International Journal of Water Resources and Arid Environments 3(1): 11-18, 2014
ISSN 2079-7079

Waste Water Sterilization by Cobalt Co-60 for the Agricultural Irrigation: A Case Study

[1]S. Sabbagh, [2]A.S. El Mahmoudi and [2]Y.Y. Al-Dakheel

[1]Teachers College, King Faisal University, KSA
[2]Water Studies Center, King Faisal University, KSA

Abstract: The aim of this paper is to study of establishment a fourth stage of the secondary and tertiary treatments plant for sterilization wastewater. This will reduce the biological loading including vital viruses and parasite eggs by usage of gamma radiation of the Cobalt-60 (^{60}Co-γ) (1.16 Me.V and 1.33 Me.V. The cobalt can't make artificial radiation; therefore it is safe and cheap to solve the chemical treatment problems and to avoid chlorine components in the environment. In this comparative study it was completed between the electron rays (e-beam), UV lamps, ozone unites, chlorine, mechanical regimes treatment and gamma rays for sterilization of both of wastewater and sludge samples from Al Hofuf wastewater treatment plant with determining advantages and disadvantages for each of these sterilization methods and the location where it should to be applied. It was found that a 16.2 kGy dose is generally suitable for the wastewater sterilization and it could be raised to above 25 kGy in case of only secondary treatment stage is applied and 27 kGy for sludge (SAL= 10^{-6}). This will reduce the chlorine poisons and the waste of livestock chicken and fishes and the industrial dismissal in the environment. Also it was clarified the biological reason behind of not applying these sterilization methods outside the experimental plants by studying the plant stages of the secondary and tertiary treatment in Al Hofuf, Saudi Arabia, which it was to let the aerobic bacteria to feed on organic material in wastewater and then the subsequent processing stages in the sedimentation downstream and using the irradiation first at the entrance of the station prevent to take advantage of that. This study demonstrated the potential of ionizing radiation to disinfect sewage and sludge and to increase the water quality in the wastewater by lowering the total heterogeneous bacteria.

Key words: Sterilization · Wastewater treatment · Water reuse · Sludge · Gamma-irradiation · Cobalt-60 · e-beam · UV · Al Hofuf · Saudi Arabia

INTRODUCTION

Water resources are essential and play a significant role in the development processes. The Kingdom of Saudi Arabia (KSA) is known by its arid conditions and limited renewable freshwater resources. Surface water in KSA is very limited and of a little significance in the water budget of KSA. To meet the increasing water demands in domestic, industrial and agricultural sectors, various alternative supplies are surface water, renewable groundwater resources, treated wastewater, desalinated water and non-renewable groundwater.

Al Hassa Oasis is one of the main and old agricultural centers in Saudi Arabia. Al Hassa oasis with an area of 20,000 hectares is located 70 km west of the Arabian Gulf (Fig. 1). An irrigation network of 1,450 Km of concrete canals and drainage network were put into operation in 1971 [1]. This irrigation project delivers 328 million m^3 of groundwater for about 22, 000 farms. Nowadays, Al Hassa Oasis, face shortage of water resources seriously. The present pumped groundwater amount is not enough to meet the increasing demand on the water and the alternative to solve this problem is to reuse wastewater from Al Hofuf sewage plant after treatment. Therefore, the treatment and re-utilization of industrial and life wastewater are even more important.

With increasing interest in wastewater reuse and in disinfection techniques that reduce the toxicological impact of wastewater to the environment [2], alternatives to chlorine are being studied. One such alternative is radiation processing [3, 4]. It appears that both gamma and electron beam irradiation offer alternatives that insure disinfection and may have the added benefit of increasing the water quality by reducing the chemical constituents

Correponding Author: S. Sabbagh, Teachers College, King Faisal University, KSA. E-mail: said-sabbagh@hotmail.com

