Asian Journal of Chemistry; Vol. 23, No. 8 (2011), 3334-3338

ASIAN JOURNAL OF CHEMISTRY

www.asianjournalofchemistry.co.in

Study of Andimeshk's Drinking Water Resources in Iran

G. BADALIANS GHOLIKANDI[1,*], M. AHMADI[2], S. HADDADI[3] and E. DEHGHANIFARD[4]

[1]Power and Water University of Technology/Water Research Institute, Tehran, Iran
[2]Department of Environmental Health, Ahwaz Jundishapour University of Medical Sciences, Ahwaz, Iran
[3]Faculty of Environment, University of Tehran/Water & Wastewater Research Center, Water Research Institute, Tehran, Iran
[4]Environmental Health Engineering Department, School of Public Health, Iran University of Medical Sciences, Tehran, Iran

*Corresponding author: Fax: +98 21 77000306; Tel: +98 21 77000919; E-mail: g.badalians@yahoo.com

(*Received*: 7 May 2010; *Accepted*: 11 April 2011) AJC-9796

This study was conducted to evaluate the application of different indices for the quality evaluation of eight groundwater resources of Andimeshk city on three months. Six corrosion indices of Langelier saturation index, Ryznar (saturation) index, calcium carbonate precipitation potential, Puckorius scaling index, Aggressiveness index and Larson-Skold corrosive index, were determined. Most of these resources had a high amounts of sulfate and affected the Laurence corrosion index, however were not exceeded the WHO standards. In the view of Larson-Skold corrosive index these water resources are corrosive for water facilities affected by chloride and sulphate, such as mild steel facilities. This index caused different results among other indices. From other indices, Ryznar (saturation) index and Puckorius scaling index indices showed different results among other indices and while other indices defined some resources as a non-corrosive, Ryznar (saturation) index and Puckorius scaling index predicted as a corrosive. In just one of the water resources, all the six indices had same results (moderately corrosive). Application of one index may not be able to predict water corrosivity, some factors such as water quality and water installation material should be regarded too. Some of those resources had high amounts of nitrate and phosphate which were contaminated by agricultural and domestic wastewaters.

Key Words: Aggressive indices, Water quality, Andimeshk city, Corrosion.

INTRODUCTION

Providing sufficient quantities of freshwater, which are important for life survival, are in short supply in many regions of the world[1]. Generally, the water required for domestic consumption should possess a high degree of purity and it should be free from suspended and dissolved impurities, bacteria, *etc*.[2]. Essential elements are provided by water, but when polluted it becomes the source of undesired substances dangerous to human health[3]. Groundwater is important as a water resource and is the primary source of water supply for many countries in the world. Italy, Germany and Oman, for example, all rely on groundwater for over 85 % of their water supply. Austria relies on groundwater for over 95 % of its supply. California and Canada, for comparison, derives 30 and 25 % of their supply from groundwater in an average year. Although many municipalities are entirely dependent on groundwater[4,5]. Groundwater has excellent natural quality, usually free from pathogens, colour and turbidity and can be consumed directly without treatment. However, groundwater quality is highly dependent on the nature of the aquifers[6,7], use of land (*e.g.* mining and agricultural activities)[8-11], domestic and industrial discharges[8,10] and on the ambient climatic conditions[6]. The chemical quality of groundwater is a measure of its suitability as a source of drinking water and for other purposes and also influences ecosystem. Changes in quality of groundwater with subsequent contamination can, undoubtedly, affect human health[12].

The physical and chemical quality of water could affect on water facilities by corrosion or sedimentation on them and those problems could affect on water quality.

Some of common problems arising in pipelines transporting terrestrial waters are corrosion and/or aggression and therefore afterward economic cost, operational, structural failures, health and aesthetics problems[13,14]. The effect and intensity of that depends on the water quality and also the pipe substance[15]. Some important factors which affect on that could be noticed as environmental and microbial parameters, temperature, pH, velocity, pipe substance, the oxygen concentration, the kind and concentration of chlorine, concentrations of chloride, sulphate, carbon and mineral calcium[16]. The corrosion causes the entrance of pipe substances into water and this problem could affect the water quality. The water corrosion problem has been one of the important problems in water facilities. Therefore, some efforts have been done for predicting this parameter which has caused to creation of indices to define the water quality.

