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LSI characteristics based on seasonal changes at water treatment plant of Korea

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ABSTRACT

Corrosion indices have a historical as well as practical relevance in assessing drinking water treatment systems. The Langelier saturation index (LSI) is commonly used as a corrosive index for drinking water. The systematic regulations including LSI as guideline for reducing corrosion have been established in Korea since 2011. However, studies in terms of seasonal changes are still required even though there are data to analyze corrosion indices. In this paper, LSI, Ryznar stability index (RSI), and aggressiveness index (AI) values of water produced by Seongnam water treatment plant (S. WTP) were analyzed and compared. RSI gives information on corrosion progress and scale in the pipe. AI is a simplified index of LSI, and both indices are based on calcium carbonate saturation. Two-stage control of the LSI value as a measure of the corrosive tendency of water is an alternative proposal. Temperature, pH, alkalinity, calcium hardness, and TDS were measured to evaluate water corrosiveness. Results for one-year period (2009) show that LSI varies in the ranges from –1.3 to –1.8, RSI varies from 10.2 to 10.9 while AI varies from 10.1 to 10.8. LSI increased by 4.3 times during the rainy season (July–September) but not during other seasons. During the same period, RSI increased up to 4.5%, while AI decreased to 3.1%. These values show that the water produced at S. WTP is very corrosive. One potential reason for the increase in LSI is that alkalinity and calcium hardness decrease to 20 and 9%, respectively, during heavy rainfall.

Keywords: Corrosion Index; Langelier Saturation Index (LSI); Ryznar stability index (RSI); Aggressiveness index (AI); Corrosion factors

1. Introduction

Corrosion is the result of the electrochemical reactions between water and the metal elements [1]. The occurrence of scaling and corrosion in natural and treated water can cause serious operational and cost problems [2]. Corrosion increases the concentrations of certain toxic metals in tap water, such as lead, nickel, cadmium, iron, copper, and zinc. Corrosion products attached to pipe surfaces or accumulated as sediments in the distribution system can shield micro-organisms from disinfectants. These organisms can reproduce and cause secondary problems such as bad tastes, odors, slimes, and additional corrosion. It may sometimes be necessary to construct a new distribution

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system, which requires a lot of money. Therefore, corrosion indices are useful criteria for assessing and controlling corrosion and scaling in the water treatment plant [3,4].

In general, the corrosion factors affecting the corrosion indices consist of temperature, pH, calcium hardness, alkalinity, dissolved oxygen, and total dissolved solids (TDS) [5]. It is essential to control water quality for preventive coating against corrosion when calcium hardness and alkalinity are generally low in raw influent water.

Recently, the desalination process using reverse osmosis membranes has increased in many developed countries because of reduced costs of RO membrane modules. The pH of treated water is strongly acidic (pH 5.5 to 6.0) and contains high concentrations of CO_2 and O_2 [6,7]. When the saturation of CO_2 decreases in the piping system, it means that CO_2 is released from the water, leading to an increase in the pH value, thereby the possibility for $CaCO_3$ to precipitate increases [8]. Synthetic dolomite ($CaCO_3 + MgCO_3$), lime, and carbon dioxide gas are used to lower the acidity and to increase hardness and alkalinity.

The Langelier saturation index (LSI) is the most widely used indicator of corrosion potential [9] and a qualitative index only indicating of the solution is under saturated or supersaturated with $CaCO_3$ [10]. It is calculated from pH, calcium, total alkalinity, TDS, and temperature. If the treated water has a positive LSI, it tends to be scaling. When it has a negative LSI, the water has a tendency for corrosion potential. The Ryznar stability index (RSI) is another similar index, a practical scope of the LSI based on experience, where if the index is less than 5, the water will be scaling; if between 5 and 7, little scaling or corrosion is expected; and if more than 7, the water will tend to be corrosive [11]. The aggressiveness index (AI) is a simplified index based on the effects of pH, alkalinity, and calcium. If the AI measure is less than 10, the water is strongly corrosive; if between 10 and 12, it is moderately corrosive; and if greater than 12, it is scaling [12].

