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Assessment of the Potential of Scale Formation and Corrosivity of Tap Water Resources and the Network Distribution System in Shiraz, South Iran

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Abstract: The aim of this research is to study the potential of scale formation and corrosivity of water resources and the network distribution system of Shiraz in Fars province, South Iran. The Langelier saturation index (LSI) was used to assess the scale formation and corrosivity. The index was calculated based on the principle of calcium deposition. This research was done through 118 water resources samples which include wells and surface water and many different points in the network distribution system during late Summer and early fall, 2007. The mean LSI value for all the samples was 0.417. Although, the results indicated the scaling potential in all water samples, monitoring the corrosion rates was done on a regular basis. Seasonal changes can affect water quality, and therefore the corrosion rates.

Key words: Shiraz, corrosion, LSI, scale formation

INTRODUCTION

Potable water that is chemically and bacteriogically safe for human consumption should be provided for any community. Internal corrosion of piping is a serious problem in drinking water industry. According to ISO 8044 standard, corrosion is a physico-chemical reaction between metal and its surrounding environment. Corrosion changes metal properties. In addition to not being economic, corrosive water has the potential of degrading water quality and therefore affects the health of consumers (Mahvi and Eslami, 2005). Corrosion tends to increase heavy metals concentration. In general, different water resources have different water characteristics and therefore its tendency to corrode the water pipe is also different. The potential to form a protective layer containing a mixed precipitate of calcium carbonate and iron oxides depends on many different chemical and biological parameters such as pH, residual chlorine, hardness, temperature, total dissolved solids, alkalinity, acidity, dissolved salts, dissolved gases and microorganism (Viessman and Hammer, 2004).

Corrosion products can shield microorganisms from disinfectants. These microorganisms can cause many problems such as slimes, bad odor and taste (Bina and Porzamani, 2005). Atasoy and Yesilnacar (2009) also used Langelier Index and Ryznar Index to determine the degree of scale formation tendency/corrosivity of groundwater samples. The groundwater of Harran plain in Turkey had intense corrosion tendency. The amount of CO_2 from the soil zone respiration and high sulfate concentration contributed the corrosivity of groundwater (Atasoy and Yesilnacar, 2009). A current study indicated that the loss of chlorine dioxide in corroded iron pipes was significant and its effect was more than the total organic carbon (Zhang *et al*., 2008). According to Edwards, in many countries like Japan, England and Australia the cost of corrosion was almost 3 to 4% of their total income (Edwards, 2002).Therefore, corrosion control is an effective way to maintain water quality and providing the health of consumer. According to Environmental Protection Agency (EPA) standard, drinking water should not be corrosive.

The Langelier Saturation Index (LSI) and the Ryzner Stability Index (RSI) are commonly used as the indicators of water scale potential. The quality of tap water resources regarding the potential of scale formation and corrosivity in Tafila, Jordan was determined by various indices, LSI, RSI and the calcium carbonate precipitation potential (Al-Rawajfeh and Al-Shamaileh, 2007). Melidits also used the marble test and LSI value to determine the corrosion or deposition effect of Paradises well water, in Hrysoypolis in Greece (Melidis *et al*., 2007). The tendency of water to precipitate

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$CaCO_3$ or to dissolve it was determined by these indices. However, using the LSI and RSI as corrosion index should be done very conservatively. Calcium carbonate precipitation is inhibited by the presence of certain compounds. Conversely, the formation of $CaCO_3$ precipitate under-saturated water condition was observed (Lisitsin *et al*., 2005). Measuring metal concentration in the water distribution system is considered the best way to determine population exposure and it is the most appropriate method to assess the corrosion rate (Eaton *et al*., 1995).

Considering the fact that pipes are used for a long period of time, corrosion control is very important to maintain water quality and pipe integrity. Since, there were limited time and facility and lack of such study in Shiraz water resources, LSI was used to predict the potential of scale formation and corrosivity. This study aimed at determining the corrosivity or scale formation potential of the groundwater and surface water in Shiraz, South of Iran using LSI. For this purpose, 78 wells and one dam resource and 39 points through the network distribution system in a time interval of three months in Shiraz were analyzed for the parameters of temperature, pH, total alkalinity, calcium hardness, Total Dissolved Solids (TDS) and Electrical Conductivity (EC).

MATERIALS AND METHODS

Experiments: Samples were collected from selected sites for chemical analysis.

