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Quality of Potable Water in Kuwait

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Abstract: Problem statement: Kuwait is an arid country with limited natural water resources. As such, Kuwait produces its drinking water using the Multi-Stage-Flash method (MSF) in distillation plants to produce distilled water from sea water. The distilled water is blended with the brackish groundwater in different blending ratios, to produce drinking water, as recommended by World Health Organization (WHO). **Approach:** The main purposes of this study were to determine the best blending ratios in the blending plants of Kuwait to get the best quality of drinking water according to the WHO guidelines and to reveal and control the corrosivity of the produced drinking water. In order to find out the best blending ratio, samples of drinking water from the different blending plants and groundwater samples from water well fields have been collected during 2007-2008 and analyzed for the determination of basic cations and anions. Moreover, water samples collected from the main pump stations were analyzed for Langelier Index, to reveal the corossivity level of the drinking water. **Results:** It was found that the best blending ratio between distilled water and brackish groundwater to obtain drinking water is in the range of 7-8% at Shuwaikh blending plant, 8-9% at Shuaiba blending plant and 8% at Doha blending plant respectively. While the best blending ratio at Az-Zour blending lines is between 3-4% and between 4-5% at Sabiya blending lines. **Conclusion:** It was found that the produced distilled water is corrosive and causing red water problem. In addition, it was found that the mean value of the Langelier Index at Shuaiba pump station is (-0.6) and the mean value of the total alkalinity is 21.4 mg L^{-1} as $CaCO_3$, which reveals that the drinking water from Shuaiba plant is more corrosive than the drinking water from the other plants.

Key words: Blending ratio, brackish water, distilled water, fresh water

INTRODUCTION

Location of the study area: Kuwait is located at the north shore of the Arabian Gulf and lies between 28°30'-30° 30'N latitudes and 46°30'-48°30' E longitudes, covering an area of 18,000 Km^2. It is covered with sands and gravels, rising gradually from the Arabian Gulf shores towards southwest. The climate is extremely hot, dry in summer and mild to cold in winter. The rainfall is scarce and limited to the period from October to May with an average of 110 mm $year^{-1}$. Due to lack of surface water and scarcity of rainfall, the groundwater is the only natural resource in Kuwait. Brackish groundwater is located in the Kuwait Group and the Dammam Formation aquifers and has a salinity ranging from 3.000-10.000 mg L^{-1}. The brackish groundwater is being produced from the water well fields of Sulaibiya, Shigaya, Al-Wafra, Um-Qudair and Al-Atraf areas (Fig. 1). The production of the brackish groundwater is about 121 Million Imperial Gallons per Day (MIGD), which is mainly used for irrigation, domestic purposes and blending with distilled water.

Thus, in view of the scant natural fresh water resources and the increase of population and water demand, Kuwait since founded has to look for other sources to secure potable water requirements. Therefore, Kuwait depends on seawater desalination for its fresh water supply (Al-Jaralla and Al-Fares, 2009).

Distillation plants: In the past the people of Kuwait relied on a scant number of wells to satisfy their water needs. Those wells accompanied with fresh water transported by boats from Basra, Iraq were the main source of water supply to the people. Transporting water by boats continued for some time, where in 1939 a company was established to manage the fleet of water carriers from Iraq, by constructing three reservoirs on the shore for storage.

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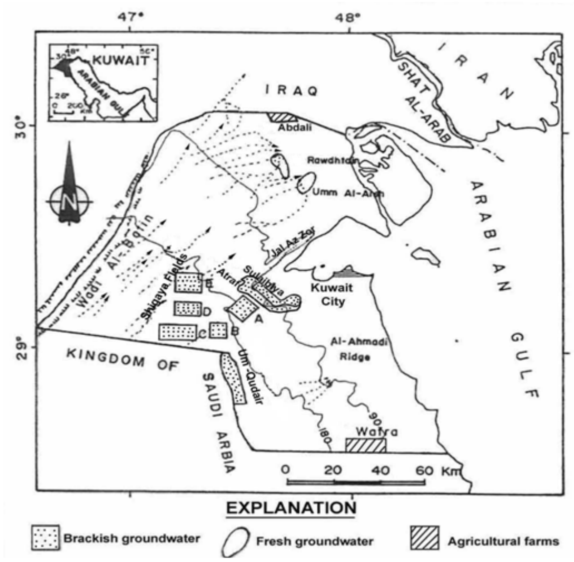