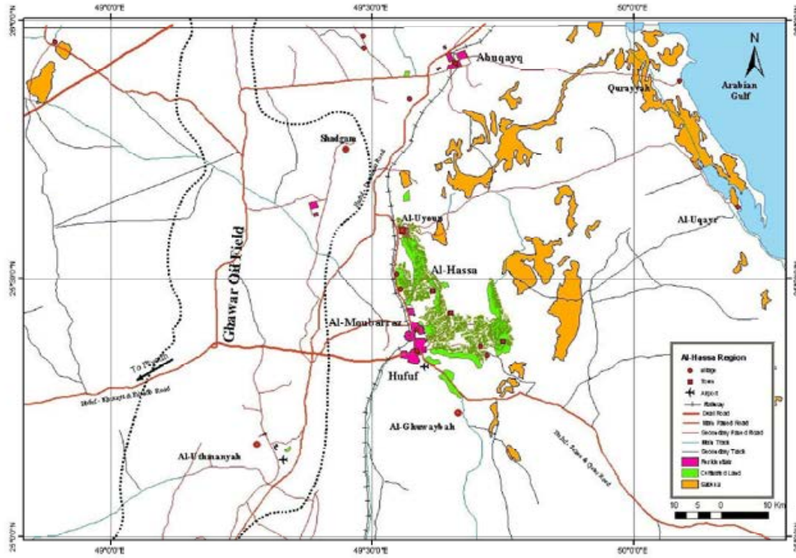

Fig. 1: Base map of Al Hassa Oasis and Al Hofuf Town.

such as the biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC), all at the same time. There have been numerous studies reported in this area [5-13]. Treatment of sludge using irradiation has also been studied (for example, [14-17].

Radiation treatment has also been suggested as a way to pre-treat groundwater in extraction wells as it is pumped up [18]. In addition to disinfection, they showed that the irradiation of groundwater using ^{60}Co (in situ) served two purposes, reduction of biofouling of the wells and removal of cyanide and COD in the water. One of the main reasons for exploring this new technology was to provide an alternative to chlorination for disinfection. There are three reasons that are cited for attempting to find a substitute for chlorine: (1) its toxicological effects to aquatic organisms; (2) the inefficiency of chlorine to remove viruses from wastewater; and (3) the formation of by-products by the combination of chlorine and inorganic ammonia, forming chloramines and /or organic material in the waste, forming organohalogen compounds such as trihalomethanes and haloacetic acids.

There are many kinds of methods of wastewater treatment. Compare with other techniques, the method of applying of ionizing radiation has its special properties and advantages [19]. For example, it can treat some organic systems which are difficult to be degradated biologically and does not cause secondary pollution. There is no trace of polluted materials left in the wastewater after degradation finally. Moreover, the irradiation technique is especially effective for sterilization and killing bacteria.

The combined methods of radiation technique with other methods were also studied [20-23]. Hence, the utilization of radiation technique (including ^{60}Co-γ irradiation, electron beam and UV radiation, etc.) in wastewater treatment is drawing more and more attention around the world.

In present study, ionizing radiation is used as a method for wastewater treatment by the use of irradiation, so as to provide valuable experimental data for the future application of irradiation in the environmental protection in Al Hassa as a case study. The wastewater treatment plant of Al Hofuf is the biggest wastewater treatment plant in the area. The amount of tertiary treated water from Al Hofuf plant is about 70000 cubic meters per day while the amount of treated water from the secondary stage is about 130000 cubic meters per day.

The objective of this study was to determine the effectiveness of gamma irradiation in the disinfection of wastewater/sludge and the improvement of the water quality by studying the inactivation of microorganism in the wastewater and sludge with irradiation at different doses on samples from Al Hofuf municipal wastewater treatment plant.

MATERIALS AND METHODS

Irradiation: The studies were conducted using a laboratory scale ^{60}Co gamma source. The irradiations were conducted at 25 °C using ^{60}Co Gamma Cell 220 from MDS-Nordion-Canada International available at Institute of Atomic Energy Research, King Abdulaziz City for Science

