water must be of good quality for the people’s health at the point of delivery to the user [2]. Lack of people's access to drinking water is due to the reduced source of water caused by population growth, economic development and changing lifestyles. The problem is aggravated by loss of water due to the frequent incidents of leakages in the distribution pipeline caused by corrosion.

Decreasing of water supply is due to the loss of water, both the physical and nonphysical aspects in the distribution network to the public. Although the distribution pipeline has been designed for corrosion resistance, around 30% of water supplied to consumers is lost in distribution network due to leakages. In Italy, water loss ranged from 20-65%, with an average of about 40% [3]. Studies conducted in Europe in 2004 showed that the corrosion that occurs in the water distribution pipes cause about 30% of water lost to the consumer [4]. In the United States, the loss of water due to leakages reached 15%, and 89 percent are caused by damages to the pipeline due to corrosion that occurs in the inner and outer pipes [5]. In Indonesia, water loss ranged from 30 to 40%, and most of the water loss is due to leaks in the pipe by corrosion [6].

The leakages of drinking water distribution pipelines are generally caused by a lack of corrosion assessment and poor maintenance. This occurs because the pipe is usually located underground. To overcome this problem, corrosion assessment methods and effective parameters are necessary to obtain the accurate data and information from the pipelines. This will ensure a better decision for the repair or replacement of pipes before they fail.

■2.0 CORROSION ON DRINKING WATER DISTRIBUTION PIPELINES

Corrosion activity occurs as a natural reaction between a metallic structure and its environment. When exposed to oxygen and water, the metal will undergo a process called oxidation. When a metal experiences oxidation, the basic element of metal, reacts with the hydroxide ion to form corrosion films. When the base metal is consumed to form corrosion films, the base metal experiences corrosion degradation, leading to loss of material [7, 8].

In drinking water distribution pipelines, the environment of corrosion applies to both external and internal pipe corrosions. Since most of the drinking water distribution pipes are placed in the soil, the external corrosion is related to the corrosivity of the soil [9, 10]. Meanwhile, the internal corrosion is related to the aggressivity of water leading to pipe wall loss [11].

Corrosion of pipes caused a reduction in mass of the pipe due to oxidation, which causes the formation of precipitate or oxide layer on the surface of the pipe. As a result of physical damage pipes and decreased strength, so it will be easily damaged when receiving mechanical or hydraulic shock loads that occur because of improved roads or ground movement.

Corrosion products of metal oxides formed on the surface of the pipe can also accumulate and form tuberculosis, thus inhibiting the flow rate and increasing head losses and decreasing flow capacity [12]. Tuberculosis which do not damage the layer followed by formation of the next layer, can cause internal corrosion acceleration [11].

Corrosion products, in the form of metal oxide contained in the pipeline do not have strong bound to the surface of the pipe wall. This causes the particles of metal oxide to dissolve into the water stream with high flow rate [13], resulting in lower water quality and often a customer complaint as "red water" that comes out of taps [12, 14, 15].

In addition to the aforementioned problems, corrosion in drinking water is brought about by the distribution pipelines which are located underground. The underground environment can also cause leakage of the pipe wall. This leakage will allow infiltration of particles contained in the soil into the pipe and contaminating the water delivered. The particles which are carried by the flow of water is potentially infectious disease, giving rise to serious public health risk [16].

Damaged pipes due to corrosion took place in stages, where the time and mechanism of damage is relatively difficult to predict. Damage to the pipe can be either: (a) partial damage, leak or rupture of a pipe (but the pipe can still drain the water); or (b) overall damage, which affects the hydraulic equilibrium of the system, thus requiring repair or replacement [17].

In fact, corrosion is often overlooked and the maintenance is not done in a sustainable manner [18, 19]. Although the most important thing in corrosion control is the availability of data and information, however, most drinking water managers do not have the complete data and information about the failure of pipes [5, 20, 21].

To find out the actual condition of the pipe, corrosion assessment is required in the drinking water pipelines. In conducting the assessment of corrosion is necessary to know the corrosion assessment models and parameters to be measured.

■3.0 CORROSION ASSESSMENT MODELS

Corrosion assessment is the process of condition assessment for pipelines which suffer corrosion attack; hence corrosion assessment is part of condition assessment. Therefore the assessment of corrosion is the process of collection data and information. There are two methods for corrosion assessment which are direct and indirect methods. Direct assessment can be done by measurement of metal loss and corrosion rate provided by the weight loss coupons, linear polarization, electrical resistance, or galvanic current measurement techniques. Meanwhile the indirect assessment of corrosion can be obtained through continuous measurements of operational data, such as soil or fluid pH, pressure and flow of fluid. Both of the methods are followed by analysis of the data and information, for determination the current and future structure condition, hydraulic status of the pipelines and water quality.

