Investigating of the corrosion and deposition potentials of drinking water sources using corrosion index: a case study of Dehloran

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ABSTRACT

Corrosion is a physico-chemical reaction caused by materials' contact with surrounding environment which changes material's properties. The aim of this study is to investigate the potential of corrosion and sedimentation of drinking water sources in Dehloran. In this cross-sectional study, the samples were taken from 8 wells that supplied the drinking water of Dehloran within one year. To do so, parameters such as total dissolved solids (TDS), calcium hardness, total alkalinity, water temperature, pH, Langelier Saturation Index, Ryznar Stability Index, Aggressive Index, Puckorius Index were measured in all sources of drinking water in Dehloran. The results showed that the rates of TDS, turbidity and hardness of all the wells under study were lower than the national standard, so that the highest and the lowest rate of TDS respectively belonged to the well No.1, Dasht-e Akbar (1084 mg/l) and the well No. 5, Bareh Bijeh (132 mg/l). Moreover, the highest and the lowest rate of turbidity respectively were related to the well No. 2, Bareh Bijeh (0.99 NTU) and the well No. 1, Dasht-e Akbar (0.25 NTU). For all the studied wells, Langelier Saturation Index was -0.43 to +0.19, Ryznar Stability Index was 7.52 to 9.07, Puckorius Index was 8.69 to 11.21, and Corrosion Index was 8.01 to 8.68. The review of the relevant indices indicates that Drinking water in Dehloran is corrosive; therefore, the quality of water in distribution network must be monitored constantly and necessary measures should be taken to control the corrosion.

KEY WORDS: Corrosion Potential, Deposition, Drinking Water, Dehloran.

1. INTRODUCTION

Water corrosion is a phenomenon caused by materials' contact with the surrounding environment. On the topic of materials engineering with regard to the nature of the corrosion process, this phenomenon is investigated in two important branches which includes erosive corrosion electrochemical corrosion. The first type includes the destruction of materials by physical factors such as clash of the suspended solids contained in pipes for water or sewage, which is probable to take place with regard to the nature of the impressive factors in metal and non- concrete pipes such as reinforced concrete. But the second type involves creating electrical panels and conducting electrochemical reactions between the surroundings and the material contained in it which occurs according to the nature of the process in metals such as steel pipes that are used in water transmission and distribution lines (Aiman, 2007).

Corrosion can influence public health, public acceptance of a water source and drinking water supply costs. Of the problems caused by the corrosion of water distribution network and houses pluming the lifetime reduction of pipes land accessories, the necessity of replacement of decayed pipes and pierced, increase of the amount of lost water and the occurrence of secondary contamination of the distribution network can be referred to that impose huge costs to cities' water annually (Tabandeh, 2016).

Now issues such as corrosion and sedimentation issues have devoted a significant percentage of annual income of countries to themselves. In the United States annually more than $ 333 billion (more than 4 to 5 per cent of the U.S. GDP) is spent for the losses caused by the corrosive acids and for preventing it. Despite the lack of precise statistics on damage caused by corrosion and sedimentation in Iran, investigating the refined urban water losses shows that annually more than 33 percent of distributed water (global average 8 percent) is wasted due to the decay resulting from the corrosion of water transmission and distribution pipes. It is obvious that the costs of repair and replacement of worn-out pipes will multiply the loss (Pirsaheb, 2016; Li, 2014; Dargahi, 2016). In addition to entering financial damage to the facilities, corrosion can cause the arrival of heavy metals such as lead, cadmium, copper and chrome to the distribution network and can threaten the health of consumers (Edwards, 2002; Agatemor and Okolo, 2008). The most important health issue related to corrosion is the presence of contaminants such as cadmium and lead that causes serious risks for public health (Kurdi, 2015; Dargahi, 2013). Research shows that lead and cadmium are two potential toxic metals that can enter into the body of water of distribution network due to the corrosion of distribution network pipes (Tabandeh, 2016). The U.S. Environmental Protection Agency has classified lead in Group B2 of carcinogen in humans because this element has a cumulative property and inhibits the activity of hemoglobin-producing enzymes and causes anemia and nervous disorders. Other side-corrosion products such as copper, zinc, iron and manganese are secondary standards for water and are aesthetically important (Alipour, 2015). These metals will stain containers and create metal taste in water. Copper makes block spots and lead creates metal taste in water (Agatemor and Okolo, 2008).

