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WATER QUALITY ON SOLAR WATER HEATERS IN REMOTE ISLANDS

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Abstract

The use of solar water heaters (SWHs) in Taiwan's remote islands has encountered scaling and corrosion problems attributed to sources of water. In this study, the Langelier Saturation Index (LSI), Ryznar Stability Index (RSI), Puckorius Scaling Index (PSI) and Larson-Skold Corrosive Index (LSCI) were employed to assess scaling and corrosion caused by tap-water and groundwater used for SWHs in Penghu, Kinmen, and Lienchiang Counties. The LSI, RSI and PSI results show a slight scaling tendency in Penghu County, but there is a corrosion tendency in Kinmen and Lienchiang Counties. Nevertheless, all LSCI values show a serious corrosion tendency. In addition, chloride ion (Cl^-) concentration levels are all higher than 35 mg/L, resulting in corrosion found in absorbing plates of SWHs using 304 stainless steel. Therefore, more corrosion-resistant metals are required for SWHs.

Keywords: *solar water heater; remote islands; water quality; scaling; corrosion*

1. Introduction

Solar thermal energy is widely used in many countries (Weiss et al., 2014). SWHs are mainly composed of four parts: solar collector, water storage tank, piping, and control systems. The absorbing plate is generally made of copper, aluminum, stainless steel or flexible polymer. Packing material between inside and outside barrels for a stainless-steel water storage tank is for thermal insulation. In Taiwan, the climatic conditions are predominantly sunny. The solar radiation ranges from 1,200 to 1,700 kWh/m^2/year. To disseminate SWHs, the Bureau of Energy, Ministry of Economic Affairs (BEMOEA, 1986–1991 and 2000–present) and some regional governments have established subsidy programs (Chang et al. 2013). The Energy Research Center at National Cheng Kung University (ER/NCKU) has been authorized by the BEMOEA to organize an operation unit for the second subsidy program since 2000. The accumulated area of solar collectors installed in 2012 reached 2.25 million m^2 (Lin et al. 2013). Note that the Low Carbon Island Project, including Penghu, Kinmen and Lienchiang Counties, was also launched in 2012 and promotion of SWHs was part of the project.

Service period of SWHs is of great concern for end users. In 2013, telephone interviews were conducted by the ER/NCKU for 6,482 SWHs installed in 2000, in which 3,379 end users (52.1%) were reached. The survey showed that there were 95.3% systems in operation, indicating the service period of SWHs more than 12 years at least. Further, malfunction of SWHs has been reported from time to time. In the period of 2000-2012, 942 cases were documented by the ER/NCKU, in which 555 of them (58.9%) were associated with leakage (corrosion or pitting) in absorbing plates, gate valves, storage tanks or pipe joints, resulting a reduction in service period (1-5 years).

In Taiwan, water resources are rich. Tap-water is the principal domestic water supply and the water quality is stable. In contrast, the principal domestic water sources in remote islands are tap-water from desalination and re-treatment groundwater. To assess water quality on SWHs in remote islands, this study sampled tap-water and groundwater from households with SWHs. Analyses of water quality were conducted, including pH, total alkalinity, total hardness, chloride, and sulfate. The water quality assessment methods including LSI, RSI, PSI and LSCI, were employed to estimate the tendency of scaling and corrosion (Langelier 1936;

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Ryznar 1944; Larson and Skold 1958; Carrier 1965; Puckorius 1983; Degremont 1991; Seneviratne 2007; Prisyazhniuk 2007; Gacem et al 2012). The values of LSI, RSI, and PSI are primarily used to estimate the scaling potential of calcium carbonate ($CaCO_3$) in water. It is also known that LSI is the oldest and most commonly used. However, Seneviratne (2007) thought LSI does not estimate the corrosivity of water because corrosion may still occur due to dissolved oxygen and solids, such as chlorides or sulfates which increase the conductivity of water and corrosion rates. Nevertheless, the LSCI proposed by Larson and Skold (1958) can be employed to estimate the corrosiveness of water on low-carbon steel and steel samples. In this study, the water quality survey aimed to address the corrosion problem on the service life of SWHs.