Study site description: Shiraz is situated between the 29th and 38th degrees of longitude, and between the 40 and 52 degrees of latitude, and is 1500 feet above the sea. Shiraz has a moderate climate. It is located in the South of Iran (Fig. 1). Precipitation is mainly in late fall, Winter and early Spring. Shiraz drinking water is supplied by 122 deep wells (78 of them are in use) of which 81 wells are alluvial and 41 wells are calcareous, which are located within or outside Shiraz. In addition, Dorodzan dam, which is located 80 km East of Shiraz, is the only surface water resource which is used to supply Shiraz drinking water. This study was conducted in three months from July through late October in 2007. City map was provided and

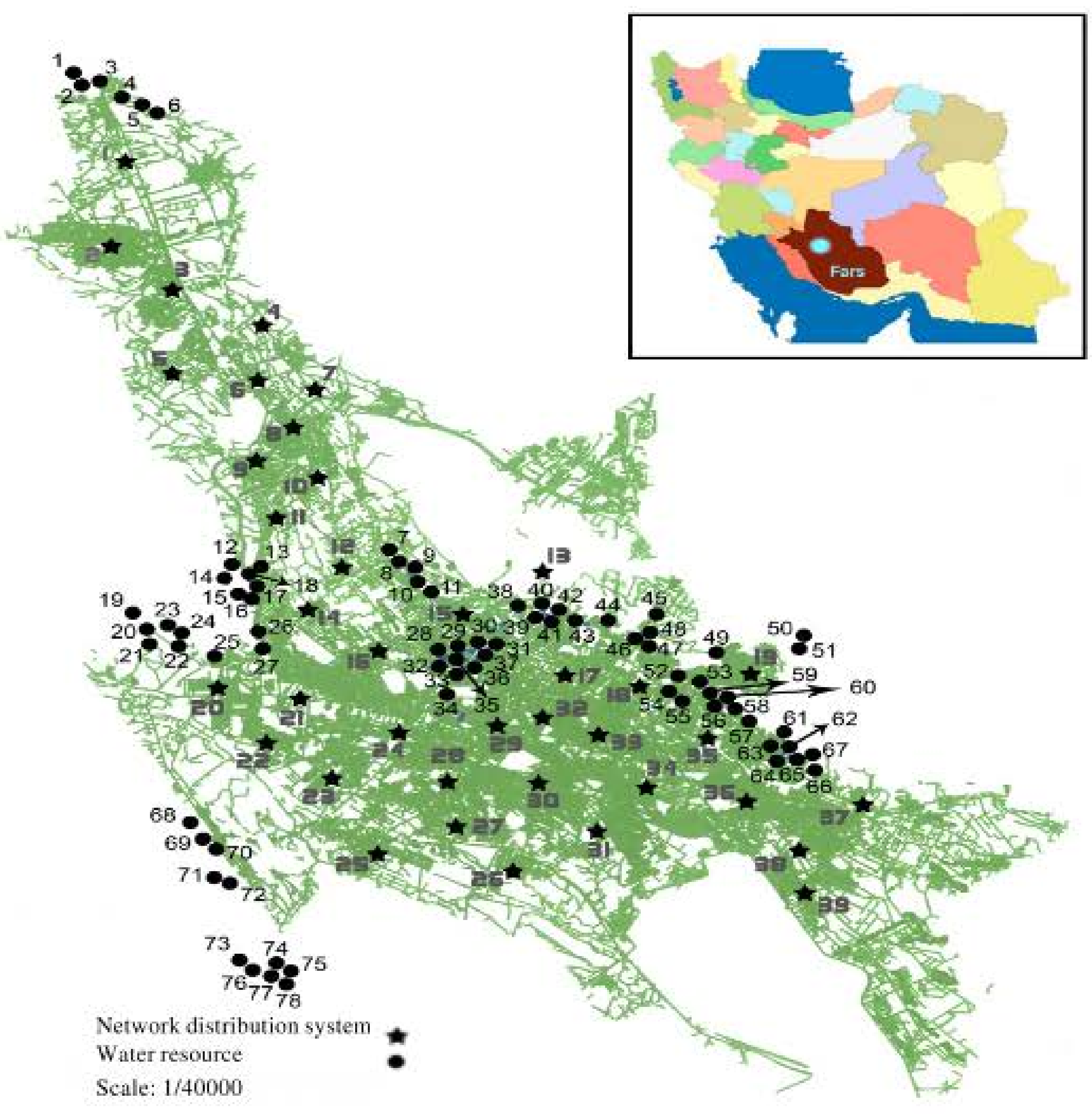

Fig. 1: The location of sampling points from 79 water resources (•) and 39 (*) stations in network distribution system in Shiraz

then was divided into 32 regions. Randomized sampling was done inside the regions including 39 points in the network distribution system and 79 water resources including wells and Dorodzan dam.