Based on a report by the Korean Ministry of Environment, the pH limit (pH 5.8) in Korean regulations is lower than that of Europe and the USA. This means that corrosion potential in Korea is high compared with other countries [13,14]. In particular, the majority of the rainfall during the year occurs during the rainy season (July–September). During this season, the decrease in alkalinity makes the water strongly corrosive [15]. In July 2012, LSI was assigned as the main index for water quality assessment in water treatment plants.

The purpose of this study was to evaluate the corrosion factors affecting LSI, RSI, and AI based on monthly data, which were collected during dry and rainy seasons from the Seongnam water treatment plant (S. WTP).

2. Methods

2.1. Outline of S. WTP

S. WTP managed by the Korea Water Resource Corporation (K-water) operates total seven steps as shown in Fig. 1. It provides 3 million people with clean water of 786,000 m^3/d and operates identical technology every year. Corrosion factors such as pH, TDS, temperature, calcium hardness and alkalinity show different results according to the seasonal changes of Korea, which is monsoonal with rainfall being four times greater in summer than in winter. All of them which are affected from rainfall in rainy season cause high extent of corrosion and therefore, they have stronger corrosiveness in rainy season than in dry season. Changes in the corrosion indices as a result of increased rainfall during the rainy season were also examined. The addition of excessive amounts of coagulant and liquefied chlorine during the water treatment process reduces the pH level, with the corresponding change in the LSI value describing strong corrosiveness [16]. To determine the annual rainfall of Seongnam City in 2009, average rainfall data were obtained by using the Data Extractor program provided by Korea Meteorological Administration.

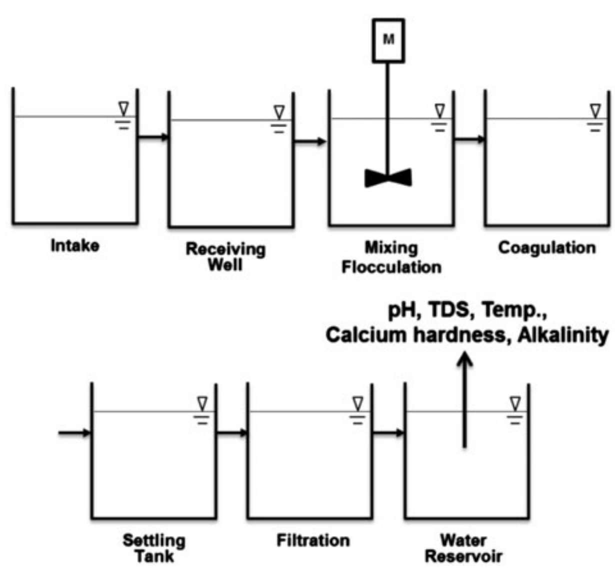


Fig. 1. Distribution diagram of S. WTP.

2.2. Langelier saturation index

The LSI, a numerical index of water properties, is calculated as the difference between pHs and measured pHa, as shown in Eq. (1). The value makes it possible to estimate the probability of water to cause corrosion of steel, or the tendency of water to form scale.

pHa and pHs were measured by auto pH meter and method calculated form the data of the chemical analysis, respectively, every week in S. WTP. It was obtained as a monthly average value. TDS and temperature were also obtained in the same way as above. Calcium hardness and alkalinity were obtained by standard method for the water and wastewater.

$$\text{LSI} = \text{pHa} - \text{pHs} \tag{1}$$

where pHa is measured pH, and pHs is calculated by Eq. (2):

$$\text{pHs} = \{(9.3 + A + B) - (C + D)\} \tag{2}$$

where A = TDS (mg/L), B = temperature (℃), C = calcium hardness (mg/L as $CaCO_3$) and D = Alkalinity (mg/L $CaCO_3$). If LSI is less than −1.0, scale can form from precipitation of $CaCO_3$. If LSI is more than 1.0, the water will dissolve $CaCO_3$ indicating strongly corrosive water. If LSI is close to zero, the water is neutral and stable, and will not cause corrosion or scaling.