Great solutions have been offered by scientists and researchers in order to avoid corrosion and sedimentation in the facilities. Nevertheless, taking advantage of the predictive methods, coupled with the use of any method of control, can reduce the effects and damage caused by these phenomena in the water treatment industry in a more optimal way. With this perspective, attention to the water quality delivered to the customer will be particularly important (Dargahi, 2015). Water tendency to sedimentation and corrosion will be specified by examining water stability. Sustainable water slightly tends toward corrosion and sedimentation and its values are different for the types of use (Swietlik, 2012). Application of corrosion indices is an indirect way in simple measuring and diagnosis of water tendency towards corrosion and sedimentation. Common indices include: Langelier Saturation Index (LSI), Ryznar stability index (RSI), aggressive index (AI) and Puckorius index (PI) (Shams, 2012). Simultaneous utilization of several corrosion indices can make more balance water status with more certainty in order to take control measures (Vairavamoorthy, 2007).

Ahmadi (2013), carried out a study on the analysis of water distribution network fracture in Ahwaz. The results indicated that the most important causes of pipes breakage were the corrosive property of water and pipes' being depreciated.

The results of the study conducted by Kalantari (2013) entitled "Investigating the quality and determining the sustainability indices of drinking water resources in villages of Qom province" showed that the water situation in the studied area was corrosive.

With regard to health and economic harms caused by corrosion and sedimentation in water supplies, water quality monitoring is always necessary in terms of these two phenomena. Therefore, this study aims to investigate the potential of corrosion and sedimentation of drinking water sources in Dehloran.

2. MATERIALS AND METHODS

This cross-sectional study was conducted in 2014 in the city Dehloran. The experiments were conducted in collaboration with Water and Sewage Company and physico-chemical data and test results were analyzed and compared with national standards. The number of water resources assessed in this study includes 8 wells that are being used. Sampling was done according to standard method (10200 - B), temperature and pH determined by pH meter model E520 manufactured of Switzerland at site and determining of Total Dissolved Solids (TDS), calcium hardness, alkalinity, had done in laboratory according to standard method manual in accordance with the above instructions (Protocols 2540-C, 2320-B and 2340-C) (APHA, 2003). The amount of pHs has been measured through the following equation using the rates of alkalinity, calcium hardness, temperature, total dissolved solids (TDS), and pH.

The values of numerical coefficients (A, B, C, D) are obtained from Table (1).

$$pHs = \{(9.3 + A + B) - (C + D)\} \quad (1)$$

Corrosion indices have been measured based on recommended equation as the following:

Determining Langelier Saturation Index (LI): The following formula is used to determine this index (Davil, 2009; Deshommes et al., 2010).

$$Li = pH - pHs \quad (2)$$

When the index is negative, water's being corrosive is imminent. If the index is positive the water tends to sequester calcium carbonate, and if Langelier index is zero, the water is in the balance state not aggressive state and is not inclined to deposit a protective calcium carbonate coating.