Using corrosion indices is a simple numerical way to predict the quality of water in terms of corrosion. Indices based on calcium carbonate saturation are useful in connection with the corrosion of unlined iron pipe and cementitious materials. These indices include Langelier saturation index (LSI) or Langelier index (LI), calcium carbonate precipitation potential (CCPP) and Ryznar (saturation) index (RSI)[16]. Other indices of corrosion are Puckorius scaling index (PSI), Larson-Skold corrosive index (LSCI), Stiff-Davis index (SDI), Oddo-Tomson index (OTI) and AWWA Aggressiveness index (AWWAI) or AI[17]. Corrosion indices can be applied as a management tool for potential determination of corrosion in water sedimentation and also solving the problem of this phenomenon. In many cases, regardless of water quality and facility materials, one or number of indices is chosen and the decision will be made based on their results. Current indices, which have been used for determination of corrosion potential, comprise specific parameters with different impact factors. However, some of those parameters may be similar. The index selection is sometimes depended on data availability of water quality and simplicity in index calculations. In this study, several indices were chosen for determination of corrosion potential, of Andimeshk water resources and results were compared to show importance of index selection.

EXPERIMENTAL

Andimeshk city with the area of 3120.5 km^2 is located in the west of Khuzestan province and its population is about 180,000 people. The drinking water resource of this city is supplied from 8 springs which are Kooy Lour springs (No. 2, 3 and 4), Kooy Shohada (No. 3, 6 and 8) and Kooy Niroo (No. 9 and 10) springs. Table-1 shows detailed information of those springs. The length of water supply network of this city is 250,000 m. Water of springs enters to the network after chlorination.

This study was conducted in three months (August to October) of 2007. Sampling and analyses were in accordance with standard methods for the examination of water and wastewater.

Corrosive indices: As mentioned above, different indices have been used for determining the water corrosion. From those, six famous indices of LSI, RSI, PSI, LSCI, CCPP and AI were chosen for the water resources of Andimeshk city. Table-2 compares these indices and delineates relationship between values of them and corrosion intensity.

The Langelier saturation index (SI) is described as the difference between the actual pH of the water and the saturation pH:

$$SI = pH - pH_s$$

$$pH_s = pCa^{2+} + pAlk + (pK_2 - pK_s)$$

where pH_s (the saturation pH) is the pH at which, with no change of alkalinity, calcium content or dissolved solids, the water would neither deposit nor dissolve calcium carbonate; the other terms are as follows[18]:

pCa^{2+} is the negative logarithm of the calcium concentration, expressed as mg $CaCO_3$/L, pAlk is the negative logarithm of the alkalinity to methyl orange, expressed as mg $CaCO_3$/L, pK_2 is the negative logarithm of the ionization constant of HCO_3^- and pK_s is the negative logarithm of the solubility product of $CaCO_3$. The Ryznar index, a more sensitive formula for predicting calcium carbonate scale formula, is also known as the Ryznar stability index (RSI). The formula is: $2pH_s - pH_{actual}$. The indices can also been used to estimate the degree of calcium carbonate scale which will form in drinking water and in cooling water. By more positive the LSI value, the more the scale will form; however, for the RSI, the smaller the index, the greater the scale formation. The LSI and RSI can give contradictory predictions based on the same water quality information[19].

The calcium carbonate precipitation potential (CCPP), as a water stability index, is more reliable to use since this index provides a quantitative measure of the calcium carbonate deficit or excess of the water, giving a more accurate guide as to the likely extent of $CaCO_3$ precipitation. Previously, CCPP has been less usual due to time-consuming the longhand calculation procedure and quite tiresome. The AWWA (1996) released a PC-based spreadsheet program based on the Rothberg, Tamburini and Winsor model, which allows fast calculation of a number of corrosivity indices, including CCPP. The program also allows calculation of the effects of various chemical additions to water[20].

Unlike other indices which ignore the buffering capacity of the water and the maximum quantity of precipitate that can form in bringing water to equilibrium; The PSI attempts to quantify the relationship between saturation state and scale formation by incorporating an estimate of buffering capacity of the water into the index. This index is similar to the RSI; however the pH_{eq} is used instead of the pH[21].