Fig. 1: Location map of the groundwater well fields in Kuwait

The first major breakthrough came in 1951 when Kuwait Oil Company (KOC) build a small sea water desalination plant with a capacity of 80.000 gallon day $^{-1}$ at the port of al-Ahmadi (Mina Al-Ahmadi) and distributed part of the water to the town of Kuwait. The first major desalination plant was built in 1953 with a capacity of 1 million gallons day^{-1} (mgpd). In 1978 another desalination plant was build in Doha. The capacity of the Doha plant is 42 mgpd.

The country was and is very anxious to exploit all available groundwater both freshwater for drinking and brackish water for irrigation. As for fresh groundwater it is considered a matter of prime importance. Fresh groundwater was discovered in limited quantities at both Al-Rawdhatain and Umm Al-Aish fields. Pumping operations commenced in 1962, whereas the estimated natural reserve of both fields is about 40,000 million gallons. In 1980 the Rawdhatain Water Production and Bottling Projects started to produce 1800 m^3 year^{-1} of mineral water. The Umm Al-Aish field is currently producing 8000 m^3 year^{-1} of water. Besides freshwater the country makes use of its large supply of brackish groundwater. The authority distributes this water to the consumers through separate network parallel to the freshwater network. The brackish water is intended to be used for various purposes, such as blending with distilled water, irrigation, live stock watering and construction works. It is worth mentioning that. The number of consumers connected to the fresh water network totaled 140.824 by the year 2007, while consumers connected to the brackish water network totaled 80.218 by the end of the same year (Alhumoud *et al*., 2003; MEW, 2008).

Currently, there are six distillation plants in Kuwait, the distillation units use the Multi Stage Flash evaporation method. Each distillation unit consists a number of stages ranging between 24-26 stages, with different unit capacities of 4.4, 7.2 and 12.5 MIGD according to each station. The Al-Zour North seawater desalination plant alone, operating since 2007, produces 567,000 m^3 day^{-1} of freshwater, equivalent to about 29.3% of the total production capacity. It is the fifth largest desalination plant in the world in terms of production capacity (Al-Damkhi *et al*., 2009). A new RO desalination plant is being built in Kuwait scheduled to begin production in 2010. The plant, worth US$320 million, will supply drinking water for 450.000 residents in Kuwait with a capacity of 137,000 m^3 day^{-1} (Wangnick, 2004; Bains, 2008; Al-Damkhi *et al*., 2009). However, the total capacity of the distillation units in the power stations is 419.1 MIGD including High Temperature Operation (HTO) of distiller units at most of Doha West and all of Az-Zour South Station (MEW, 1994; 2008).

Drinking water production: In order to produce drinking water according to the WHO guidelines, distilled water, which is produced from the distillation plants is being mixed with the brackish groundwater produced from the water well fields. This process takes place either in the blending plants or in the blending lines operated by the Chemical Works Administration of MEW, distributed in Shuwaikh, Shuaiba, Doha, Az-Zour and Sabiya, where the disinfection of the produced drinking water is carried out by injecting the chlorine solution in order to kill the bacteria and the harmful organisms in water. In addition caustic soda solution is added to maintain the pH value of the water within the required limits according to the (WHO) guidelines for drinking water. The drinking water network starts from the blending plants' lines and passes through main reservoirs, main pump stations, main trunk lines, strategic water reservoirs sites, distribution lines, water towers, tanker filling stations and ends with consumers feeding points.