Determining RyznarStability Index (RI): The following formula is used to determine this index (Rossum and Merrill, 1983; Pishnamazi, 1998).

$$RI = 2pHs - pH \quad (3)$$

Determining Aggressiveness Index (AI): The following formula is used to determine this index (Singley and Lee, 1994).

$$AI = \{pH + Log\ [(A)(H)\} \quad (4)$$

A: total alkalinity in mg/lit $CaCO_3$, H: Calcium hardness in mg/lit $CaCO_3$

Determining Puckorius Scaling Index (PI): The following equation is used to determine this index

$$PI = 2pHs - pHeq \quad (5)$$

PI =Puckorius Index, pH = pH water saturated with calcium carbonate

pH = pH_{eq} water in equilibrium which is obtained through equation (Pishnamazi, 1998).

$$pHeq = 1.465 + Log\ (T.ALK) + 4.54 \quad (6)$$

T.ALK = Total alkalinity in mg/lit

Table.2 is used for temperatures 0 to 60°C and shows the equity of different amounts of Ryznar index, which are always positive, with water behavior (Babaie, 2008).

Table.1. Values of numerical coefficients (A, B, C, D) to calculate the pH (AWWA, 1995).

TDS (mg/l)	A	Temp. (^{0}C)	B	Calcium hardness (mg/l, $CaCO_3$)	C	Alkalinity (mg/l, $CaCO_3$)	D
50-300	0.1	0-1	2.6	10-11	0.6	10-11	1.0
400-1000	0.2	2-6	2.5	12-13	0.7	12-13	1.1
		7-9	2.4	14-17	0.8	14-17	1.2
		10-13	2.3	18-22	0.9	18-22	1.3
		14-17	2.2	23-27	1.0	23-27	1.4
		18-21	2.1	28-34	1.1	28-35	1.5
		22-27	2.0	35-43	1.2	36-44	1.6
		28-31	1.9	44-55	1.3	45-55	1.7
		32-37	1.8	56-69	1.4	56-69	1.8
		38-43	1.7	70-87	1.5	70-88	1.9
		44-50	1.6	88-110	1.6	89-110	2.0
		51-55	1.5	111-138	1.7	111-139	2.1
		56-64	1.4	139-174	1.8	140-176	2.2
		65-71	1.3	175-220	1.9	177-220	2.3
		72-81	1.2	230-270	2.0	220-270	2.4
				280-340	2.1	280-350	2.5
				350-430	2.2	360-440	2.6
				440-550	2.3	450-550	2.7
				560-690	2.4	560-690	2.8
				700-870	2.5	700-880	2.9
				870-1000	2.6	890-1000	3.0

Table.2. Equality of different values of Ryznar Index with water behavior

Water status	Ryznar index
High sedimentation	4-5
Slight sedimentation	5-6
Equilibrium	6-7
Slightly corrosive	7-7.5
Highly corrosive	5.5-7.8

3. RESULTS

In order to determine the potential of corrosion and sedimentation of drinking water in Dehloran, water quality parameters including pH, total alkalinity, total hardness, turbidity, and total dissolved solids (TDS) were measured. The average of the obtained results is briefly displayed in Table.3. Based on the results of the analysis of the samples and their comparison with the corresponding standard it is estimated that the parameters of total dissolved solids (TDS) and turbidity of drinking water sources of the city are less than the relevant standard and total alkalinity in all drinking water sources in the city, is less than 200 (mg/l $CaCO_3$). Also, the total hardness of all water sources that were studied (except the wells number 1 and 2 in Dasht-e Akbar), is less than the national standard (500 mg/l $CaCO_3$).

Table.3. Analysis results of physic-chemical quality of quality of drinking water sources in Dehloran

Sample code	TDS (mg/l)	Temperature (^{0}C)	Turbidty (NTU)	Total hardness (mg/l $CaCo_3$)	Calcium (mg/l)	Alkalinity (mg/l $CaCo_3$)
Well No. 1, Dasht-e Akbar	1084	16.5	0.25	730	150	97.5
Well No. 2, Dasht-e Akbar	1150	17.5	0.75	620	135	92.5
Well No. 3, Dasht-e Akbar	805	16.2	0.6	480	29	87.5
Well No. 1, Bareh Bijeh	138	17.6	0.34	76	36	77.5

Well No. 2, Bareh Bijeh	142	18	0.99	72	39	72.5
Well No. 3, Bareh Bijeh	1444	19.3	0.63	76	34	77.5
Well No. 4, Bareh Bijeh	46	18.6	0.62	76	37	72.5
Well No. 5, Bareh Bijeh	132	18.4	0.42	72	30	72.5
National standard	500	-	5	200-500	300	-

Table.4 shows the results of calculation of corrosion indices in each of the drinking water resources of Dehloran. As can be observed, in terms of Ryznar index, Puckorius index, aggressive index, and Langelier index, all drinking water resources in Dehloran are corrosive.