2. SWHs in remote islands

As shown in Fig. 1, Penghu County (119°19' to 119°43' E, 23°12' to 23°47' N) with 37,151 households lies approximately on the Tropic of Cancer. There are five townships (Husi, Baisha, Siyu, Wang-An and Cimei township) and one city (Magong city). Kinmen County (118°24' E, 24°27' N) with 36,558 households, made up of 12 jurisdictional islands, is located in the subtropical oceanic climate zone. There are six townships (Jincheng, Jingsha, Jinhu, Jinning, Lieyu and Wuqiu). Lienchiang County (119°51' to 120°31' E, 25°55' to 26°44' N) with 2,423 households, which also lies within the subtropical oceanic climate zone, is the smallest county in Taiwan. There are four townships (Nangan, Beigan, Jyuguang and Dongyin). Juguang Township includes two major islands: Dongju Island and Xiju Island.

As previously mentioned, scaling and corrosion are of great concerns for SWHs in remote islands. As shown in Fig. 2a, there is pipe blockage caused by scaling (calcium carbonate analyzed by X-ray diffraction). Figure 2b shows pitting near the weld on a storage tank, made of 304 stainless steel. The maximum diameter of pitting hole was larger than 1 mm. Figure 2c shows absorption tube and pipe welding (304 stainless steel) leaks due to corrosion and subsequent scaling. It is considered that the pitting problem was caused by poor welding, high chloride concentration in the water, and high temperature accelerated corrosion.

Fig. 1: Remote islands location map.

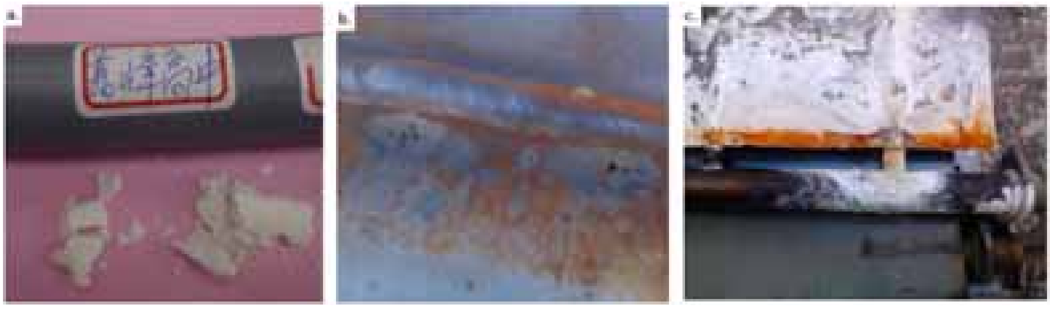

Fig. 2: (a) scaling of the connecting pipe; (b) pitting near the weld on storage tank; and (c) corrosion and scaling on solar collector plate.

In Taiwan, most tubes of collector plate and water storage tanks are made of 304 stainless steel, which is an alloy with higher levels of chromium (Cr) and nickel (Ni). It is known that the corrosion resistance of stainless steel is due to a sufficient amount of chromium to form a thin layer of a passivation film (chromium oxide). When the passive film is damaged by corrosion, uniform or localized corrosion will occur on the surface. According to the study by Parrott and Pitts (2011), when welding stainless steel, the high temperatures in the slow cooling process make the chromium and carbon form chromium carbide near the weld, causing the chromium to deplete. This makes the chromium passivation film easily damaged by corrosion, forming a significant local corrosion. Kopeliovich (2012) showed that electrochemical corrosion (oxidation-reduction reaction) by the chloride ions breaks down the passivation film on a stainless steel surface, and then causing pitting. Thus, presence of chloride ions (Cl^-) accelerates the corrosion rate. Figure 3 shows the concentration limits of 304 and 316 stainless steel at pH = 7 by chloride ions (Huang and Huang 2006). As the temperature reaches 80 ˚C, pitting occurred in 304 stainless steel, when the chloride ion concentration is higher than 35 mg/L. For 316 stainless steel, pitting occurred when the chloride ion concentration is higher than 130 mg/L.