However, the drinking water gross production rose from 1.773 MIG year^{-1} in the late 50-119.774 MIG year^{-1} in 2008, while the per capita average consumption of drinking water rose from 4,604-35.912 IG year^{-1} in 2008. Figure 2 and 3 represent the production and consumption of drinking water for the period 2005-2008, where the maximum production recorded was 374.641 MIGD in September 2008, while the maximum consumption recorded was 374.806 MIGD in September 2008.

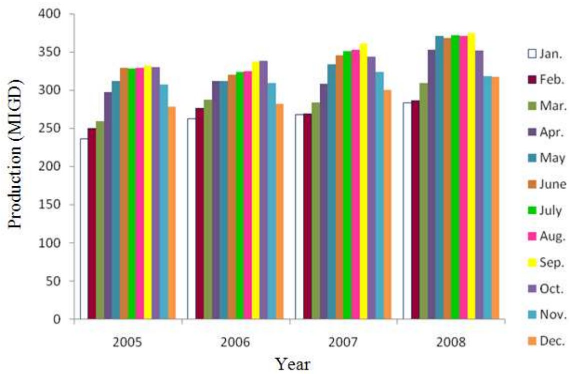

Fig. 2: Production of potable water during the period 2005-2008

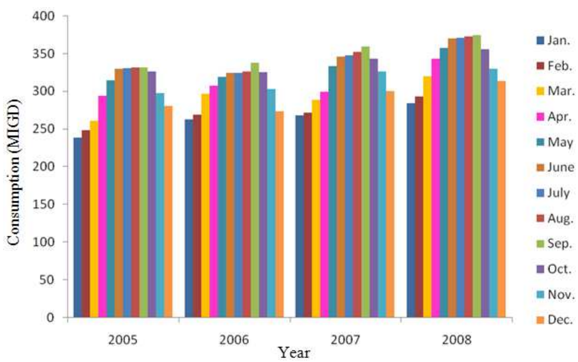

Fig. 3: The consumption of the drinking water during the period 2005-2008

Therefore, the main objectives of the study are to determine the best blending ratios between the distilled water and the brackish groundwater in the blending plants or lines to get the best quality of drinking water according to the WHO guidelines. In addition, to reveal and control the corrosivity of the produced drinking water based on the Langelier Index determination.

Water well fields and production of groundwater: The groundwater well fields which are located across the country include both operational fields and those currently under development and construction. There are 13 groundwater well fields in Kuwait located in the north, south and centre of the country. Two of the water well fields are privately owned, with the abstracted groundwater being used for irrigation of private farms. The remaining water well fields are owned by the MEW.

Furthermore, the three water well fields, Kabad, Al-Atraf and NW Um-Qudair are under construction. The greatest expected production is from Um-Qudair field at a rate of 40 MIGD. The maximum total production for all fields is estimated to be 123 MIGD. Groundwater production from the MEW well fields has been regulated since the mid 1970 sec, due to the risk of saline water intrusion (Al-Ruwaih *et al.*, 2005).

Groundwater quality: Brackish groundwater quality varies from one field to another depending on the utilized aquifer. Table 1 displays the chemical Analysis of the brackish groundwater in Kuwait. The salinity of the groundwater ranged from 2.330-3.190 mg L^{-1} in Um-Qudair field, from 2.564-3.045 mg L^{-1} in Shigaya fields, from 3.686-4.378 mg L^{-1} in Sulaibiya field, from 3.849-6.366 mg L^{-1} in Al-Atraf field and from 5.066-6.180 mg L^{-1} in Al-Wafra Field. The groundwater is of Na_2SO_4 in Um-Qudair, Shigaya and Suaibiya fields, where as NaCl type is dominant in Al-Atraf and Al-Wafra fields (Hadi and Al- Ruwaih, 2005; 2008).