Analytical methods: The samples were collected in 300 mL polyethylene bottles. According to the standard method, the samples were analyzed for total alkalinity and calcium hardness (Eaton *et al.*, 1995). The temperature, pH, electrical conductivity and Total Dissolved Solids (TDS) were determined at the sampling point in the field by Aqua-conductivity TDS and temperature meter.

LSI was determined by the following relationship:

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

where, pH is measured pH of the water and pH_S is pH at $CaCO_3$ saturation and is determined by the following equation:

$$pH_S = pK_2 - pK_S + p\,[Alk_t] + 5pfm \quad (2)$$

Where:

pK_2-pK_S = Constants based on ionic strength and temperature

pCa^{+2} = Negative logarithm of the calcium ion concentration, mole L^{-1}

$pAlk_t$ = Negative logarithm of the total alkalinity, equivalents L^{-1}

pfm = Negative ionic strength coefficients at water temperature

A negative number of LSI indicates corrosive water and there is no potential to scale. A positive number of LSI indicates over saturated and it can precipitate calcium carbonate. If LSI is zero, water is at equilibrium.

Equation 1 was used to measure LSI and then the potential of scale formation and corrosion of water sample were determined.

Pearson coefficient in SPSS 11.5 software was used for data analysis.

RESULTS AND DISCUSSION

To determine the corrosion potential, different chemical water quality parameters such as temperature, pH, total alkalinity, calcium hardness, Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were measured in the 39 points in the network distribution of water supply municipality of Shiraz and 79 different water resources including wells and dam resources in a time interval of three months. The pH of the samples ranged from 6.92 to 8.3. Calcium hardness concentration ranged from 79 to 490 mg L^{-1} it as $CaCO_3$. The lowest concentration of calcium hardness (79 mg L^{-1} it as $CaCO_3$) was found in the North part of Shiraz, Derak Mountain. The highest TDS concentration (1398 mg L^{-1}) it was found near the cement factory. The majority of water samples have a high concentration of TDS. The range for EC is 297 to 2020 μmho cm^{-1}.

According to LSI value, water scale formation and corrosion potential for water samples from different network distribution system and water resources were presented, respectively in Table 1 and 2. The value of LSI for water samples in Shiraz network distribution system and drinking water resources in respect to the equilibrium line were presented, respectively in Fig. 2 and 3.

Shiraz water resources had medium to very hard water (calcium hardness of 118 to 419 mg L^{-1} it as $CaCO_3$) except three water resources with calcium hardness of less than 100 mg L^{-1} it as $CaCO_3$ located in the Northern Shiraz (Derak mountain). According to LSI value, water had a low to medium potential for scale formation (92.4%) and only 1.3% of the water resource had a trace potential of corrosion. The result of chemical water quality parameters in Dorodzan dam indicated that water had a mild hardness (130 mg L^{-1} it as $CaCO_3$) and therefore had a moderate scaling potential at total alkalinity of 200 mg L^{-1} it as $CaCO_3$ and pH equal to 7.9.

Results also indicated that water samples from the network distribution system were ranged from mild to very

Table 1: The potential of scale formation and corrosivity of water according to LSI value in Shiraz network distribution water samples

Site No.	LSI value	Status	Site No.	LSI value	Status
1	0.247	Slight scale forming	21	0.504	Mild scale forming
2	0.314	Slight scale forming	22	0.5	Mild scale forming
3	0.389	Slight scale forming	23	0.753	Mild scale forming
4	0.453	Slight scale forming	24	0.304	Slight scale forming
5	0.359	Slight scale forming	25	0.409	Slight scale forming
6	0.557	Mild scale forming	26	0.365	Slight scale forming
7	0.41	Slight scale forming	27	0.232	Slight scale forming
8	0.448	Slight scale forming	28	0.318	Slight scale forming
9	0.447	Slight scale forming	29	0.461	Slight scale forming
10	0.448	Slight scale forming	30	0.243	Slight scale forming
11	0.478	Slight scale forming	31	0.652	Mild scale forming
12	0.501	Mild scale forming	32	0.85	Mild scale forming
13	0.571	Mild scale forming	33	0.401	Slight scale forming
14	0.488	Slight scale forming	34	0.961	Mild scale forming
15	0.31	Slight scale forming	35	0.473	Slight scale forming
16	0.406	Slight scale forming	36	0.634	Mild scale forming
17	0.483	Slight scale forming	37	0.808	Mild scale forming
18	0.606	Mild scale forming	38	0.478	Slight scale forming
19	0.717	Mild scale forming	39	0.835	Mild scale forming
20	0.458	Slight scale forming			