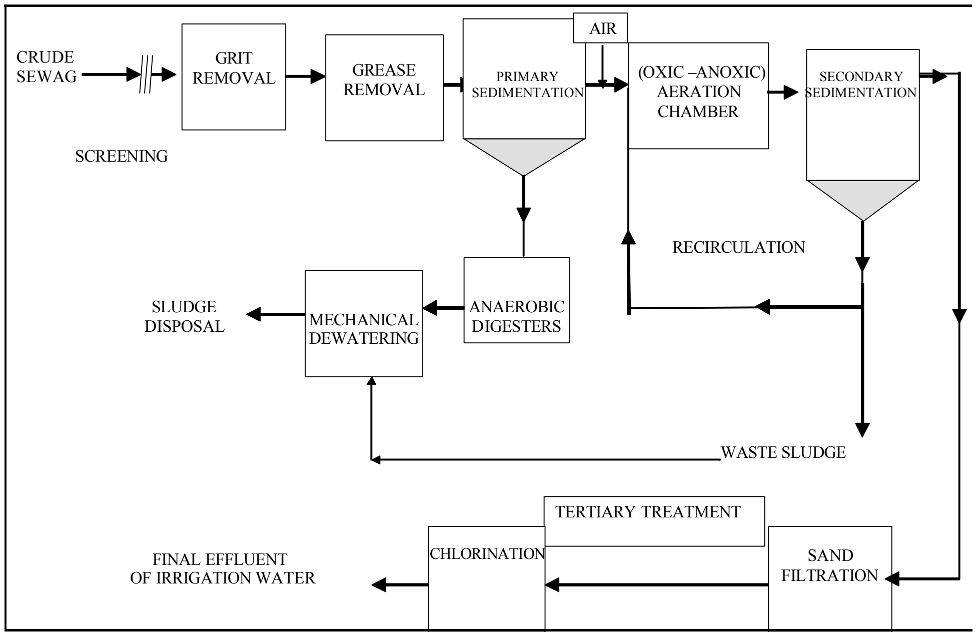

Fig. 2: Schematic of the Wastewater Treatment Plant at Al Hofuf, Saudi Arabia.

Table 1: The relationship between absorbed dose and irradiation time for the ^{60}Co irradiation used in this study

Absorbed dose (KGy)	Irradiation time(seconds)
15	5081
20	6775
25	8469

and Technology (KACST), Saudi Arabia. The absorbed dose was diversified. The dose rate for all of the experiments was 10.626 kGy/h and the irradiation range was from 0 to 25 kGy. The irradiation time and correspondent doses are shown in Table (1).

Wastewater and Sludge Sampling: Several samples of effluent, before and after chlorination, were obtained from Al Hofuf wastewater treatment Plant. Also, sludge samples from sludge ponds, just prior to its discharge were collected. Figure 2 shows schematic for Al Hofuf wastewater treatment plant.

Microbial Assay: The Heterotrophic Plate Count (HPC) for estimating the number of live heterotrophic bacteria was used to provide a total estimate (Method 9215 A). Estimates of total and fecal coliform bacteria were determined by the membrane filter procedures Method 9222 B and Method 9222 D, respectively [24]. Figure (3) shows typical species of the detected heterotrophic bacteria investigated in this study.

RESULTS AND DISCUSSION

Inactivation of Microorganism in the Wastewater: Several samples were obtained from Hofuf Wastewater Treatment Plant to examine the inactivation of microorganism at various radiation doses. Table 2 summarizes the data for the total heterogeneous bacteria for effluent/sludge samples collected from different places/stages of treatment Plant at various radiation doses. With the reference to Fig. 2, these samples include: 1) sewage water from aeration chamber, 2) sewage water from sewage ponds, before secondary treatment, 3) sludge after drying and Squeezing, 4) sewage water after secondary treatment (Before Sand Filtration), 5) sewage water samples before chlorination and 6) sewage water samples after chlorination.

Figure (4a) shows the inactivation of coliform (organisms) in the unchlorinated effluent samples at various radiation doses. Figure (4b) shows the plot of the logarithmic of Colony forming units (CFU)/g for effluent samples collected from aeration chamber versus gamma radiation doses for the purpose of calculation of the D_{10} value, the reduction to 10^3 ppm value and D_1as shown in Table 3.

The D_{10} value, the dose required to achieve a reduction of 90%, was obtained for the unchlorinated effluent sample and sludge sample (Table 3). The total coliform appeared to be very sensitive to radiation with low D_{10} values (Fig. 4b and 5 b).