Collection and analysis of drinking water samples:
Field analysis: Field Analysis of pH, EC, temperature, residual chlorine and turbidity are usually made at the time of sampling, using portable equipments. Chlorine residual sampling is done at the consumer's faucet and at the plant. Sampling at the consumer's faucet is done to determine whether consumers are receiving water that is safe to drink.

Drinking water quality: Drinking water should be safe chemically, physically and biologically. Chlorine is the most widely used chemical for the treatment of drinking water and this process is used in Kuwait as well. Color, turbidity, taste, odor and harmful microorganisms must be absent. TDS should be< 500 mg L^{-1} (Al-Kuwait and Al-Yawm, 2001; Fredrick, 1990; AWWA, 1985) for the water to be of good quality. Water with more than 1000 mg L^{-1} of dissolved solids usually contains minerals which give it a disagreeable taste or make the water unsuitable in other respects. The palatability of drinking water has been rated by panels of tasters in relation to its TDS level as follows: Excellent, less than 300 mg L^{-1}; good, between 300 and 600 mg L^{-1}; fair, between 600 and 900 mg L^{-1}; poor, between 900 and 1200 mg L^{-1} and unacceptable, greater than 1200 mg L^{-1}. Water containing extremely most commonly used low concentrations of TDS may be unacceptable because of its flat, insipid taste. Table 2 shows the quality classification of drinking water based on TDS values according to WHO guidelines, 2006.

However, in Kuwait the groundwater produced from the water well fields is brackish, with a TDS in the range of 2.000-10.000 mg L^{-1}. Therefore, the produced distilled water is pure and has low concentrations of dissolved salts, gases and a total alkalinity of less than 1 mg L^{-1} as $CaCO_3$, which is not suitable for human use. Thus, this distilled water is blended with the brackish groundwater to produce fresh water suitable for drinking.

Table 1: Chemical analysis of the brackish groundwater from the water well fields, (mg L^{-1})