Table 2: The potential of scale formation and corrosivity of water according to LSI value in Shiraz water resources samples

Site No.	LSI value	Status	Site No.	LSI value	Status
1	0.232	Slight scale forming	41	0.119	Slight scale forming
	0.375	Slight scale forming	42	0.641	Mild scale forming
3	0.43	Slight scale forming	43	0.463	Slight scale forming
4	0.275	Slight scale forming	44	0.318	Slight scale forming
5	0.263	Slight scale forming	45	0.226	Slight scale forming
6	0.21	Slight scale forming	46	0.188	Slight scale forming
7	0.272	Slight scale forming	47	0.152	Slight scale forming
8	0.154	Slight scale forming	48	0.088	Slight scale forming
9	0	Balance	49	0	Balance
10	0.293	Slight scale forming	50	0.589	Mild scale forming
11	0.377	Slight scale forming	51	0.128	Slight scale forming
12	0.354	Slight scale forming	52	0.098	Slight scale forming
13	0.37	Slight scale forming	53	0.843	Mild scale forming
14	0.326	Slight scale forming	54	0.491	Slight scale forming
15	0.396	Slight scale forming	55	0.846	Mild scale forming
16	0.841	Mild scale forming	56	0	Balance
17	0.141	Slight scale forming	57	0.466	Slight scale forming
18	0.752	Mild scale forming	58	0.408	Slight scale forming
19	0.44	Slight scale forming	59	0.151	Slight scale forming
20	0.667	Mild scale forming	60	0.191	Slight scale forming
21	0.218	Slight scale forming	61	0.582	Mild scale forming
22	0.218	Slight scale forming	62	0.815	Mild scale forming
23	0.064	Slight scale forming	63	0.262	Slight scale forming
24	0.176	Slight scale forming	64	0.713	Mild scale forming
25	0.478	Slight scale forming	65	0.464	Slight scale forming
26	0.483	Slight scale forming	66	0	Balance
27	0.601	Mild scale forming	67	0.227	Slight scale forming
28	0.17	Slight scale forming	68	0.586	Mild scale forming
29	0.297	Slight scale forming	69	0.656	Mild scale forming
30	0.833	Mild scale forming	70	0.205	Slight scale forming
31	0.806	Mild scale forming	71	0.236	Slight scale forming
32	0.462	Slight scale forming	72	0.663	Mild scale forming
33	-0.37	Slight corrosion	73	0.536	Mild scale forming
34	0.522	Mild scale forming	74	0.586	Mild scale forming
35	0.102	Slight scale forming	75	0.302	Slight scale forming
36	0.51	Mild scale forming	76	0.76	Mild scale forming
37	0.641	Mild scale forming	77	0.232	Slight scale forming
38	0	Balance	78	0.521	Mild scale forming
39	0.41	Slight scale forming	79	0.507	Mild scale forming
40	0.865	Mild scale forming			

hard (118 to 490 mg L^{-1} it as $CaCO_3$). The LSI value was ranged from (0.23 to 0.96). In general, water did not have a corrosion potential and even a protective $CaCO_3$ lining on pipes could be formed.

According to our study, the mean value of LSI for 118 water samples was 0.417. Samples exhibited a slight scaling potential, according to LSI value.

Since, Shiraz network distribution water system is fed by many different water resources with different water quality parameters, the mixing of water resources in pipes caused a trace to moderate scale formation potential making it more suitable for drinking, considering physico-chemical properties.

Pearson coefficient with a confidence level of 95% (α = 95%) was used for correlation between the LSI value and the quality parameters (temperature and pH). Data analysis showed significant difference between LSI and temperature and pH ($p<0.001$) and a positive correlation was observed.