TABLE-1
CHARACTERISTICS OF WATER RESOURCES

Well No.	2 Lour	3 Lour	4 Lour	3 Shohada	6 Shohada	8 Shohada	9 Niroo	10 Niroo
Depth (m)	100	110	110	100	103	103	108	110
Optimum flow rates of pumps (m^3/h)	100	190	200	100	200	240	240	200

TABLE-2
COMPARISON OF COMMON STABILITY INDICES [Ref. 22]

Stability characteristics	LSI	AI	LSCL	CCPP as mg/L $CaCO_3$	RSI & PSI
Highly aggressive	<-2.0	< 10.0	> 1.2	< -10	> 10.0
Moderately aggressive	-2.0 to < 0.0	10.0 to < 12.0	0.8 to < 1.2	-10 to -5	6.0 to < 10.0
Non-aggressive	> 0.0	> 12.0	< 0.8	> -5	< 6.0

$$PSI = 2\,(pH_s) - pH_{eq}$$

where: $pH_{eq} = 1.465 \times \log 10\,(\text{Alkalinity}) + 4.54$

The LSCI index is partly higher than other indices and considers effects of parameters like chloride and sulfate in the corrosion amount. The index is the ratio of equivalents per million (epm) of sulfate and chloride to the epm of alkalinity in the form bicarbonate plus carbonate[21]:

$$\text{Larson-Skold index} = \frac{(\text{epm } Cl^- + \text{epm } SO_4^{2-})}{(\text{epm } HCO_3^- + \text{epm } CO_3^{2-})}$$

The Aggressive index (AI), sometimes replaced with the Langelier index as a water corrosion index, is originally developed for monitoring water in asbestos pipe. The AI includes the actual pH, calcium hardness and total alkalinity. In general, it is more applicable and convenient than the LI. The AI is less accurate as an analytical tool than the LI, because the AI does not include the effects of temperature or dissolved solids[22].

$$\text{Aggressive index (AI)}^{22} = pH + \log \text{Calcium hardness} + \log \text{Total alkalinity}$$

In this study, the EXCEL and SPSS15 software were used in order to simplify the calculation of some complicated formulas.

RESULTS AND DISCUSSION

Quality of drinking water in Andimeshk city: Table-3 shows ranges of measured parameters and their standard limits in accordance with world health organization (WHO). Although nitrate and phosphate amounts were more than standards, other parameters were in standard range. The nitrate limit must be less than 50 mg/L (WHO standard), however springs No. 3 and 4 of Kooy Lour and No. 3 and 6 of Kooy Shohada exceeded the standard and even were double. Nitrate pollution is one of the important problems in groundwater. One of the main resources of this pollution is using agricultural fertilizers in soil. These water resources had a high amount of nitrate due to fertilizer usage in soil. Nitrate is not very dangerous, however may cause the Methemoglobine disease due to nitrate reduction to nitrite in children bodies.

The amount of phosphate in springs No. 2 and 4 of Kooy Lour and No. 8 of Kooy Shohada exceeded the standard limit (0.2 mg/L). These polluted springs, except spring No. 4 of Kooy Lour, were different from polluted springs by nitrate. Moreover, the correlation analysis showed no relation between nitrate and phosphate amounts in polluted springs; while the phosphate amount had a significant counter correlation with alkalinity (the correlation coefficient of 0.604). It seems that the phosphate pollution was due to natural resources which may be increased by alkalinity increasing and therefore more solubility of phosphate may occur in water. In other hand, phosphate pollution may not cause from manmade activities, so its initial resources may differ from nitrate resources.

Corrosivity of water resources: The problem in the corrosion of iron and steel pipes is the wall corrosion of pipes and pollutant entrance to water. In the concrete pipe, the corrosion affects on its lime and caused the lime entrance and pH increasing in water. These effects vindicate the corrosion control in water facilities. The prerequisite of the corrosion control is corrosion prediction. Application of water indices is helpful due to their feasibility. However, each corrosion index doesn't comprise all effective factors of the corrosion. In this study, six corrosion indices of LSI, RSI, CCPP, PSI, AI and LSCI were used for determining the corrosion potential in water resources of Andimeshk city which were eight springs. In almost all the resources, three indices of LSI, CCPP and AI had same results and RSI and PSI indices had different results and also the LSCI index had very different results from other indices. However, all results of six indices were the same in one spring. The quality of water has an important effect on the index selection. Moreover, it was showed that if the total amount of chloride

TABLE-3
WATER QUALITY PARAMETERS IN THE WATER SAMPLES (MEAN VALUES±STANDARD DEVIATION)