Well No.	EC ($\mu S\ cm^{-1}$)	pH	TDS	Na	K	Ca	Mg	Cl	SO_4	HCO_3	Water types
Um-Qudair field											
2	4647	6.93	2690	606	12.36	390.0	108.0	897	1482	96.00	Na_2SO_4
6	4070	7.00	2330	396	14.17	374.0	108.0	542	1438	92.00	Na_2SO_4
12	4706	6.70	2720	690	29.00	433.0	111.0	951	1480	64.00	Na_2SO_4
16	5444	7.10	3190	572	9.68	480.0	133.0	1100	1275	61.00	Na_2SO_4
18	4370	7.10	2650	995	10.91	384.0	149.0	1450	1902	91.00	Na_2SO_4
22	4913	7.20	2850	697	9.58	466.0	112.0	1125	1563	62.00	Na_2SO_4
25	4514	7.04	2600	460	17063.00	400.0	127.0	659	1310	70.00	Na_2SO_4
49	4883	6.89	2830	617	17.00	435.0	147.0	1274	1256	77.00	Na_2SO_4
50	4897	6.90	2840	608	19.00	471.0	122.0	1142	1208	77.00	Na_2SO_4
53	4797	7.06	2770	605	17.00	396.0	113.0	1080	1104	89.00	Na_2SO_4
Shigaya field											
D1	3234	7.36	2620	658	8.62	245.4	108.4	406	1736	108.30	Na_2SO_4
D3	3513	7.51	2846	492	12.30	282.0	112.4	480	1358	136.60	Na_2SO_4
D4	3382	7.60	2739	487	12.33	269.0	135.0	345	1614	119.60	Na_2SO_4
D5	3306	7.70	2678	485	11.40	269.0	124.0	291	1650	105.40	Na_2SO_4
D6	3645	7.53	2678	481	10.02	271.8	137.0	540	1329	140.40	Na_2SO_4
D10	3400	7.50	2754	450	10.14	271.0	121.7	450	1195	134.30	Na_2SO_4
D11	3380	7.60	2738	496	11.84	266.0	120.0	325	1627	105.80	Na_2SO_4
D13	3333	7.30	2699	453	11.44	295.0	126.0	450	1542	134.00	Na_2SO_4
D16	3344	7.70	2708	473	10.36	297.0	114.0	421	1422	114.00	Na_2SO_4
D18	3665	7.70	2968	574	11.28	271.0	136.0	505	1543	134.00	Na_2SO_4
D19	3760	7.60	3045	542	9.98	297.0	126.0	528	1513	120.00	Na_2SO_4
C105	3167	7.77	2565	755	10.97	277.0	110.0	662	1696	102.00	Na_2SO_4
C107	3225	7.69	2612	637	13.13	277.0	99.0	367	1810	109.00	Na_2SO_4
C110	3166	7.90	2564	605	11.64	264.0	124.0	490	1560	104.00	Na_2SO_4
C111	3180	7.76	2576	579	12.03	280.0	116.0	518	1512	100.00	Na_2SO_4
Sulaibiya field											
26	5088	7.41	4121	450	20.25	468	180	702	1508	127.00	Na_2SO_4
27	5020	7.50	4066	522	17.75	499	206	795	1960	122.00	Na_2SO_4
28	4551	7.50	3686	545	11.54	452	170	560	1779	129.00	Na_2SO_4
5688	65	7.00	4321	592	35.3	508	211	851	1988	91.00	Na_2SO_4
71	5405	7.10	4378	424	18.28	489	180	939	1405	126 .00	Na_2SO_4
78	5181	7.00	4167	430	11.73	458	208	919	1368	118.70	Na_2SO_4
83	4908	6.90	3975	439	13.96	483	169	970	1503	119.70	Na_2SO_4
90	4534	7.19	3673	595	16.43	512	148	831	1650	137.40	Na_2SO_4
100	4966	7.40	4022	410	19.32	616	189	593	1969	149.30	Na_2SO_4
Al-Atraf field											
AT.1	7389	7.10	5985	977	21.30	621	204	1827	1617	79.52	NaCl
AT.3	6550	7.00	5306	1100	18.84	606	199	2078	1617	94.26	NaCl
AT.4	6776	7.30	5489	1250	19.35	588	175	2014	1693	89.80	NaCl
AT.5	6590	7.26	5337	875	19.77	507	225	1720	1594	89.70	NaCl
AT.6	7241	7.32	5865	810	17.66	560	174	1599	1503	84.42	NaCl
AT.7	7741	7.00	6366	940	26.00	746	174	2088	2579	84.36	Na_2SO_4
AT.8	6099	7.30	4940	1050	19.43	480	194	1810	1653	108.06	NaCl
AT.9	6481	7.28	5249	910	20.96	520	160	1770	1583	103.58	NaCl
AT.10	7518	7.20	6089	988	21.73	524	251	1928	2028	71.54	Na_2SO_4
AT.11	6040	7.40	4892	1208	16.67	456	179	2015	1789	115.16	NaCl
AT.12	5950	7.40	4819	1430	14.55	448	197	2211	1837	114.00	NaCl
AT.13	5696	7.30	4613	1350	18.20	480	145	2085	1751	115.96	NaCl
AT.23	4752	7.32	3849	1325	16.25	353	140	1913	1389	141.00	NaCl
AT.24	4882	7.24	3954	1250	14.30	336	177	1815	1662	119.92	NaCl
AT.25	6990	7.50	5032	859	16.10	549	143	1903	1312	112.00	NaCl
Al-WAFRA field											
2	7725	7.40	6180	1093	31.0	378	442	2428	1658	149.00	NaCl
10	6255	0.04	5066	1055	24.0	315	382	2177	1547	127.60	NaCl

Blending ratio: Distilled water is produced from six distillation plants located at Shuwaikh, Shuaiba, Doha (East and West), Az-Zour and Sabiya. In addition, there are five blending plants located at Shuwaikh, Shuaiba, Doha, Az-Zour and Sabiya, where blending of distilled water with brackish groundwater is carried out. Using the following mass balance equation proposed by Himmelblau and Riggs (1982).