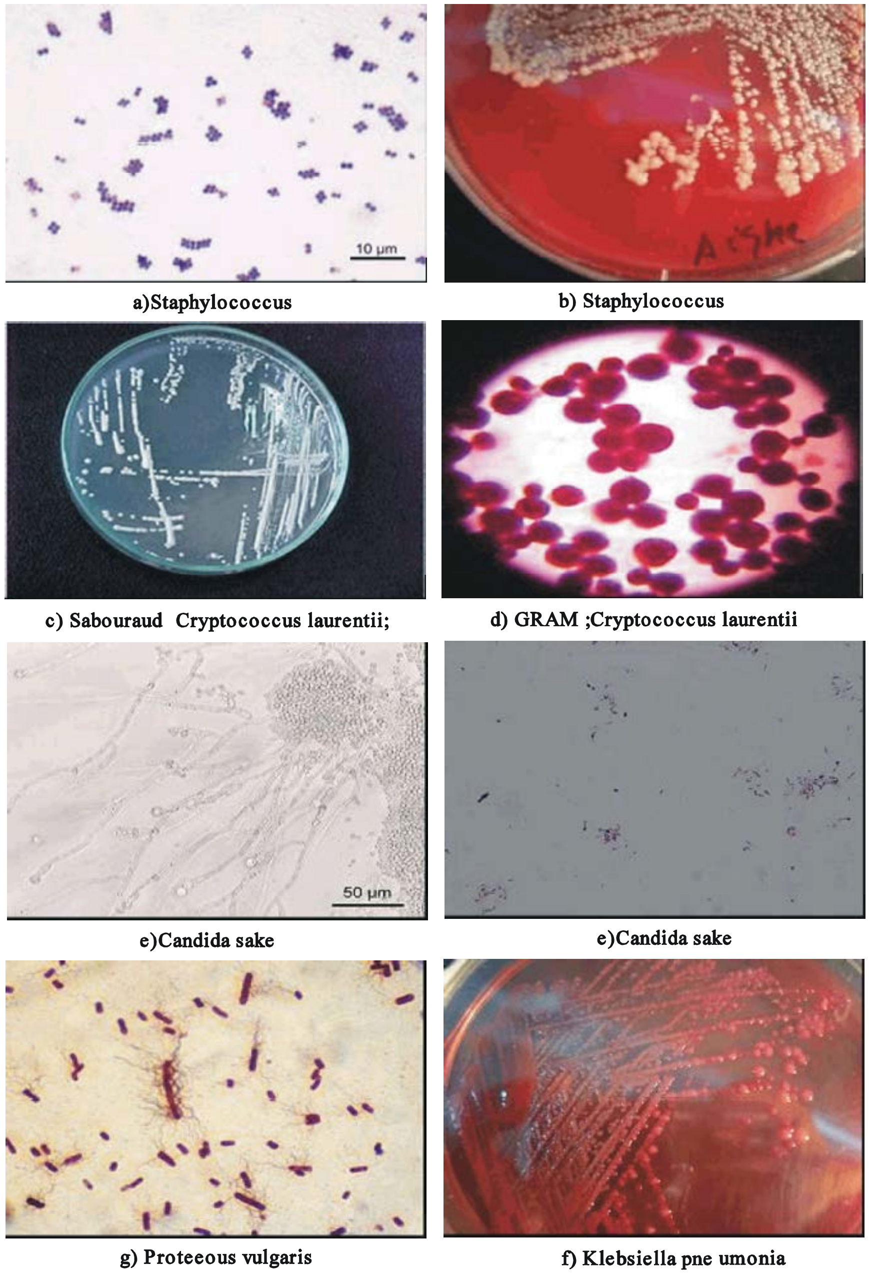

Fig. 3: Typical bacteria species found in the investigated samples

Table 2: Inactivation of total heterogeneous bacteria in unchlorinated, chlorinated secondary effluent and sludge with several irradiation doses for samples collected from Al Hofuf wastewater treatment plant