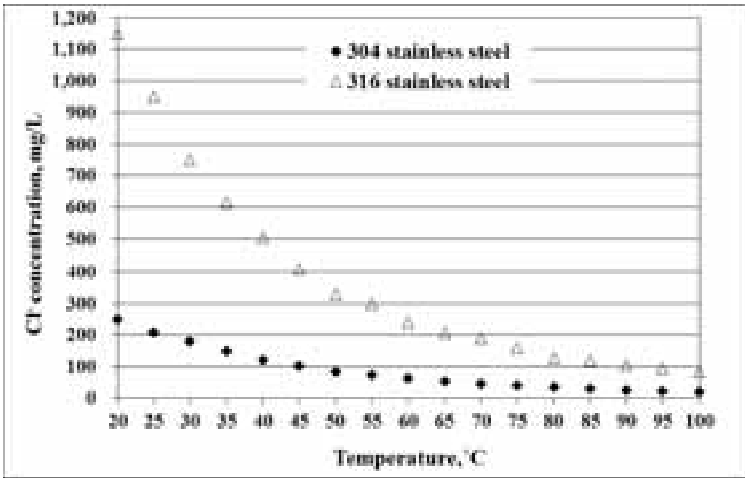

Fig. 3: Concentration limits of stainless steel corroded by chloride ions. (Huang and Huang, 2006).

3. Water quality Index-Assessment Methods

Water quality data for tap-water and groundwater were obtained from households with SWHs installed in 2013 and 2014. LSI, RSI, PSI, and LSCI were employed to assess scaling and corrosion in SWHs. The water qualities were analyzed by the Sustainable Environment Research Center/NCKU. In the remote islands, the temperature of SWHs can reach 70~80 ˚C in summer. Therefore, the designed water temperature was at 80 ˚C in this study.

3.1. LSI Assessment Method

Langelier (1936) first proposed a procedure for calculating the degree of saturation of water with respect to calcium carbonate, known as Langelier Saturation Index (LSI). Prisyazhniuk (2007) pointed out that LSI makes it possible to estimate the ability of water to corrode steel, or the tendency of water to form scaling.

Interpretation of LSI was given by Carrier Air Conditioning Company (U.S.), as shown in Table 1 (Carrier 1965). In the "Handbook of Drinking Water Quality" (DeZuane, 1997), LSI is given as follow.

$$LSI = pH - pH_S \quad (1)$$

where pH is measured in a solution of hydrogen ion activity; pH_S is a saturated sodium carbonate solution of hydrogen ion activity, as shown in Equation 2.

$$pH_S = (9.3+A+B)-(C+D) \quad (2)$$

where:

$A = (\log_{10}(TDS) -1)/10$; TDS: total dissolved solids, mg/L

$B = -13.12 \log_{10} (T + 273) + 34.55$; T : temperature, ˚C.

$C = \log_{10}$ (Hardness) - 0.4; Hardness, mg/L

$D = \log_{10}$ (Alkalinity); Alkalinity concentration, mg/L

Tab. 1: Interpretation of LSI (Carrier 1965)

LSI Value	Indication
2.0	Scale forming but non corrosive
0.5	Slightly scale forming and corrosive
0.0	Balanced but pitting corrosion possible
-0.5	Slightly corrosive but non-scale forming
-2.0	Serious corrosion

3.2. RSI Assessment Method

Ryznar Stability Index (RSI) was proposed by Ryznar (1944). The index is based on the calcium carbonate saturation index in water and can estimate the ability of scaling or corrosion, where $RSI = 2pH_S - pH$. Further, Table 2 shows the interpretation of RSI (Carrier 1965).