The blending plants use a Blending Ratio (BR) calculated according to the following equation:

$$\text{Blending ratio (\%)} = \frac{\text{Net production of brackish water day}^{-1}}{\text{Net production of distilled water day}^{-1}} \times 100 \quad (1)$$

Equation 1 is used to calculate the blending ratio to be used according to the production of brackish groundwater and distilled water, based on the set blending ratios (Perry and Green, 2008). Generally, at the blending plants, it is ensured that the TDS concentration of the produced drinking water does not exceed 500 mg L^{-1}, as per the WHO guidelines, 2006.

Blending plants: Description of the blending plants are outlined in a report by MEW (2007), where the processes of mixing and disinfection are taking place to produce drinking water.

Table 3 summarizes the minimum, maximum and the recommended range of blending ratios at different chemical blending plants and lines in Kuwait during 2003-2008, where the produced drinking water is rated as good/excellent. As per the WHO guidelines, TDS level is as follows: Excellent, less than 300 mg L^{-1}; good, 300-600 mg L^{-1}; Fair, 600-900 mg L^{-1}; Poor, 900-1200 mg L^{-1} and unacceptable, greater than 1200 mg L^{-1}. Water with extremely low concentration of TDS may also be unacceptable because of its flat, insipid taste (WHO, 1996; 2006). It shown from the table that the best blending ratio in Shuwaikh plant ranged between 7 and 8%, Shuaiba blending plant is 8%, Doha blending plant, where the 8%, Az-Zour blending lines ranged between 3 and 4% and Sabiya blending lines ranged between 4 and 5% to obtain TDS less than 300 mg L^{-1}.

In addition it is clear from Table 3 that the blending plants at Shuwaikh, Shuaiba and Doha which receive almost similar qualities of brackish groundwater, the recommended blending ratios are almost the same, even though they are received brackish groundwater from different groundwater fields (Sulaibiya, Shigaya and Um-Gudair). While in the other blending lines at Az-Zour and Sabiya, which receive another qualities of brackish groundwater from Al-Wafra and Al-Atraf fields have a similar recommended blending ratios.

The recarbonation process: The produced distilled water has very low concentration of dissolved salts, gases and total alkalinity as $CaCO_3$ is <1 mg L^{-1} and not suitable for drinking. The high purity renders the water to be chemically very aggressive towards nearly all components in the water distribution system, resulting in very severe corrosion problems. One of the by-products of this chemical attack is ferric hydroxide, a red-brown rust, which results in what is called “red water” in Kuwait (Al-Rqobah and Al-Munayis, 1989). Reddish or red-brown stains are usually associated with iron in the water. Iron types found in water are: Oxidized, soluble, colloidal, bacteria and organic-bound. Each of these types presents a potential problem. As little as 0.3 ppm in a water supply can cause staining of clothes and fixtures. The problem of the red-brown rust still exists in Kuwait since the water the sources of the fresh water are still the same (sea water from the Gulf).

The corrosion control in the distribution system involves two approaches; material selection and pacification treatment. Pacification treatment to control water quality for corrosion is limited to certain kinds and quantity of chemicals, since great volume of water must be supplied at low cost without any effect on taste, odor, color, turbidity and toxidity. These chemicals are basically used to adjust the pH, to form precipitates by using inhibitors and to form carbonate coating. Thus, to achieve the corrosion inhibition of iron pipes, the recarbonation process was applied for the treatment of the distillate produced by the multistage flash evaporators in the plants in Kuwait (WRDC, 1999).