2.3. Ryznar stability index

The RSI takes into account the empirical data on the intensity of corrosion observed in municipal water supply pipelines. The RSI is calculated using Eq. (3):

$$\text{RSI} = 2\text{pHs} - \text{pHa} \tag{3}$$

RSI also used identical method above to calculate Eq. (3).

2.4. Aggressiveness index

The AI is a simplified index based on LSI and calculated using Eq. (4). AI also used identical method above to calculate Eq. (3).

$$\text{AI} = \text{pHa} + \log(C \times D) \tag{4}$$

2.5. Corrosion factors affecting the corrosive indices

Table 1 shows the corrosion factors affecting LSI, RSI, and AI. While LSI and RSI have five corrosion factors, AI has three. LSI is simple and easy to evaluate measure of corrosiveness. It has been assigned for periodical water monitoring in Korea. In this study LSI, RSI, and AI were evaluated to understand the corrosion factors affecting these corrosion indices.

3. Results and discussion

3.1. Characteristics of influent and effluent in dry/rainy season

Influent water characteristics of the S. WTP during dry and rainy season are shown below (Table 2).

The pH range observed was larger during the dry season compared with the rainy season. The high TDS values mean that there were large amounts of particulates carried with the influent. Even though the average pH during the rainy season was lower than during the dry season, the calculated LSI was similar because the temperature and TDS were higher during the rainy season.

Fig. 2 shows the change in temperature and precipitation during the dry and rainy seasons. In July, the rainy season started with increasing precipitation and increased temperature of influent/effluent. The average rainfall was 76% higher during the rainy season (240 mm) compared with the dry season (56 mm). Influent and effluent temperatures were almost the same. The average temperature was 12℃ during the dry season and 24℃ during the rainy season.

3.2. Monthly changes in corrosion indices (LSI, RSI, and AI)

Fig. 3 shows the monthly corrosion indices (LSI, RSI, AI). LSI ranged from –1.8 to –1.3. This index became higher until the start of the rainy season, when it decreased corrosiveness increased. RSI ranged from 10.2 to 10.9 and showed a trend of increasing corrosiveness during the rainy season. AI changed from 10.1 to 10.8 and also showed a trend of increasing corrosiveness during the rainy season.

3.3. Monthly changes in corrosion factors affecting the corrosion indices

Fig. 4 shows monthly changes in temperature, alkalinity, and calcium hardness, which affected the corrosion indices. We measured a decreasing trend in alkalinity and calcium hardness, and higher temperatures during the rainy season compared with the dry season. These trends were observed because of dilution of the source water with rainfall from the intake area. Park and Kong [14] reported that alkalinity and calcium hardness became low in the upper stream of

Table 1
Corrosion factors affecting corrosion indices

Corrosion index	pH	TDS	Temperature (°C)	Calcium hardness	Alkalinity
LSI	•	•	•	•	•
RSI	•	•	•	•	•
AI	•	–	–	•	•

Table 2
Influent water quality at the S. WTP

Season	pHa	Temperature (°C)	TDS (mg/L)	Calcium hardness (mg/L)	Alkalinity (mg/L)	pHs	LSI
Rainy (7,8,9)	7.7	27.8	114.2	43.1	38.8	8.6	–0.96
Dry	8.2	12.7	114.8	55.3	45.8	8.7	–0.51

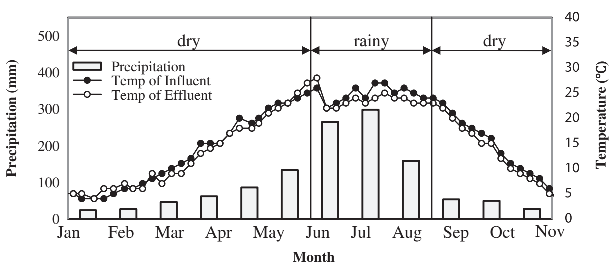


Fig. 2. Monthly precipitation data and temperature of influent/effluent.