Tab. 2: Interpretation of RSI (Carrier 1965)

RSI Value	Indication
4.0 – 5.0	Heavy scale
5.0 – 6.0	Light scale
6.0 – 7.0	Little scale or corrosion
7.0 – 7.5	Corrosion significant
7.5 – 9.0	Heavy corrosion
> 9.0	Corrosion intolerable

3.3 *PSI Assessment Method*

The Puckorius Scaling Index (PSI) was proposed by Puckorius (1983). PSI is a modification of RSI with similar interpretations as shown in Table 2. When estimating the scaling and corrosion tendency of the solution, PSI addressed the buffering capacity in water and the maximum quantity of precipitate that can form when bringing water to equilibrium (Puckorius 1983). Therefore, the equilibrium pH (pH_{eq}) is adopted rather than pH, in which $PSI = 2pH_S - pH_{eq}$, where $pH_{eq} = 1.465 \times \log_{10}(\text{Alkalinity}) + 4.54$. The scaling was more serious with a smaller value of PSI, while a tendency of corrosion is observed for PSI > 6.0. It is also noted that the pH value for PSI is calculated according to the balanced hydrogen-ion activity in a solution, rather than measuring the pH with relevant apparatus. Therefore, the resulting PSI value is considered to be more accurate, comparing to both LSI and RSI values.

3.4 LSCI Assessment Method

The Larson–Skold Index (LSCI) describes the corrosivity of water toward mild steel (Larson and Skold 1958). The index is based on an evaluation of in-situ corrosion of mild steel lines transporting Great Lakes water. The index is the ratio of equivalents parts per million (ppm) of sulfate (SO_4^{2-}) and chloride (Cl^-) to the ppm of alkalinity in the form of bicarbonate plus carbonate ($HCO_3^- + CO_3^{2-}$), as given in Equation 3.

$$LSCI = \frac{C_{Cl^-} + C_{SO_4^{2-}}}{C_{HCO_3^-} + C_{CO_3^{2-}}} \quad (3)$$

where C was the concentration of mg/L (ppm); SO_4^{2-} was sulfate; Cl^- was chloride; HCO_3^- was bicarbonate; and CO_3^{2-} was carbonate.

LSCI does not considered temperature or pH buffering capacity as factors affecting corrosion behavior. However, previous studies indicated that stainless steel, copper, and aluminum can demonstrate pitting corrosion in environments that contain chlorine ions (Gallegos et al. 2005; Liang and Zhang 2006; Ghali 2010; Parrott and Pitts 2011; Kopeliovich 2012). Further, LSCI was interpreted as follows (Prisyazhniuk 2007):

LSCI < 0.8 — chlorides and sulfates did not influence the natural formation of the protective film;
0.8 < LSCI < 1.2 — chlorides and sulfates would hinder the formation of a protective film. A higher, as compared with normal, rate of steel corrosion was observed;
LSCI > 1.2 — as the value of the index grew, an increasingly higher rate of localized corrosion was observed.

4. Results and Discussion

Seneviratne (2007) demonstrated that scale formation and corrosion become more significant, as the temperature of a system increases. In this study, a hypothetical temperature of 80 °C was employed to estimate the indicators for assessing scaling and corrosion. Corrosion of metal components in SWHs is expected to be more significant when LSI value is less than zero, RSI value is greater than 7.0, PSI value is greater than 6.0, and LSCI value is greater than 0.8.

4.1 *Penghu County*

The results for SWHs using tap-water in Penghu County are shown in Table 3. Based on the analyses, the values of LSI, RSI and PSI showed a slight scaling tendency when SWHs using tap-water have, except for Siyu Township with a slight corrosion tendency due to a lower pH value. In addition, The LSCI is the ratio of ppm (mg/L) of SO_4^{2-} and Cl^- to the ppm of alkalinity. For the tap-water from desalination or groundwater re-treatment, it contains higher salts. The values of LSCI values for SWHs using tap-water are greater than 1.2, indicating a serious corrosion problem. Thus, although the values of LSI, RSI and PSI showed tap-water show a slight scaling tendency, a higher value Cl^- will result in corrosion of the passivation film on stainless steel surface. For SWHs using groundwater, the results are shown in Table 4. The values of LSI, RSI and PSI values show a serious scaling tendency for SWHs using groundwater, while the values of LSCI indicate a serious corrosion problem.