	Places and the stages of the samples collection					
Dose (KGy)	Sewage water from samples Aeration Chamber	Sewage water Samples Before Secondary treatment (ponds of sludge collection)	Sludge after drying and Squeezing (with moisture of about70 %)	Sewage Water After Secondary Treatment (Before Sand Filtration)	Sewage Water samples Before chlorination	Sewage Water samples After chlorination
	Colony Forming Units (CFU)/g					
0.0001	9800000	1600000	6200000	77000	27000	8500
15	30000	7500	15000	95	2500	910
20	640	750	850	50	85	50
25	600	150	520	35	60	25

Table 3: D_{10} values for total coliform bacteria in the effluent samples before chlorination and for sludge from Al Hofuf wastewater plant

Sample Type	D_{10} (KGy)	D(KGy)reduction to 10^3 ppm	D_1(KGy)
Unchlorinated effluent sample	2.7	10.8	16.2
Sludge Sample	4.5	18	27

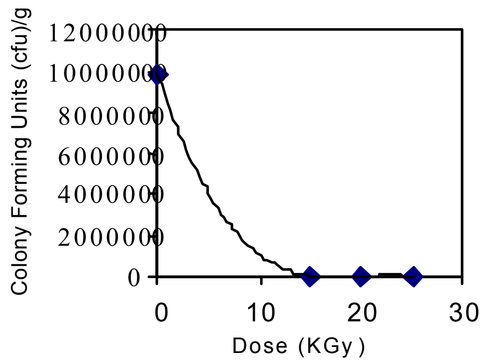

Fig. 4a: Inactivation of Colony forming units (CFU)/g for effluent samples collected from aeration chamber with gamma radiation.

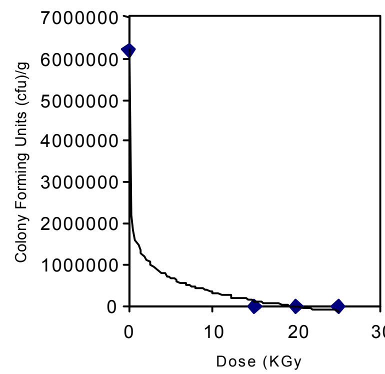

Fig. 5a: Inactivation of Colony forming units (CFU)/g for Sludge samples after drying and squeezing with gamma radiation.

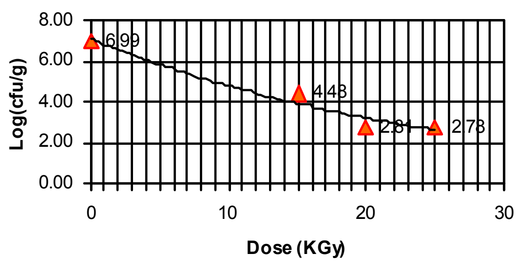

Fig. 4b: Log of Colony forming units (CFU)/g for effluent samples collected from aeration chamber versus. gamma radiation.

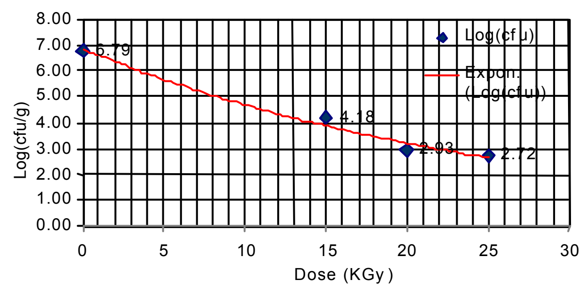

Fig. 5b: The plot of the logarithmic of Colony forming units (CFU)/g for sludge samples versus gamma radiation doses

Accordingly, if we want to disinfect wastewater to 10^3 ppm we find according to the formula D_{10}:

$$10^7 to 10^3 = 4.\log reduction \quad \text{(Fig. 4b)}$$
$$D....value..2.7.kGy.x4..\log reduction = 10.8kGy$$

And D_1 then is:

$$10^7 to 10^1 = 6.\log reduction$$
$$D....value..2.7.kGy.x6..\log reduction = 16.2kGy$$

Also, if we want to disinfect *sludge* to 10^3 ppm we find according to the formula D_{10} :

$$10^7 to 10^3 = 4.\log reduction \quad \text{(Fig. 5b)}$$
$$D....value..4.5.kGy.x4..\log reduction = 18kGy$$

And if we calculate D_1 the dose needed for full sterilization:

$$10^7 to 10^1 = 6.\log reduction$$
$$D....value..4.5.kGy.x6..\log reduction = 27kGy$$

The inactivation of coliform in the chlorinated effluent samples at various radiation doses is shown in Fig. 6. It is worthy to mention, the effect of the chlorination on decreasing of total number of coliform organisms in the wastewater sample is obvious if it compared with total number of coliform organisms in unchlorinated samples (Table 2 and Fig. 6) and however, it still needs for irradiation to reduce the total number of coliform organisms to acceptable limit of reusing the treated wastewater.