Table 2: Quality classification of drinking water, (WHO, 2006)

Water class	TDS (mg L^{-1})
Excellent	<300
Good	300-600
Fair	600-900
Poor	900-1200
Unacceptable	>1200

Table 3: Summary of the blending ratios and the recommended blending ratios at the blending plants and lines in Kuwait, 2003-2008

Site	Min. BR (%)	Max. BR (%)	Recommended blending ratio (%)	TDS (mg L^{-1}) at the Recommended blending ratio	Remarks
Shuwaikh	6.1	13.7	7-8	274-300	Excellent
Shuaiba	2.3	14.1	8- 9	267-300	Excellent
Doha	2.9	15.0	8	298	Excellent
Az-Zour	1.7	6.4	3-4	186- 248	Excellent
Sabiya	2.0	9.0	4-5	226-282	Excellent

Table 4: Summary of the Langelier Index of the main pump stations 2008

L.I	Shuwaikh	Shuaiba	Doha	Az-Zour	Sabiya
Min.	-0.03	-0.12	-0.04	-0.03	-0.01
Max.	-0.62	-1.08	-0.36	-0.62	-0.59
Mean.	-0.335	-0.60	-0.16	-0.325	-0.29

Table 5: Summary of the mean values of the total alkalinity of the main pump stations during 2008

Pump station	Mean values of T. Alk. (mg L^{-1})	Recarbonation process
Shuwaikh	45.91	Applied
Shuaiba	21.40	Not applied
Doha	38.10	Applied
Az-Zour	28.82	Applied
Sabiya	53.78	Applied

Distilled water from MSF distillation plants is acidified in an absorption tower using CO_2 gas. The acidified water is then augmented by bicarbonate ions using $CaCO_3$ in a number of limestone dissolution filters.

The excess CO_2 presents in the recarbonated water leaving the limestone dissolution filters is degasified in a stripping tower using air. The degasifier is a packed counter flow type stripping tower. At the bottom of the tower, air is distributed to remove the CO_2 gas. Finally, 15wt% solution of caustic soda is dosed into the water stream for the final adjustment of pH value to about 8.0. It can be observed that this recarbonation process resembles the natural carbonation process taking place in aquatic system.

The recarbonated water leaving the limestone dissolution filters contains some excess of CO_2 and very little dissolved oxygen and is therefore fed to a stripping tower. By direct counter current contact with air, more oxygen can be dissolved and the pH value can be slightly controlled by the flow rate of air. The stripping tower is packed with the same material as the absorption tower and is designed with a diameter of 2.6 m and a height of about 7.7 m respectively.

Calculation of langelier index: Several methods can be used to determine the calcium carbonate stability of water. A common method is the Langelier Index. This index is equal to the measured pH (of the water)-the pH (saturation). The pH_s is a theoretical value in which calcium carbonate will neither be dissolved into nor precipitated from water. Therefore, if $pH-pH_s = 0$, the water is in equilibrium and will neither dissolve nor deposit calcium carbonate on the pipes. If $pH-pH_s>0$ (positive value), the water is not in equilibrium and will deposit calcium carbonate on the surface of mains and other fixtures. If $pH-pH_s<0$ (negative value), the water is not in equilibrium and will dissolve the calcium carbonate it contacts. No coating will be deposited on the distribution pipes. However, if the pipes are not protected, they may be corroded (AWWA, 1985). To calculate the Langelier saturation index, the following expression can be used (WRDC, 1999):

$$S.I. = pH\ (actual) - pH_S \quad (2)$$

and

$$pH_S = A + B - \log(Ca^{2+}) - \log(Alk.) \quad (3)$$

Where:

A = A constant, based on the temperature
B = A constant, based on the TDS of water
Ca^{2+} = Calcium ion concentration (mg L^{-1} as $CaCO_3$)
Alk. = Alkalinity (mg L^{-1} as $CaCO_3$)

The negative value of the Langelier Index indicates the corrosivity of the water, while the positive value shows that the water is a scale forming.

The calculations of the Langelier Index (based on the Eq. 2) of the water samples collected from the main pump stations of Shuwaikh Shuaiba, Doha, Az-Zour and Sabiya for the year 2008 were carried out and displayed in Table 4.