Also as shown in Tables 3 and 4, the levels of Cl^- concentration are greater than 127.3 and 203.0 mg/L for tap-water and groundwater, respectively. According to the study by Huang and Huang (2006), when the water temperature of SWHs reaches 80 ˚C and the Cl^- concentration level was higher than 35 mg/L, pitting would occur for SWHs using 304 stainless steel. Thus, the use of tap-water or groundwater for SWHs in Penghu County encounters a high risk of corrosion. Thus, 316 stainless steel or another corrosion-resistant material is required for extension of service period of SWHs.

Tab. 3: Assessment of scaling and corrosion tendency of tap-water quality in Penghu County

Tap-water	Magong	Husi	Baisha	Siyu	Wang-an	Cimei
Alkalinity, mg/L	87.9 ± 49.3	69.6 ± 40.0	257.2 ± 71.5	81.0 ± 5.3	110.0 ± 53.7	116.0 ± 5.7
pH	7.8 ± 0.5	7.7 ± 0.3	8.0 ± 0.3	7.2 ± 0.1	7.7 ± 0.1	7.8 ± 0.3
Cl^-, mg/L	177.3 ± 38.5	176.1 ± 24.3	223.4 ± 62.4	127.3 ± 7.5	253.5 ± 79.9	281.5 ± 13.4
SO_4^{2-}, mg/L	48.9 ± 23.5	49.5 ± 24.9	41.9 ± 15.9	11.7 ± 4.7	70.5 ± 15.1	38.5 ± 3.0
TDS, mg/L	494.3 ± 99.7	473.6 ± 112.6	774.8 ± 62.7	338.0 ± 3.5	672.0 ± 524.6	788.5 ± 31.8
Hardness, mg/L	111.0 ± 61.0	91.1 ± 55.7	126.5 ± 34.2	55.6 ± 63.6	172.5 ± 79.9	255.0 ± 0.0
HCO_3^-, mg/L	86.9 ± 48.7	69.1 ± 39.6	254.8 ± 71.4	80.9 ± 5.3	109.4 ± 53.3	115.2 ± 6.1

CO_3^{2-}, mg/L	0.9 ± 1.0	0.4 ± 0.5	2.4 ± 1.7	0.1 ± 0.0	0.6 ± 0.4	0.8 ± 0.4
LSI	0.7 ± 0.8	0.3 ± 0.5	1.4 ± 0.3	-0.3 ± 0.5	1.0 ± 0.5	1.3 ± 0.3
RSI	6.5 ± 1.2	7.0 ± 0.9	5.1 ± 0.4	7.8 ± 0.9	5.8 ± 0.9	5.3 ± 0.3
PSI	7.0 ± 1.5	7.5 ± 1.3	5.0 ± 0.7	7.7 ± 0.9	6.1 ± 1.2	5.5 ± 0.1
LSCI	3.7 ± 2.6	4.1 ± 2.0	1.2 ± 0.8	1.7 ± 0.1	3.2 ± 1.0	2.8 ± 0.0

Tab. 4: Assessment of scaling and corrosion tendency of groundwater quality in Penghu County