Table.4. Calculation of corrosion indices of drinking water resources in Dehloran

Indices	Pi	Ai	Ri	Li	pH	pH
Well No. 1, Dasht-e Akbar	8.69	8.01	7.59	- 0.09	7.5	7.41
Well No. 2, Dasht-e Akbar	9.11	8.46	7.52	+ 0.19	7.7	7.89
Well No. 3, Dasht-e Akbar	9.51	8.33	8	- 0.1	7.9	7.8
Well No. 1, Dasht-e Akbar	9.07	8.13	7.82	- 0.12	7.7	7.57
Well No. 1, Bareh Bijeh	10.81	8.37	8.98	- 0.43	8.55	8.12
Well No. 2, Bareh Bijeh	10.81	8.39	8.96	- 0.41	8.55	8.14
Well No. 3, Bareh Bijeh	10.81	8.42	8.93	- 0.38	8.55	8.17
Well No. 1, Bareh Bijeh	11.21	8.68	9.07	- 0.32	8.75	8.43
Well No. 4, Bareh Bijeh	11.11	8.65	9.02	- 0.32	8.7	8.38
Well No. 5, Bareh Bijeh	10.81	8.42	8.93	- 0.38	8.55	8.17

DISCUSSION

The results of this study indicate that some of the assessed parameters for measuring Langelier and Ryznar indices including temperature, pH, alkalinity, calcium concentration and total dissolved solids are not in the range of national standards; for example, in 100% of cases calcium concentration is less than the standard limit and the concentration of total dissolved solids in all the examined wells is less than the standard limit. In the study conducted by Kargar, comparison of quality parameters measured in water of Gorgan distribution network with standard values showed that all parameters were equal to the standards and only the alkalinity was higher than the standard rate (Karegar and Haybati, 2006). Alkalinity and pH together determine the degree of sustainability of water. The higher is alkalinity, the more will be calcium carbonate sedimentation and consequently the less will be the rate of water corrosiveness. For water with high alkalinity it is necessary to decrease pH for making water sustainable and for water with low alkalinity such as drinking water sources of Dehloran it is essential to increase water pH for making water sustainable. In the study carried out by Ebrahimi. On potential of corrosion and sedimentation of drinking water in Koohdasht by using corrosion indices, the results indicated that water has corrosive property and control measures should be taken in relation to pH balance and water stabilization (Ebrahimi, 2012).

Water corrosion and sedimentation are among the most important issues that must be paid more attention in monitoring water distribution systems because lack of attention to chemical quality of water in terms of chemical balance and monitoring each one of the above phenomena can cause a lot of health and economic damage. According to Langelier index, all of the eight studied sources are corrosive except the second source of Dasht-e Akbar and there was no sedimentation in any of the drinking water sources of Dehloran.

Aiman (2006) did a research entitled "Evaluating the quality of drinking water and its potential in the formation of sediment and corrosion" in Talifa Province is South of Jordan with LSI and RSI indices. The analysis of the results showed that the value of LSI was negative and within the range of -0.39 to -1.5 which indicated the corrosive status of water. Its reason was attributed to heating and evaporation of water along with the release of CO_2 (Aiman, 2006). The results are consistent with the findings of present study.