The fluctuation in the Langelier Index values depends on the variation of the total Alkalinity dosage in the distilled water, as it's presented in Table 5. Moreover, the Langelier Index values indicate the importance of the application of the recarbonation process, in order to reduce the corrosivity of the drinking water in the network. However, it is noticed that Shuaiba drinking water is more corrosive (the mean value of the Langelier Index is-0.6), than the drinking water in the other pump stations (Shuwaikh, Doha, Az-Zour and Sabiya).This is due to the fact that the recarbonation process has not yet been applied in the Shuaiba distillation Plant.

CONCLUSION

Kuwait produces its drinking water using the Multi-Stage-Flash Method (MSF) in distillation plants to produced distilled water from sea water. The distilled water produced is blended with the brackish groundwater, in order to produce drinking water in accordance with the World Health Organization (WHO) guidelines. The mixing operation takes place in the blending plants or blending lines to get the best quality of drinking water. Based on the data collected during 2003-2008 from the MEW, the range of the blending ratios was from 6.1-13.7% in Shuwaikh blending plant. From 2.3-14.1% in Shuaiba blending plant. From 2.9-

15% in Doha blending plant. From 1.7-6.4% in Az-Zour blending lines. And from 4-5% in Sabiya blending lines. This information indicates that the produced drinking water in Kuwait is rated as an excellent/good according to the WHO guidelines.

Accordingly, to obtain an excellent quality of the drinking water, where the TDS<300 mg L^{-1}, water samples from all the blending plants and lines at different blending ratios have been collected and analyzed for 18 months during 2007-2008. It is found that the best blending ratio for Shuwaikh is between 7 and 8%, for Shuaiba is between 8 and 9%, for Doha is 8%, for Az-Zour is from 3-4% and for Sabiya is between 4 and 5% respectively.

In Kuwait, the produced distilled water is proved to be corrosive and causing red water problem. The recarbonation plant was established in 1987 and designed to yield recarbonated water with a total alkalinity of 60-80 mg L^{-1} as $CaCO_3$. Accordingly water samples collected from the main pump stations to calculate the Langelier Index, to reveal the corossivity of the drinking water.

It is found from the Langelier Index values, that all the drinking water is slightly corrosive, in which the range of the mean values of the total alkalinity is from 21.4-53.78 mg L^{-1} as $CaCO_3$, where the designed total alkalinity was recommended to be from 60-80 mg L^{-1} as $CaCO_3$. Also, it is found that the mean value of the Langelier Index at Shuaiba pump station is (-0.6) and the mean value of the total alkalinity is 21.4 mg L^{-1} as $CaCO_3$, which reveals that the Shuaiba drinking water is more corrosive than the drinking water in the other pump stations. This is due to the fact that the recarbonation process has not yet been applied in the Shuaiba distillation plant. Also it indicates the importance of the application of the recarbonation process to reduce corrosivity of the drinking water in the distribution networks.

Recommendations: One of the major factors for an excellent operation and improving the quality of the drinking water in Kuwait is to control the blending ratios between the distilled water and the brackish groundwater. Therefore, the following recommendations should be taken into consideration:

- To apply the best blending ratios which were determined in the blending plants or lines during this study. In Shuwaikh the blending ratio is from 7-8%, from 8-9% at Shuaiba and 8% at Doha respectively. Whereas the best blending ratio at Az-Zour is between 3% and 4% and in the range of 4-5% at Sabiya
- The bicarbonate content in the distilled water should be increased to prevent the corrossivity of the produced drinking water
- The total alkalinity as $CaCO_3$ should be in the range of 60-80 mg L^{-1}, as a designed value
- The recarbonation process should be applied in Shuaiba distillation plant and all new distillation projects in Shuaiba north, Az-Zour north and Sabiya plants. In order to prevent the accumulation of red oxides (red water) in the drinking water system
- The static mixers should be used in the blending plants of Shuwaikh and Shuaiba respectively, to obtain a chemically homogeneous product ,and to control the produced drinking water quality to the desired values and smooth operation

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