Groundwater	Magong	Husi	Baisha	Siyu	Wang-an*	Cimei
Alkalinity, mg/L	153.0 ± 40.0	177.3 ± 128.7	286.0 ± 107.0	138.5 ± 78.5	144.0	287.5 ± 13.4
pH	8.4 ± 0.3	7.5 ± 0.4	8.0 ± 0.3	7.7 ± 0.3	7.4	7.9 ± 0.0
Cl^-, mg/L	306.8 ± 151.8	203.0 ± 89.9	254.7 ± 67.0	214.0 ± 116.0	893.0	236.5 ± 46.0
SO_4^{2-}, mg/L	37.3 ± 16.8	35.1 ± 7.6	66.5 ± 15.8	114.9 ±138.7	7.7	124.5 ± 33.2
TDS, mg/L	764.8 ± 309.4	562.8 ± 146.5	842.7 ± 206.5	616.0 ± 390.3	2050.0	1018.0 ± 53.7
Hardness, mg/L	127.6 ± 77.7	185.2 ± 109.2	224.0 ± 109.3	135.5 ± 163.4	332.0	242.5 ± 99.7
HCO_3^-, mg/L	149.0 ± 41.0	176.5 ± 128.2	283.3 ± 107.8	137.5 ± 77.5	143.7	285.3 ± 13.5
CO_3^{2-}, mg/L	3.8 ± 1.9	0.7 ± 0.6	2.7 ± 0.7	0.9 ± 0.9	0.3	2.2 ± 0.0
LSI	1.6 ± 0.2	0.8 ± 1.1	1.7 ± 0.1	0.7 ± 1.3	1.0	1.7 ± 0.2
RSI	5.2 ± 0.5	5.9 ± 1.9	4.5 ± 0.6	6.3 ± 2.3	5.4	4.5 ± 0.4
PSI	5.9 ± 0.9	5.7 ± 2.2	4.5 ± 1.2	6.5 ± 2.4	5.0	4.3 ± 0.4
LSCI	2.4 ± 1.1	2.4 ± 2.7	1.2 ± 0.5	2.2 ± 0.6	6.3	1.3 ± 0.0

* Only one sample

4.2 *Kinmen County*

For SWHs using tap-water in Kinmen County, the data are shown in Table 5. The values of LSI, RSI, and PSI show a slight to serious corrosion tendency for SWHs using tap-water, corresponding to a lower value in the pH value. The LSCI analysis also indicates a serious corrosion problem (2.8 ≥ LSCI ≥ 1.7), except for the Lieyu Township. Note that tap-water in Lieyu Township is mainly from the rain-water in a reservoir. Therefore, the corrosion problems should be less significant. Further, the results for SWHs using groundwater are listed in Table 6. The values of LSI, RSI, and PSI show a slight to serious corrosion tendency. In addition, the values of LSCI are higher than those of tap water (9.1 ≥ LSCI ≥ 1.2). Higher LSCI value of groundwater in Jinning is due to low alkalinity concentration but not high Cl^- concentration. Except for the Lieyu Township, the levels of Cl^- concentration are 45.2-104.5 and 69.0-167.0 mg/L for tap-water and groundwater, respectively. Although the effect of Cl^- concentration level on corrosion problem for SWHs is less significant those systems installed in Penghu County, better corrosion-resistant materials are also required.

Tab. 5: Assessment of scaling and corrosion tendency of tap-water quality in Kinmen County

Tap-water	Jincheng	Jinhu	Jinsha	Jinning	Lieyu*
Alkalinity, mg/L	35.0 ± 10.4	66.4 ± 9.7	61.5 ± 26.7	36.3 ± 14.3	56.0
pH	6.3 ± 0.5	7.1 ± 0.4	7.5 ± 0.4	6.2 ± 0.7	6.9
Cl^-, mg/L	54.3 ± 15.5	104.5 ± 28.0	101.2 ± 54.1	45.2 ± 2.9	5.5
SO_4^{2-}, mg/L	15.7 ± 15.6	72.1 ± 27.9	68.4 ± 32.9	17.5 ± 33.3	5.1
TDS, mg/L	204.2 ± 58.6	387.4 ± 45.8	355.2 ± 143.8	185.8 ± 43.4	203.0
Hardness, mg/L	36.5 ± 12.3	122.8 ± 20.3	106.4 ± 42.1	28.0 ± 6.1	36.0
HCO_3^-, mg/L	35.0 ±10.4	66.3 ± 9.7	61.3 ± 26.8	36.3 ± 14.3	56.0

CO_3^{2-}, mg/L	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.2	0.0 ± 0.0	0.0
LSI	-1.6 ± 0.6	0.0 ± 0.3	0.2 ± 0.4	-1.8 ± 0.8	-0.8
RSI	9.5 ± 0.8	7.1 ± 0.4	7.0 ± 0.7	9.8 ± 1.0	8.4
PSI	9.0 ± 0.7	7.0 ± 0.4	7.4 ± 1.0	9.2 ± 0.7	8.2
LSCI	2.0 ± 0.4	2.8 ± 1.0	2.7 ± 0.8	1.7 ± 0.4	0.2