The inspection of data listed in Tables 2 and 3 and Figures 4-6, It was found that, although, a considerably higher dose was required to lower number of bacteria for the coliform organisms, it was observed greater than 99% removal.

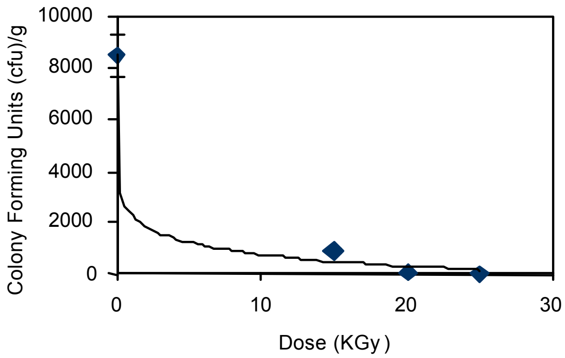

Fig. 6: Inactivation of colony forming units (CFU)/g for water samples collected after chlorination with gamma radiation.

There have been numerous studies reported in using of sludge sterilization. [6] reported that sludge could be sterilized using a dose up to 4 KGy from electron accelerator. While, [25], found that D_{10} for sludge is 5 kGy. [26] reported that the best treatment effect reached when the absorbed dose is about 17.5 kGy. These variations in the suggested doses by these studies are attributed to that, the bacteria and viruses are variant groups. Moreover, some species could survive even higher doses are implemented.

It is well known, that of the sterilization of medical instruments is executed at dose of 50 kGy and for spices it needs 10 kGy for sterilization. So, a dose of 2-4 kGy is not enough to sterilize the sludge (solid waste), as it is reported in some studies. In our review to these studies we noticed that some of these studies were conducted their experiments after air processing and some of them were effective after exposing the samples to the sun for seven days.

Also it is not enough to accept the D_{10} limit, the residual 10% of the viruses, germs and bacteria it might be very dangerous for the human and animal health. However, the using of the gamma irradiation has the advantages over the other methods for bacteria sterilization.

Thus, according to the current study and to the D_{10} values, it is found that dose 4 KGy is not enough to sterilize the sludge and to kill viruses. Complete inactivation of total coliform with no regrowth was achieved at a dose of 25 kGy in the sludge samples.

A dose of 25 kGy is necessary for the sterilization of the AIDS virus, which is still able to drop with the sludge and wastewater even after treatment by chlorine, despite the ability of chlorine sterilization at only very high concentrations and localized and these concentrations cannot be used in wastewater. Some experiments note that the minimum dose for the termination of HIV is 30 kGy [27].

Also, it was found the biological reason behind of not applying these sterilization methods at the entrance of experimental plants by studying the station stages of the secondary and tertiary treatment plant in Al Hofuf, which it was to let the aerobic bacteria to feed on organic material in wastewater and then the subsequent processing stages in the sedimentation downstream and if the irradiation is used at the entrance of the station will prevent to take advantage of that.

Due to some organism can live up to use of dose off 50 KGy, we recommend to utilize Gamma rays or ultra violet rays (UV) after the tertiary treatment stage at Al Hofuf wastewater plant. This would improve the economics of the process and reduce any public acceptance issues associated with the use of radioisotopes. This will call a fourth treatment stage of the secondary and tertiary treatments plants for sterilization wastewater. For the case of Al Hofuf wastewater treatment plant we suggest to fix the UV lamps at the entrance of irrigation canals in which the treated wastewater is discharged or anywhere along these irrigation canals.