Generally, corrosion monitoring aims to get the following information: (1) related to the condition of pipelines, were required to avoid the occurrence of abruptly failure of equipment that could lead to interruption of the operations; (2) about the relationship between the corrosion process and operating variables, so the pipelines can be used more efficiently; (3) about the level of contamination of the fluid during the operational process; and (4) related to the condition of pipelines can prevent failures and disasters [22].

The data and information of drinking water distribution pipelines, is very important in corrosion management, because it should be the reference in making the decision whether a pipeline will be rehabilitated or replaced [23]. The collection of pipe attribute data includes pipe attributes, environmental attributes and operational attributes [24]. There are two main approaches for assessing the condition of a pipe. The first assessing approach is direct inspection and the second approach is based on indirect indicators, such as soil properties [17].

■4.0 CORROSION ASSESSMENT PARAMETERS

Many different mechanisms and parameters are involved in corrosion and failure of pipes [11]. Generally, some parameters of corrosion and influence corrosion failure of drinking water pipelines is covered into three factors, i.e. physical, operational and environmental [24].

4.1 Physical Factors

Generally, the physical factors affecting the occurrence of damage to the pipeline include: material, dimension and surface roughness of pipes, however, corrosion damage usually characterized by measuring: mass change and pipe wall thinning [25]. The mass change was measured after the corrosion products were removed and the underlying metal would remain intact which will result in two measures of damage: mass loss and corrosion penetration [26]. The mass loss and corrosion penetration can be converted to corrosion rates by dividing the exposure time. This calculation assumes that the corrosion rates are effectively constant over the exposure time.

Mass loss can be converted to an average penetration rate using the density of the metal. The ratio of the maximum measured penetration to the average penetration calculated from mass loss is the pitting ratio, which is a measure of the propensity of the environment to cause local variations in the corrosion rate over the surface of metal, where the pit being a high corrosion rate at a small spot [26].

To anticipate corrosion attack, the pipelines are protected by coatings, but no coating is perfect, therefore the initiation of external corrosion on the pipe is generally caused by coating defect. Therefore, the coating must be periodically checked, because the condition of the layer is also important to influence the occurrence of damage to pipes. The coating can be checked by impressing an electric signal on to the pipe and measuring its strength along the pipe. If the coating is uniform, the signal should decrease linearly along the pipeline [27, 28].

4.2 Operational Factors

The operational factor is related to the performance of the water flow inside the pipe [25]. The parameter consist of transient pressure, flow rate and flow capacity.

4.3 Transient Pressure

Transient pressure can be a significant cause of pipe failures. Some authorities consider that this can be the most important cause of induced stress failures. The original design would be based on an operating pressure with a maximum test pressure that would allow for surges and other intermittent pressure variations. In the normal operating life, the pipe should be quite capable of working within this design range. However if there are increases in operating pressures beyond those allowed in the design, can be accelerating the corrosion rate of the pipe and when the pipe has deteriorated, then there is a likelihood of failure [11].

4.4 Flow Rate

Flow rate causes vary corrosion effects in water pipelines. The flow rate is an important parameter in the scale formation processes [29]. Increasing the flow rates may cause the dissolved oxygen in water are becoming more widely, thus speeding up the corrosion reaction and accelerate the deposition of corrosion products on the pipe surface. In the rapid flow of water, the resulting precipitate a protective layer tends to be more dense and minimizing the porous. However, the faster flow rate can cause erosion of sediment contained a protective layer on the metal surface [30].

4.5 Flow Capacity

Flow capacity is one important parameter in the assessment of internal corrosion of water pipes. The lower capacity cause precipitation of the sediment in water flow on the pipe wall and become the media for corrosion. Theoretically, the flow capacity can be calculated by multiplying the flow velocity and the pipe cross-sectional area. However, in practice the flow capacity can be determined by measuring the volume flow over time

4.6 Environmental Factors

Environmental factors that influence the occurrence of damage to the pipe are environmental conditions that directly affect and decrease the ability of pipeline damage [25]. For water distribution pipelines, environmental corrosion applies to both external and internal pipe corrosions. The external environment is the environment around the outside of the pipe wall and the internal environment is the environment in the inside of the pipe.

4.7 External environment

The parameters of external environment that affect the corrosion of water distribution pipelines is soil corrosivity. Soil resistivity is generally accepted as the primary indicator of soil corrosivity. Soil resistivity is the reciprocal of conductivity, the lower the resistivity, the easier current will flow through the soil. In particular there are no established standards for determining soil corrosivity, but based on the value of soil resistance, soil corrosivity can be generally classified, as shown in Table 1 [7].

Table 1 Soil corrosivity [7]

Corrosivity	**Very Corrosive**	**Severely Corrosive**	**Moderately Corrosive**	**Mildly Corrosive**	**Progressively Less Corrosive**
Resistivity (ohm-cm)	< 500	500 - 1.000	1.000 – 2.000	2.000 – 10.000	> 10.000

Corrosivity of a particular soil is also affected by several other parameters [28, 31]. Thus some parameters can be assessing to evaluate the soil resistivity. It is consist of: soil moisture, pH, and sulfide and chloride concentration.