* Only one sample

Tab. 6: Assessment of scaling and corrosion tendency of groundwater quality in Kinmen County

Groundwater	Jincheng	Jinhu	Jinsha	Jinning	Lieyu
Alkalinity, mg/L	84.7 ± 103.7	81.2 ± 46.8	109.5 ± 68.8	11.0 ± 7.6	136.7 ± 35.5
pH	5.5 ± 1.1	6.3 ± 0.9	6.7 ± 1.0	4.8 ± 0.6	6.6 ± 0.2
Cl^-, mg/L	69.0 ± 39.8	99.6 ± 46.6	167.0 ± 20.2	75.2 ± 40.1	106.1 ± 95.7
SO_4^{2-}, mg/L	35.0 ± 43.3	49.2 ± 37.7	93.3 ± 26.2	16.7 ± 12.0	66.0 ± 30.0
TDS, mg/L	453.0 ± 233.3	425.5 ± 213.3	657.3 ± 151.1	275.5 ± 195.8	646.2 ± 223.5
Hardness, mg/L	108.6 ± 65.7	111.6 ± 69.7	176.5 ± 88.7	54.7 ± 46.5	215.3 ± 85.9
HCO_3^-, mg/L	84.6 ± 103.7	81.1 ± 46.8	109.3 ± 68.8	11.0 ± 7.6	136.6 ± 35.5
CO_3^{2-}, mg/L	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.2	0.0 ± 0.0	0.1 ± 0.0
LSI	-1.9 ± 2.2	-0.9 ± 1.5	-0.1 ± 1.3	-3.6 ± 1.1	0.1 ± 0.3
RSI	9.3 ± 3.2	8.1 ± 2.1	7.0 ± 1.6	12.0 ± 1.7	6.5 ± 0.5
PSI	7.8 ± 3.3	7.1 ± 1.6	6.3 ± 1.2	10.8 ± 1.6	5.5 ± 0.6
LSCI	2.5 ± 2.1	1.9 ± 0.7	4.0 ± 4.0	9.1 ± 4.5	1.2 ± 0.8

4.3 *Lienchiang County*

The results for SWHs using tap-water in Lienchiang County are listed in Table 7. The values of LSI, RSI and PSI also indicate a slight to serious corrosion tendency, except for Dongju Island, which shows a slight scaling tendency. The values of LSCI range from 1.2 to 24.1. A higher rate of steel corrosion can be expected. For SWHs using groundwater, the data are shown in Table 8. In Beigan and Dongju Islands, the values of LSI, RSI, and PSI show a slight scaling tendency, while there is a slight to heavy corrosion tendency in other townships. From the analysis of LSCI, ranging from 1.4 to 4.1, the rate of steel corrosion for SWHs using groundwater is less significant than that using tap-water. Further, the levels of Cl^- concentration are also shown in Tables 7 and 8. The values are 80.9-162.5 and 121.5-199.7 mg/L for tap-water and groundwater, respectively. Thus, the level of Cl^- concentration is also a critical issue for SWHs installed in Lienchiang County.

Tab. 7: Assessment of scaling and corrosion tendency of tap-water quality in Lienchiang County

Tap-water	Nangan	Beigan	Xiju Island	Dongju Island	Dongyin
Alkalinity, mg/L	53.0 ± 1.4	40.0 ± 0.0	11.0 ± 1.4	113.0 ± 1.4	6.0 ± 0.0
pH	7.6 ± 0.0	7.9 ± 0.0	7.6 ± 0.0	7.4 ± 0.2	7.0 ± 0.2
Cl^-, mg/L	122.5 ± 6.4	162.5 ± 3.5	114.0 ± 0.0	80.9 ± 3.4	140.7 ± 8.1
SO_4^{2-}, mg/L	52.1 ± 1.9	22.8 ± 0.6	4.4 ± 2.2	26.8 ± 2.1	3.6 ± 1.5
TDS, mg/L	369.0 ± 14.1	354.5 ± 7.8	227.5 ± 12.0	379.5 ± 6.4	293.3 ± 12.6
Hardness, mg/L	107.0 ± 5.7	63.4 ± 0.0	13.9 ± 8.4	139.0 ± 0.0	11.5 ± 4.2
HCO_3^-, mg/L	52.8 ± 1.4	39.6 ± 0.0	10.9 ± 1.4	112.7 ± 1.3	6.0 ± 0.0