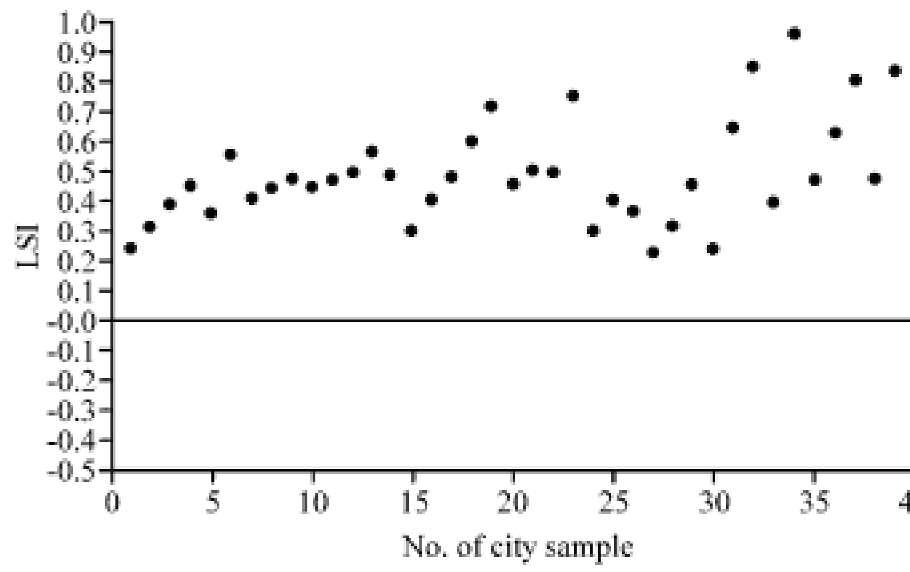

Fig. 2: The value of LSI for water samples in Shiraz network distribution system in respect to the equilibrium line

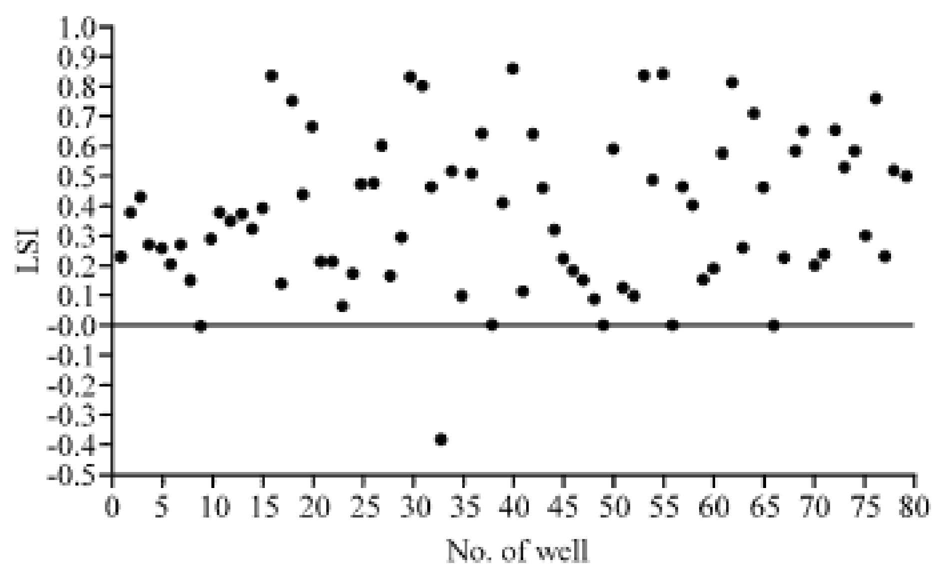

Fig. 3: The value of LSI for water samples in Shiraz drinking water resources in respect to the equilibrium line

Mahvi and Eslami indicated that Zanjan (Central Iran) water resources were corrosive, based on LSI value. They concluded a high possibility of damaging in the pipes (Mahvi and Eslami, 2005). However, the quality of tap water in Bagbedarn, Esfahan was not corrosive and at the same time, water had a tendency to form a protective layer in the pipes (Bina and Porzamani, 2005). Although, the quality of tap water resources regarding the potential of scale formation and corrosivity in Tafila, Jordan indicated corrosion conditions, this image changes upon heating and evaporation of water with the release of CO_2 (Al-Rawajfeh and Al-Shamaileh, 2007). Atasoy and Yesilnacar (2009) also showed that the groundwater of Harran plain in Turkey had intense corrosion tendency. Their results showed that precipitation, excessive irrigation, and change in groundwater level caused seasonal variation in corrosive characteristics (Atasoy and Yesilnacar, 2009).

CONCLUSION

One hundred and eighteen tap water samples, 79 water resources and 39 stations in Shiraz network distribution system were used to determine the potential of scale formation and corrosion. Langelier Saturation Index (LSI) confirmed that the potable water of municipality Shiraz was not corrosive and did not cause any damage in the network distribution system pipes. Furthermore, its water had a high tendency to form a protective layer in pipes. However, water authorities should monitor corrosion rates on a regular basis to determine changes of corrosiveness during seasons with high or low precipitation. Measuring metal concentration especially heavy metals contents in Shiraz water distribution system is also recommended. Because of the severe health effects of heavy metals, it is recommended to control the level of the heavy metals contents in Shiraz drinking water.

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