CONCLUSIONS

It was found that a 16.2 kGy dose is generally suitable for the wastewater sterilization and it could be raised to above 25 kGy in case of only secondary treatment stage is applied and 27 kGy for sludge. This will reduce the chlorine poisons and the waste of livestock chicken and fishes and the industrial waste in the environment. Also it was clarified the biological reason behind of not applying these sterilization methods outside the experimental plants by studying the station stages of the secondary and tertiary treatment in Al Hofuf, Saudi Arabia, which it was to let the aerobic bacteria to feed on organic material in wastewater and then the subsequent processing stages in the sedimentation downstream and using the irradiation first at the entrance of the station prevent to take advantage of that. Also the only way for sludge sterilization is Gamma rays and there is nothing can compare with it.

We recommend utilizing ultra violet rays (UV) after the tertiary treatment stage at Al Hofuf wastewater plant. This would improve the economics of the process and reduce any public acceptance issues associated with the use of radioisotopes.

Overall, irradiation appears to be an alternative to tradition chlorination of wastewater, especially if reuse is to be considered. The improvement in quality of the irradiated samples was demonstrated by the reduction in bacteria. Radiation of the wastewater provided adequate disinfection while at the same time increasing the water quality. This treatment could lead to additional opportunities for the reuse of this valuable resource.

ACKNOWLEDGMENTS

The authors would like to express their sincere appreciation to Deanship of Scientific Research, King Faisl University for the financial support of this study under fund grant No. 90109. Special thanks go to Dr. Ahmed Basfar, Dr. Ahmed Al-Harbi. Thanks to Mr. Mohamed Al Kulaib, for his assistance in the sampling collection. The authors are indebted to Water and Drainage Organization, Al Hofuf, for their support and help. The authors would like to express their thanks to the wastewater Organization in Aleppo, Syria for allowing accessing their data bank.

REFERENCES

1. Abderrahman, W.A. and T.A. Bader, 1992. Remote-Sensing application to the management of agricultural drainage water in severely arid region-a Case-Study. J. Remote Sensing of Environment, 42: 237-246.
2. Ward, R.W. and G.M. DeGraeve, 1980. Acute residual toxicity of several disinfectants in domestic and industrial wastewater. Water Resources Bulletin. Am. Water Resources Assoc., 16(1): 41-48.
3. Bryan, E.H., D.A. Carlson, R.I. Dick, G. Hare, P. Kruger, J.F. Swinwood and T.D. Waite, 1992. Radiation Energy Treatment of Water, Wastewater and Sludge. ASCE, New York, NY, pp: 50.
4. Swinwood, J.F., Waite, P. Kruger and S.M. Rao, 1994, Radiation Technologies for Waste Treatment: A Global Perspective. IAEA Bull., 1: 11-15.
5. Ahlstrom, S.B., 1985. Irradiation of municipal sludge for agricultural use. Radiat. Phys. Chem., 25: 1-10.
6. Farooq, S., C.N. Kurucz, T.D. Waite, W.J. Cooper, S.R. Mane and J.H. Greenfield, 1992. Treatment of wastewater with high energy electron beam irradiation. Water Sci. Tech., 26: 1265-1274.
7. Farooq, S., C.N. Kurucz, T.D. Waite and W.J. Cooper, 1993. Disinfection of wastewaters: high-energy electron vs gamma irradiation. Water Res., 27: 1177-1184.
8. Borrely, S.I., M.H.O. Sampa, M. Uemi, Del N.L. Mastro and C.G. Silveira, 1998a. Domestic effluent: disinfection and organic matter removal by ionizing radiation. In: W.J. Cooper, R.D. Curry and K.E. O'Shea, (Eds.), Environmental Applications of Ionizing Radiation. Wiley, New York, NY, pp: 369-380.
9. Borrely, S.I., N.L. Del Mastro and M.H.O. Sampa, 1998b, Improvement of municipal wastewaters by electron beam accelerator in Brazil. Radiat. Phys. Chem., 52: 333-337.
10. Basfar, A.A. and F. Abdel Rehim, 2002. Disinfection of Wastewater from A Riyadh Wastewater Treatment Plant with Ionizing Radiation, Radia. Phys. Chem., 65: 527-532.
11. Basfar, A.A., H.M. Khan and A.A. Al-Shahrani, 2005, Trihalomethane treatment using gamma irradiation: kinetic modeling of single solute and mixtures, Radiat. Phys. Chem., 720: 555-563.
12. Yan, Y.X. and H. Liu, 2006. Optimization of irradiation cycle for enhancement of biological treatment of wastewater by low intensity ultrasound, 27(5): 898-902 (MEDLINE), School of Environment, Beijing Normal University, Beijing, China.
13. Wang, J. and J. Wang, 2007. Application of radiation technology to sewage sludge processing, Laboratory of Environmental Technology, Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing, PR China Journal of Hazardous Materials, 143: 2-7.
14. Lessel, T. and A. Suess, 1984. Ten years experience in operation of a sewage treatment plant using gamma irradiation. Radiat. Phys. Chem., 24: 3-16.
15. Swinwood, J.F. and F.M. Fraser, 1995. The Canadian sludge irradiator project: unexpected challenges and opportunities. Radiat. Phys. Chem., 46: 1147-1151.
16. Waite, T.D., T. Wang, C.N. Kurucz and W.J. Cooper, 1997. Parameters affecting conditioning enhancement of biosolids by electron beam treatment. ASCE J. Environ. Eng., 123: 335-344.
17. Zhou, L.X., Y.C. XU, T.H. Jiang, S.J. Zheng and H.L. Wu, 2002. Characterization of irradiated sewage sludge and its effects on soil fertility, crop yields and nutrient bioavailability, Nanjing Agricultural University, Nanjing, China. IAEA-TECDOC-1317- Irradiated sewage sludge for application to cropland- FAO-IAEA Division of Nuclear Techniques in Food and Agriculture.