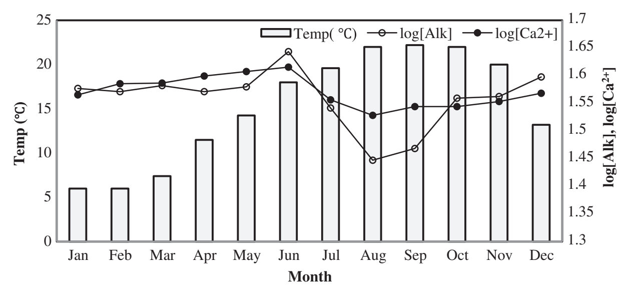


Fig. 4. Monthly changes in corrosion factors affecting the corrosion indices.

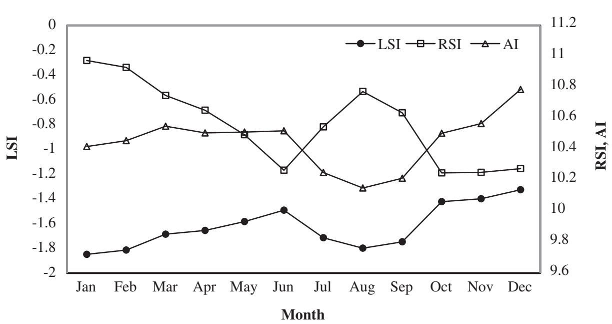


Fig. 3. Monthly changes in LSI, RSI and AI.

a river during rainfall. Rainfall has also been shown to affect the corrosion index [12].

3.4. Correlation of corrosion indices with relevant corrosion factors

Because the characteristics of influent, temperature, and precipitation are different at each WTP, major corrosion factors affecting the corrosion index could be different as well [11]. In order to find out the most important corrosion factors that affected LSI, RSI, and AI at the S. WTP, correlation analyses were performed.

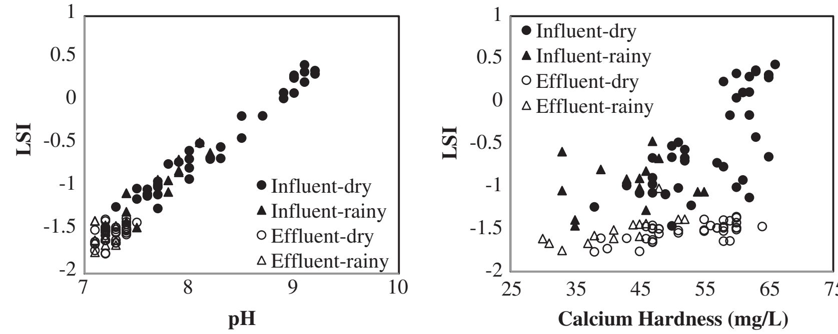
As shown in Table 3, pH is the most important corrosion factor affecting LSI at the S. WTP. The order of strength of the correlation with LSI is as follows: pH > calcium hardness > alkalinity > temperature > TDS. For RSI, pH showed the highest correlation with the index, while temperature and calcium hardness were secondly important. For AI, pH was the most important corrosion factor, while calcium hardness and alkalinity were next. This indicates that the most important corrosion factor to control is pH, although other corrosion factors could be monitored for corrosion control at the same time. AWWA recommends usage of corrosion inhibitors for controlling corrosion, such as NaOH, lime, and lime with CO_2 [17].

3.5. Seasonal factors affecting LSI

Fig. 5 shows the influence of pH and calcium hardness on LSI during the dry and rainy seasons. While the pH of influent changed from 7.8 to 9.9,

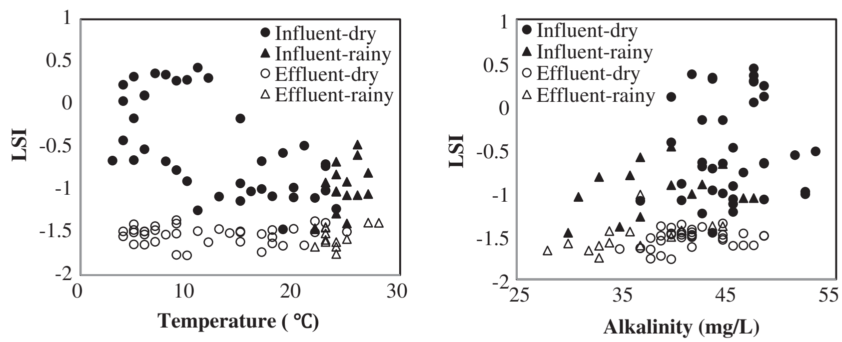
Table 3
Correlation of relevant factors with corrosion indices at the S. WTP