Parameter	2 Lour	3 Lour	4 Lour	3 Shohada	6 Shohada	8 Shohada	9 Niroo	10 Niroo	WHO guidance
Free Cl_2 (mg/L)	0.0±0.0	0.1±0.2	0.1±0.1	0.0±0.0	0.2±0.4	0.1±0.2	0.0±0.0	0.1±0.2	
TDS (mg/L)	193±5.8	417±5.8	387±40	397±15	467±5.8	340±10	317±15.3	350±20	500
EC (µS/cm)	403±6	840±10	770±70	797±32	950±10	687±21	670±17	743±11	
Turbidity (NTU)	0±0	0±0	0±0	0±0	0±0	0±0	0.7±1.2	0±0	
pH	7.7±0.0	7.6±0.0	7.4±0.0	7.5±0.0	7.6±0.0	7.6±0.0	7.8±0.0	7.8±0.1	6.5-8.5
Temperature (ºC)	25.7±0.6	25.7±0.6	26.0±1.0	25.7±0.6	26.7±0.6	25.7±0.6	25.8±0.8	25.7±1.5	
NH_3 (mg/L)	0.01±0.00	0.05±0.00	0.01±0.00	0.02±0.01	0.07±0.03	0.03±0.02	0.01±0.00	0.03±0.01	
NO_2^- (mg/L)	0.02±0.01	0.02±0.00	0.02±0.00	0.02±0.01	0.02±0.00	0.02±0.00	0.02±0.00	0.02±0.00	3
NO_3^- (mg/L)	44.2±0.9	108.2±8.7	55.3±14.0	67.5±10.3	74.7±2.0	42.2±1.6	41.5±1.1	38.1±2.8	50
PO_4^{3-} (mg/L)	0.27±0.02	0.17±0.08	0.26±0.03	0.13±0.03	0.19±0.03	0.29±0.03	0.10±0.00	0.19±0.02	
SO_4^{2-} (mg/L)	23.0±1.7	152±3.5	175±0.0	167±14.4	213±20.2	200±0.0	158±14.4	158±14.4	250
I^- (mg/L)	0.10±0.00	0.07±0.02	0.10±0.01	0.11±0.02	0.08±0.01	0.11±0.10	0.12±0.01	0.07±0.02	
Cl^- (mg/L)	11.3±1.2	11.7±1.5	16.0±4.4	70.7±2.1	6.3±0.6	10.3±0.6	22.0±2.6	28.7±2.5	250
F^- (mg/L)	0.17±0.03	0.20±0.01	0.21±0.04	0.28±0.16	0.35±0.07	0.27±0.03	0.26±0.02	0.23±0.02	2
Alkalinity (mg/L as $CaCO_3$)	68.7±11.0	226±5.1	149±3.6	206±22.9	186±1.7	92.3±6.7	140±2.1	171±11.5	
Cl + SO_4 (mg/L)	34.3±2.5	164±2.1	191±4.4	237±15.1	220±20.5	210±0.6	180±16.3	187±12.2	
Total hardness (mg/L as $CaCO_3$)	170±4	380±2	320±17	359±19	434±3	324±8	299±1	340±2	
Mg^{2+} (mg/L)	12.8±1.2	33.5±0.7	24.0±2.5	30.3±2.1	37.2±0.4	25.0±0.3	24.4±3.6	30.8±0.8	
Fe^{2+} (mg/L)	0.10±0.14	0.02±0.00	0.02±0.02	0.02±0.01	0.03±0.01	0.020±0.02	0.05±0.01	0.01±0.01	0.3
Mn^{2+} (mg/L)	0.07±0.11	0.01±0.01	0.01±0.01	0.00±0.00	0.03±0.06	0.00±0.00	0.01±0.0	0.17±0.06	0.05
Cu^{+2} (mg/L)	0.01±0.00	0.37±0.08	0.21±0.15	0.14±0.01	0.84±0.05	0.18±0.02	0.04±0.01	0.05±0.03	1.3
Cr^{6+} (mg/L)	0.07±0.00	0.07±0.01	0.06±0.01	0.07±0.01	0.06±0.01	0.05±0.01	0.05±0.01	0.07±0.01	0.1

and sulfate in a water resource is over 50 ppm, water has a corrosion potential. In this study, results of LSCI index are in accordance with that research, for all water resources.

Scaling indicators were not suitable to measure corrosive tendencies of mild steel or other metals, but rather to describe the degree of aggressiveness towards calcium carbonate scale. In fact, they have little or no consideration to chloride and sulfate content, among the most widely recognized contributors to corrosion[23]. The LSCI index has solved this defect and considers the concentration of chloride and sulfate along with carbonate and bicarbonate concentration (preservative ions against corro-sion) for the corrosion determination and prediction.

The presence of Cl^- and SO_4^{2-} in water tends to sustain corrosion by preventing protective film formation. It increases electrical conductivity of water, facilitates the flow of corrosion current and simultaneously, hinders the creation of protection layers.