Soil moisture is the significant parameter for the soil resistivity, because the hydrolyzed water molecule provides the ions required for anodic and cathodic reactions to occur. Moisture content of approximately 16% or greater is required to sustain corrosion [7].

The logarithmic scale of **pH** is a representation the alkalinity or acidity of soil. The pH value is related to hydrogen ion activity and run from 1 to 14. In the environment that contains more OH^-ions than H^+ ions showed a higher pH (alkaline) and instead. In general, for an environment that has a pH 7 is considered as a neutral environment. A value of more than 7 indicates the substance is alkaline and a value of 11 or more indicates it is very alkaline and is likely to cause corrosion. Likewise, a value of less than 7 indicates that the substance is acidic, and a value of 3 or less indicates it is a strong acid and the environment will be more corrosive.

The presence of **sulfides** in the soil indicates the presence of sulfate reducing bacteria in the environment. Bacteria can consume oxygen, thereby causing the pH gradient in a particular area. Meanwhile the presence of **chloride** ions in the soil will facilitate the process of corrosion. Chloride ion concentrations above 50 ppm will lead to a more corrosive environment.

4.8 Internal Environment

In the internal environment the corrosion of pipes affect by water aggressivity [11]. The parameter that affects the aggressiveness of water in drinking water distribution pipes are the elements or contaminants contained in the water flow in the pipe.

The **pH value** is the most of corrosion parameters of water that influence the occurrence of corrosion in pipes. The pH value is influenced by concentration of hydrogen ions contained in water. Because the hydrogen ion (H^+) is one of the main elements that accept electrons from the metal when corrosion occurs, then the pH is an important factor to measure the rate of corrosion of water. At pH values below then 5, the metal corrode rapidly and uniformly, while at pH between 5 and 9, pitting corrosion can occur if there is no protective layer is present [29]. Increasing the mass loss of the pipe, which is expressed the degree of tuberculosis [30]. At pH values higher than 9, metals are usually protected due to the formation of the passive ferric oxide film which will protect the metal [29, 30].

Hardness is another corrosion parameter of water. The hardness is caused predominantly by the presence of calcium and magnesium ions and is expressed as the equivalent quantity of $CaCO_3$. Hard water is generally less corrosive than soft water if a protective $CaCO_3$ film is formed on the metal surface. The CO_2 dissolved in water will forms carbonic acid H_2CO_3 and reduces pH by dissociation to H^+ and HCO_3^-. The bicarbonate ion $2HCO_3^-$ reacts directly with Ca^{2+} present in water to form the insoluble $CaCO_3$, which deposit on the metal surface as a protective film [14]. The tendency for calcium carbonate to precipitate depends on saturation index. If the values of saturation index negative, the water considered is corrosive, but for positive values of saturation index, the water has sufficient alkalinity to precipitate $CaCO_3$ which will reduce the corrosion.

Oxygen dissolved in water is the corrosion parameter of water also, and most affecting elements of metal corrosion, because the oxygen is an acceptor of electrons in metal corrosion. The addition of oxygen dissolved in water will react with metal and result the corrosion products of metal oxide. Corrosion rate will increase if the dissolved oxygen in water increases. However, its effect on the concentration of iron and tuberculosis may be combined, depending on the type of oxide formed [29,30].

■5.0 DISCUSSION AND SUMMARY

This paper provides general review of the models and major parameter for corrosion assessment on drinking water distribution pipelines. Both of direct and indirect models can be apply to get data and information of pipelines condition. Related to the parameters, the attention has mainly focused on physical, operational and environmental factors. For each factor the main parameters were discussed. The mass loss and pipe wall thinning are the parameters of physical factors, where can be converted to corrosion rates by dividing by the exposure time.

The parameter of the operational factors is related to the performance of the water flow in the pipe consist of transient pressure, flow rate and flow capacity. These parameters are indirect assessment parameter for corrosion on drinking water distribution pipelines. The transient pressure can be accelerate the corrosion rate of the pipe, high flow rates will increase the dissolved oxygen in water and can cause erosion of the protective layer on the pipe surface and the lower capacity can cause precipitation of the sediment in water flow on the pipe wall and become the media for corrosion.

Environmental factors that influence the occurrence of damage to the pipe is divided in to external and internal environment. The parameters of external environment is soil corrosivity, where measured by soil resistivity. However no standard for the soil corrosivity, in the particular case, the other parameters can be assessing to evaluate the soil resistivity. They are soil moisture, pH, and sulfide and chloride concentration. For the internal environment, the parameter is the water aggressivity which affected corrosion of pipes. The parameters consist of pH value, hardness and oxygen dissolved.

From the several major corrosion assessment parameters on drinking water distribution pipelines were discussed, the main parameter is the mass loss or wall thinning of the pipe. It is caused by this parameter can illustrate the actual condition of the pipe. Meanwhile the other parameter is used to estimate the future condition of the pipe.

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