	Correlation with:					
Corrosion index	pH	Temperature	TDS	Calcium hardness	Alkalinity	LSI, RSI, AI
LSI	0.507	0.078	0.005	0.494	0.280	1.000
RSI	0.500	0.419	0.054	0.336	0.271	1.000
AI	0.823			0.811	0.520	1.000



(a) pH vs. LSI (b) Hardness vs. LSI

Fig. 5. Relationship of pH and calcium hardness to LSI.



(a) Temperature vs. LSI (b) Alkalinityvs. LSI

Fig. 6. Relationship of LSI to temperature and alkalinity.

the pH of the effluent changed from 6.9 to 7.8 (see Fig. 5(a)). LSI decreased as pH decreased. This showed that LSI was more sensitive to pH than to other corrosion factors. LSI increased by a maximum of 4.3 times during the rainy season (July–September) compared with the dry season. Fig. 5(b) shows that the average concentration of calcium in the influent changed from 55 mg/L in the dry season to 49 mg/L in the rainy season. As the calcium content decreased, the corrosiveness index (LSI) increased abruptly from –0.4 to –1.6. To enhance water hardness, lime and lime with CO_2 should be included to control corrosion. According to Fig. 3, decreasing alkalinity during the rainy season was the main difference compared with the dry season.

Fig. 6 shows the influence of temperature and alkalinity on LSI. While the influent temperature changed from 4℃ to 25℃ during the dry season, it changed from 22℃ to 28℃ during the rainy season (see Fig. 6(a)). The corrosion index changed slightly from –1.54 in winter to –1.51 in summer. It was reported that corrosiveness in winter is higher than that in summer because of lower temperatures [14]. This is because higher temperatures decrease the solubility of calcium carbonate. Although the average temperature in summer was four times higher than that in winter, other corrosion factors such as calcium hardness and alkalinity were lower in summer than in winter. This was one of the reasons that the difference in LSI between winter and summer was not very large.

Fig. 6(b) shows that alkalinity decreased on average by 17% from the dry season to the rainy season. During the rainy season, the alkalinity changes differently; however, it is a critical corrosion factor in every country. Many countries have specific alkalinity standards, which are not usually the same [18].

4. Conclusions

The LSI is the most widely used indicator of corrosion potential. It is calculated from pHs, calcium, total alkalinity, TDS, and temperature. The Ryznar Stability Index (RSI) and the AI are alternative indices. LSI, RSI, and AI were evaluated at the S. WTP during dry and rainy seasons over a one-year period (2009). All corrosion factors potentially affecting LSI were analyzed by correlation analysis in influent and effluent.

Based on our analysis of LSI, RSI, and AI during dry and rainy seasons, we found that LSI changed from −1.8 to −1.3, and it became higher until the beginning of the rainy season, when it started to decrease and corrosiveness started to increase. RSI changed from 10.2 to 10.9 and showed a trend of increasing corrosiveness during the rainy season. AI changed from 10.1 to 10.8 and showed a trend of increasing corrosiveness during the rainy season.

We found a trend of decreasing alkalinity and calcium hardness and higher temperatures during the rainy season compared with the dry season.

pH was the most important corrosion factor determined after correlation analysis with LSI at the S. WTP. Water quality corrosion factors in order of importance for determining LSI were pH > calcium hardness > alkalinity > temperature > TDS.

According to this study, all of corrosion indices show mostly corrosiveness not only in rainy season but also in dry season. Particularly, LSI of influent indicates less corrosiveness than that of effluent when comparing with each corrosion factor. It means that there are any challenges during WTP. In order to prevent and decrease corrosiveness from pumping and piping systems, raw water quality changes can be monitored regularly. Raw water in rainy season spends a lot of coagulation and disinfection which can affect pH, calcium hardness, alkalinity, and TDS [17].

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