CO_3^{2-}, mg/L	0.2 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0
LSI	0.4 ± 0.1	0.4 ± 0.0	-1.2 ± 0.4	0.6 ± 0.2	-2.3 ± 0.4
RSI	6.8 ± 0.1	7.2 ± 0.0	10.0 ± 0.7	6.1 ± 0.2	11.7 ± 0.5
PSI	7.4 ± 0.1	8.3 ± 0.0	11.6 ± 0.8	6.0 ± 0.0	12.9 ± 0.3
LSCI	3.3 ± 0.1	4.6 ± 0.1	10.9 ± 1.2	1.0 ± 0.0	24.1 ± 1.5

Tab. 8: Assessment of scaling and corrosion tendency of groundwater quality in Lienchiang County

Groundwater	Nangan	Beigan	Xiju Island	Dongju Island	Dongyin
Alkalinity, mg/L	81.0 ± 32.5	123.0 ± 36.1	50.0 ± 31.1	122.0 ± 8.5	51.0 ± 14.8
pH	6.4 ± 0.4	6.8 ± 0.5	6.8 ± 0.4	7.6 ± 1.2	6.7 ± 0.3
Cl^-, mg/L	141.5 ± 13.4	199.7 ± 68.5	121.5 ± 3.5	131.6 ± 77.0	143.4 ± 42.1
SO_4^{2-}, mg/L	42.9 ± 7.1	58.5 ± 15.9	23.2 ± 17.7	39.2 ± 4.8	51.6 ± 13.2
TDS, mg/L	521.0 ± 35.4	731.0 ± 294.7	366.0 ± 130.1	492.5 ± 122.3	493.2 ± 92.1
Hardness, mg/L	174.5 ± 38.9	282.7 ± 141.4	85.3 ± 70.3	152.5 ± 24.7	92.5 ± 17.4
HCO_3^-, mg/L	81.0 ± 32.5	127.9 ± 36.0	50.0 ± 31.1	120.2 ± 6.0	50.4 ± 14.8
CO_3^{2-}, mg/L	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	1.7 ± 2.3	0.0 ± 0.0
LSI	-0.5 ± 0.6	0.3 ± 0.6	-0.7 ± 0.3	0.9 ± 1.3	-0.9 ± 0.3
RSI	7.3 ± 0.9	6.3 ± 0.8	8.1 ± 1.0	5.8 ± 1.4	8.4 ± 0.3
PSI	6.4 ± 0.8	5.4 ± 1.0	8.0 ± 1.8	5.9 ± 0.2	8.0 ± 0.5
LSCI	2.4 ± 0.7	2.0 ± 0.4	3.5 ± 1.9	1.4 ± 0.5	4.1 ± 1.3

5. Conclusions

In Taiwan, long-term groundwater pumping has caused serious seawater intrusion in remote islands. Tap-water from desalination or groundwater re-treatment results in higher Cl^- concentration level. Therefore, water quality is a critical issue to disseminate SWHs. In this study, the samples of tap-water and groundwater in remote islands were collected and analyzed. In Penghu County, the values of LSI, RSI, and PSI for SWHs using tap-water and groundwater showed a slight scaling tendency, but all LSCI values indicated a serious corrosion tendency. In Kinmen and Lienchiang Counties, all index showed a corrosion tendency for both tap-water and groundwater. In addition, the issue of higher Cl^- concentration level in Penghu County should be addressed. Therefore, the commonly 304 stainless steel used should be replaced in order to delay pitting for SWHs and extend its service life.

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