Moreover, monitoring chemical quality of water and controlling its balance can lead to the increase of the useful life of water supply utility and can reduce the possibility of water leakage and loss. These requirements are highly important in low-water countries such as Iran. In a study conducted by Savari, entitled "Comparing the methods of corrosion in drinking water distribution system in Ahvaz", the results of Corrosion index, Langelier index (-0.56), Ryznar index (8.43) showed that drinking water of the city was tending towards corrosion (Savari, 2007). The results are consistent with the findings of the present study. In the present study, the LSI index is in the range of -0.06 to -0.43 and RSI index is in the range of 7.52 to 9.07 which indicate that drinking water is Dehloran is corrosive.

Rezaei Kalantari (2013), carried out a study entitled "Investigating the quality and determining the sustainability indices of drinking water sources in Qom villages". The results showed that Langelier, Ryznar, aggressive corrosion, and Puckorius indices were -1.62, 10.5, 12.03, and 9.92, respectively.

Taqipoor (2012), did a study entitled "Investigating corrosion and sedimentation of drinking water in Tabriz". They concluded that Langelier, Ryznar, aggressive corrosion, and Puckorius indices were -0.79, 8.16, 11.16, and 8, respectively. Asgari (2015), did a study entitled "Investigating chemical quality and erosion and sedimentation indices of drinking water network in Bushehr". The results showed that the average Langelier, Ryznar, aggressive corrosion, and Puckorius indices were 0.28, 7.24, 12.02, and 7.81, respectively. In this study, drinking water of Bushehr is slightly depositing according to Ryznar index and the other indices indicate that the water is corrosive.

The results of the study by Teimoori (2012), showed that Langelier and Ryznar indices for drinking water of Kian Town were 0.68 and 8.52 respectively and the water had minor to severe corrosive property.

In the study conducted by Mokhtari (2010), under the title of "Evaluating the corrosion and sedimentation conditions of drinking water distribution network in Ardebil" by using Langelier and Ryznar indices, the results indicate that drinking water in water supply network of Ardebil is somewhat inclined to corrosion and it is necessary to pay special attention to the control of water quality based on the parameters that are used such as setting pH, alkalinity, hardness, etc, along with the use of materials and pipes that resist against corrosion in drinking water network. Aggression index is a scale of water tendency to destroy water transmission pipes that are made up of cement asbestos. This index can be used for cement asbestos pipes and temperature conditions between 4 to 27°C. If the aggression index is less than 10, water is severely erosive, and if it is 10 to 12, water is corrosive (moderate) and if it is above 12, water is depositing. According to the results of the research, most sources of drinking water in Dehloran are severely erosive.

In general, the methods that are presented for calculating the rate of water corrosion or sedimentation ignore two important parameters including buffer capacity of water and maximum amount of deposit resulting from natural water in balance conditions. Puckorius index provides the possibility to investigate the relationship between supersaturated water and sedimentation by considering the above mentioned parameters. If the index is less than 6, water has tendency towards sedimentation and if it is above 6, water has no tendency towards sedimentation and is erosive. The index for all water sources of Dehloran was more than the determined amount which is consistent with the results of the study carried out by Qazavati (2008), on drinking water of Bandar Abbass Refinery which showed that the average index during sampling was 9.04. Therefore, according to the findings, it seems essential to find strategies to control corrosion in drinking water sources of Dehloran.

4. CONCLUSION

The results of this study indicated that drinking water sources of Dehloran are corrosive according to Langelier, Ryznar, aggression, and Puckorius indices. Therefore, it is quite necessary to control corrosion process. In order to control this problematic and costly process, different methods are used such as painting the pipes, using resistant polyethylene pipes instead of metal and cement-asbestos pipes, covering pipes, maintaining properly, implementing cathode protection for metal pipes, adjusting pH and injecting prohibitive materials to the distribution system. Selecting an appropriate method to prevent corrosion process depends on chemical properties of water, the effect of selective process on other processes, and its effect on water quality. According to the conducted studies, the best and the most common method to control corrosion process is to adjust pH by lime. Adding lime to water creates a shell which is called eggshell sediment. It prevents corrosion process.

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