Chloride and sulfate are common parameters in water. Chloride ion is the strongest among the salt ions of water. chloride creates dissolving salts with most of metals and therefore protection layers made of corrosion products are not created[24]. Chloride enhances the corrosion of iron and other metals, based on the alkalinity of the water. It is assumed that chloride will take the place of oxygen in any corrosion process, as it is an effective oxidizing agent. Sulfate usually creates from dissolution of mineral sulfates in soils and rocks. Excessive concentrations of sulfate increase the corrosion rate of metals. Also, sulfate may enter in the reaction with some of minerals in the cement matrix to form products that cause physical distribution of the matrix[15].

Because of low variations of indices and consequently no effect on corrosion conclusions, the mean values of them have been shown in Fig. 1. This figure shows that the Lour spring (No. 2) was moderately corrosive. Other springs were non-corrosive based on LSI, CCPP and AI indices, however were moderately corrosive based on RSI and PSI indices. Although all water resources except the Lour spring were highly corrosive, the equivalent ratio of the total ions of chloride and sulfate divided by the carbonate and bicarbonate ions was more than 1.2. In regard to the total concentration of chloride and sulfate which was more than 50 ppm, it could be concluded that these water resources had corrosion potential.

Conclusion

The easiest way for corrosion prediction in water resources is using corrosion indices, although wrong selection of the corrosion index may cause facility destruction or impose heavy costs, due to unnecessary decisions. Using different indices for water resources caused different and even repugnant results which are depends on the quality of water and soluble contents. Therefore, each index can be used in a specified condition. However, using several indices can cause better conclusion about the quality of water.

By assessing the quality of Andimeshk water resources with considered indices, it could be concluded that the LSCI index caused different results from other indices, due to including chloride and sulfate ions for corrosion prediction. However, some water resources had same quality for corrosion. In water resources which had high concentrations of chloride and sulfate ions, results of the LSCI index were different from other indices which were considered calcium carbonate sediments. In the view of LSCI these water resources are corrosive for water facilities affected by chloride and sulphate, such as mild steel facilities.

Therefore, it is not enough to use one index to conclude whether the water is aggressive or not. To detect the corrosion property of water, water quality and water installation materials also should be taken into consideration. Proper selection of corrosion indices and prediction of corrosion potential is important due to health, economical and environmental aspects. Moreover, Corrosion indices could be used as guidance for better selection of water facilities.

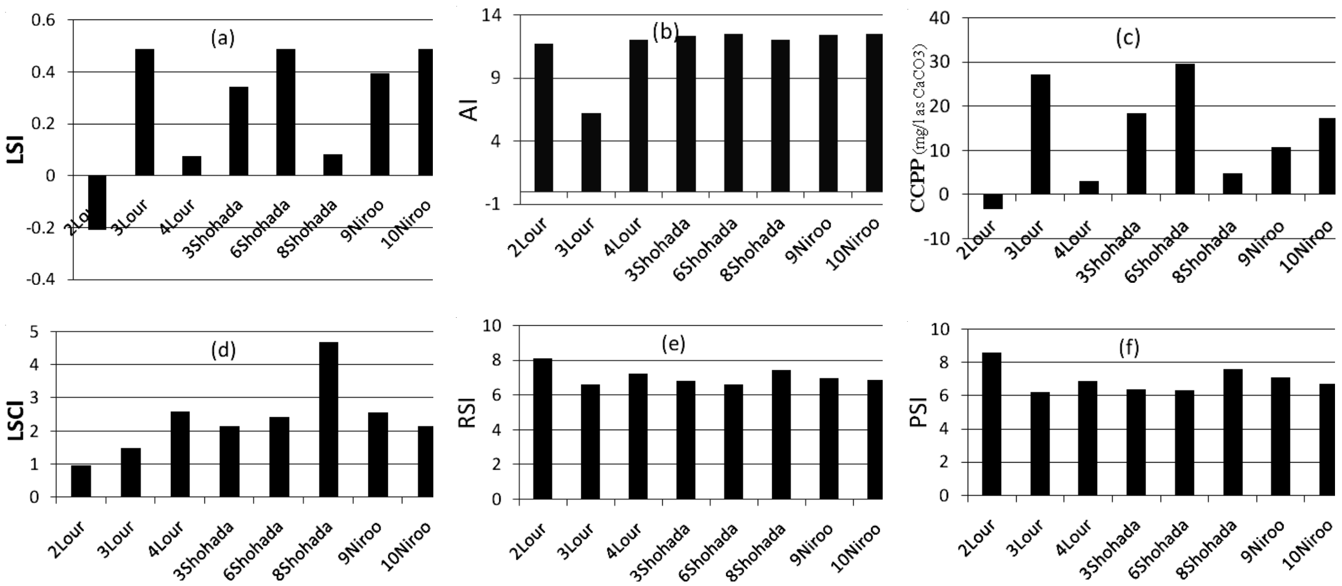

Fig. 1. Mean values of corrosion indices in Andimeshk's drinking water resources, (a) LSI, (b) AI, (c) CCPP, (d) LSCI, (e) RSI, (f) PSI