18. Vacek, K., F. Pastuszek and M. Sedlacek, 1986. Radiation processing applications in the Czechoslovak water treatment technologies. Radiat. Phys. Chem., 28: 573-580.
19. Getoff, N., 1999. Radiation chemistry and the environment. Radiat. Phys. Chem., 54: 377-384.
20. Fang, X.W. and J.L. Wu, 1999. Some remarks on applying radiation technique combined with other method to the treatment of industrial wastes. Radiat. Phys Chem., 55: 465-468.
21. Duarte, C.L., M.H.O. Sampa, P.R. Rela, *et al.*, 2000. Application of electron beam irradiation combined to conventional treatment to treat effluents. Radiat. Phys Chem., 57: 513-518.
22. Duarte, C.L., M.H.O. Sampa, P.R. Rela, H. Oikawa, C.G. Silveira and A.L. Azevedo, 2002. Advanced oxidation process by electron-beam-irradiation¬induced decomposition of pollutants in industrial effluents, Institute for Energetic and Nuclear Research-IPEN-CNEN/SP, Radiation Technology Center-TE, San Paulo, Brazil, Radiation Physics and Chemistry, 63: 647-651.
23. Pikaev, A.K., 2000. Recent environmental application of radiation technique. International Symposium on Radiation Technology and Emerging Industrial Application. 6-10 November, Beijing, People's Republic of China.
24. APHA, AWWWA, W.E.F., 1995. Standard Methods for the Examination of Water and Wastewater, American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC.
25. Ahmed, S., M.B. Hossain and S.M. Rahman, 2002. Isotope-aided studies on the effects of radiation processed sewage sludge on crop yields and bioavailability of heavy metals, Bangladesh Institute of Nuclear Agriculture, Mymensingh, Bangladesh-IAEA-TECDOC-1317-Irradiated sewage sludge for application to cropland-FAO-IAEA Division of Nuclear Techniques in Food and Agriculture.
26. Huaying, B., L. Yuanxia and J. Haishun, 2002. A study of irradiation in the treatment of wastewater. Radiat. Phys. Chem., 63: 633-636.
27. Campbell, D.G., P. Li, A.J. Stephenson, R.D. Oakeshott, 2004. Sterilization of HIV by gamma irradiation, Orthopaedic Surgery Unit, Royal Adelaide Hospital North Terrace, 5000 Adelaide, South Australia, Australia, 0341-2695 (Print) 1432-5195.