REFERENCES

1. D. Pimentel and M. Pimentel, *Ecol. Econom.*, **59**, 195 (2006).
2. P. Alexander, *Afr. J. Biotechnol.*, **7**, 1712 (2008).
3. S. Karavoltsos, A. Sakellari, N. Mihopoulos, M. Dassenakis and M.J. Scoullos, *Desalination*, **224**, 317 (2008).
4. D.L. Rudolph, D.A.J. Barry and M.J. Goss, *J. Contamin. Hydrol.*, **32**, 295 (1998).
5. M. Anthony, 24th Biennial Groundwater Conference Resources Association of California (2003).
6. A.G. Olufemi, O.O. Utieyin and O.M. Adebayo, *J. Water Resour. Protect.*, **2**, 849 (2010).
7. A. Saleh, F.M. Al-Ruwiah and M. Shehata, *J. Arid Environ.*, **49**, 761 (2001).
8. N. Rangsayatorn, *Naresuan Univ. J.*, **14**, 1 (2006).
9. S. Fetouani, M. Sbaa, M. Vanclooster and B. Bendra, *Agric. Water Manag.*, **95**, 133 (2008).
10. D.-L. Dong, Q. Wu, R. Zhang, Y.-X. Song, S.-K. Chen, P. Li, S.-Q. Liu, C.-C. Bi, Z.-Q. Lv and S.-L. Huang, *J. China Univ. Mining Technol.*, **17**, 73 (2007).
11. A. Papaioannou, P. Plageras, E. Dovriki, A. Minas, V. Krikelis, P.T. Nastos, K. Kakavas and A.G. Paliatsos, *Desalination*, **213**, 209 (2007).
12. C. Tay and B. Kortatsi, *West Afr. J. Appl. Ecol.*, **12**, (2008).
13. R.E. Lowental, I. Morison and M.C. Wentzel, *Water Sci. Technol.*, **49**, 9 (2004).
14. A. Dietrich, D. Glindemann, F. Pizarro, V. Gidi, M. Olivares, M. Araya, A. Camper, S. Duncan, S. Dwyer, A. Whelton, T. Younos, S. Subramanian, G. Burlingame, D. Khiari and M. Edwards, *Water Sci. Technol.*, **49**, 55 (2004).
15. R. Loewenthal, I. Morrison and M. Wentzel, *Water Sci. Technol.*, **49**, 9 (2004).
16. H.M. Müller-Steinhagen and C.A. Branch, *Can. J. Chem. Eng.*, **66**, 1005 (1988).
17. V.A. Prisyazhniuk, *Appl. Thermal Eng.*, **27**, 1637 (2007).
18. J.A. Wojtowicz, *J. Swimming Pool Spa Ind.*, **3**, 24 (2001).
19. S. El-Manharawy and A. Hafez, *Desalination*, **139**, 91 (2001).
20. P. Gebbie, 63rd Annual Water Industry Engineers and Operators Conference Brauer College-Warrnambool, p. 50 (2000).
21. D.D. Ratnayaka, M.J. Brandt and K.M. Johnson, Specialized and Advanced Water Treatment Processes, Water Supply, pp. 365-423 edn. 6, (2009).
22. http://www.hach.com/fmmimghach?/CODE%3AEX_LANGAGG 1428|1.
23. C.C. Chien, C.M. Kao, C.W. Chen, C.D. Dong and H.Y. Chien, *Environ. Monit. Assess.*, **153**, 127 (2009),
24. A.E. Al-Rawajfeh and E.M. Al-Shamaileh, *Desalination*, **206**, 169 (2007).

Prof. (Dr.) Ram K. Agarwal, Editor-in-Chief, Asian Journal of Chemistry presenting a copy of Asian Journal of Chemistry to Prof. (Dr.) Falah H. Hussein, Babylon University, Hilla, Iraq.