ASSESSMENT OF WASTEWATER TREATMENT AND WATER REUSE PRACTICES IN THE GULF COUNTRIES

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ABSTRACT

A major challenge for the 21 st century will be the efficient use of all resources to minimize wastage. Lack of fresh water is becoming one of the largest and most universal of the resource problems that we face in the new century. This leads us to consider the options for turning wastewaters into useful resources, with recovery of the water for reuse. Therefore, wastewater has become an essential component in the water resources and environmental management framework .

In the Gulf Corporation Council (GCC) countries , agriculture in competition with other sectors will soon face quantity and quality water problems due to limited conventional water resources and increasing water demands. Wastewater is actually considered an additional water resource and a potential source of fertilizing elements. Extensive treatment of wastewater has become necessary in order to reclaim good quality water for reuse and to protect the environment which has been adversely affected from continuous disposal of untreated or partially treated wastewaters into sensitive receiving bodies. Although substantial work on this subject has been conducted worldwide, the effectiveness of current wastewater treatment and water reuse practices in the GCC countries is yet to be assessed .

The objective of this paper is to evaluate the present status of reclaimed wastewater reuse in the GCC countries . The paper will examine the wastewater treatment technologies currently in use and analyse the data obtained on treated effluent quality. In particular , the role of tertiary treatment in effluent quality improvement will be determined and prospects for the future will be discussed. The reclaimed wastewater reuse practices will be evaluated and the institutional., legal , and financial aspects of water reuse will be screened.

INTRODUCTION

Water scarcity is a predominant problem for future developments in the Gulf region. Countries of the region are confronted with an increasing population and the associated expansion of urbanization and economic activities, all of which require more water and impose a tremendous strain on this already limited and fragile resource. While water demands will continue to increase in the Gulf region, the fixed amount of fresh water resources will always impose great challenges. Such a conflict could be resolved by different means among which desalination of sea water and reuse of treated wastewaters have emerged as attractive types of unconventional water resources for many practical, economic and environmental reasons. In particular, water reuse is viewed as a renewable resource that increases with the increase in water use

The Gulf Cooperation Council (GCC) countries, namely Bahrain; Kuwait; Oman; Qatar; Saudi Arabia; and the United Arab Emirates (U.A.E.), share common issues in water resources management. The dependency of these countries on water for their future development is particularly critical. The annual rainfall averages 50 to 300 mm only and the rainy season is rather limited in most areas. In the last decade there has been a growing demand on water for various uses in the GCC countries. Agricultural water demand constitutes the largest portion of the total water demand in these countries. It represents about 75% of the total water demand currently reported. Fresh water is often insufficient to grow crops, and food production is affected by the yearly variation in rainfall. Agriculture, therefore, depends primarily on groundwater for freshwater supplies. Excessive and uncontrolled withdrawal of groundwater for irrigation has created many environmental problems of which increased water and soil salinization are most serious. Reuse of treated agricultural water demand wastewater in irrigation appears to be a viable alternative to satisfy a portion of the

For water reuse, the technology exists that enables wastewater to be treated to different levels of purity so that treatment can be tailored to match the intended use. Fresh water generated from desalination processes is comparatively costly and is used carefully and sparingly. In some cases, desalination technology itself is considered to be an essential part of the wastewater treatment system for water reuse purposes. The performance of representative technologies is assessed in this paper.

MUNICIPAL WASTEWATER TREATMENT

There is a growing increase in wastewater quantities during the last ten years in the GCC countries due to the vigorous expansion of the wastewater collection systems to cover most of the inhabited areas. This trend will continue and, coupled with population growth, it will certainly contribute to increased wastewater quantities. Currently, from 30 to 70% of all generated municipal wastewaters are collected and treated in the GCC countries. While the majority of urban areas in these countries are served by wastewater collection and treatment systems, rural areas in Oman, Saudi Arabia and U.A.E. lack such facilities.

The municipal wastewater quantities collected in the GCC countries in the year 1998 are estimated at 1.5 billion cubic meters (bcm) per year of which the total volume of treated wastewater is estimated to be about 1.0 bcm. It is anticipated that the quantities of wastewater will continue to increase as the water use allocated for domestic and industrial purposes will increase and the population served by wastewater collection and treatment facilities will also increase. Therefore, the quantities of municipal wastewater are expected to double during the next ten years and would reach about 5 bcm by the year 2025 (Hamoda, 1995).

An examination of wastewater treatment plants in the GCC countries reveals that almost all types of processes are being used. These include (1) simple and low cost processes (sedimentation, stabilization ponds and aerated lagoons), (2) moderate cost, secondary treatment processes (activated sludge, trickling filters), and (3) the high cost advanced treatment processes (nitrification, denitrification, gravity media filtration, chemical clarification, activated carbon adsorption, reverse osmosis, etc.). However, the activated sludge process and its modifications are by far the most commonly used process of secondary treatment of wastewater in urban areas.

Centralized wastewater treatment facilities have been established in all major cities in the GCC countries. Such facilities consist of primary, secondary and tertiary treatment units in order to reclaim municipal wastewater. These systems when operated properly can produce effluents with low biochemical oxygen demand (BOD) of less than 20 mg/l and suspended solids (SS) of less than 20 mg/l which is acceptable for discharge to land or sea and for reuse in restricted agricultural and landscape irrigation. A form of effluent disinfection (e.g. chlorination) is practiced in all applications.

PERFORMANCE OF TERTIARY TREATMENT PLANTS

Performance expectations for various technologies are important with water reuse applications. Treatment levels achievable with various combinations of unit operations and processes used for wastewater treatment may vary according to the operating conditions and the system used (Tchobanoglous and Angelakis, 1995). This is the case with treatment plants in the GCC countries.

In the U.A.E., there are three major municipal wastewater treatment plants which employ tertiary treatment (Table 1) comprising rapid sand filtration (granular media) and chlorination to polish the secondary treated effluent for reuse in irrigation. These plants are located in the cities of Abu-Dhabi, Dubai and Al-Ain (Hamoda, 1995). Similarly, in Kuwait,

there are three major tertiary wastewater treatment plants (Table 2) located in Ardiya,Jahra and Rikka (Al-Essa , 1996). In Saudi Arabia (Al-Rehaili, 1997), tertiary treatment is provided to remove suspended and dissolved substances remaining after conventional secondary treatment. Strict discharge requirements, reuse of treated wastewater in food-crop irrigation, industry, and groundwater recharge all resulted in the need for better effluent quality than can be accomplished by secondary treatment of wastewater. Pollutants that are removed by tertiary treatment include biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), nitrogen (N), phosphorus (P), total dissolved solids (TDS), and many synthetic compounds, depending on the treatment scheme utilized. Examples of tertiary treatment processes include disinfection, chemical clarification, filtration, chemical and biological nitrogen removal, carbon adsorption, and desalination.

Table 3 illustrates examples of treatment plants utilizing tertiary treatment in Saudi Arabia. Table 4 presents the characteristics of treated wastewater effluents in the U.A.E. It is interesting to note that the secondary-treated effluents obtained from treatment plants are of good quality but water reuse in irrigation requires an effluent with very low suspended solids (SS), which can be hardly achieved through secondary treatment. Moreover, the tertiary treatment has an important role in effluent quality improvement since effluent quality variations are reduced considerably as the secondary-treated effluent is subjected to gravity filtration in tertiary treatment. It is also evident that tertiary treatment by gravity filtration is more stable and is capable of producing effluent with consistently low BOD, SS, and NH_3-N as shown in Table5.

The tertiary treatment of wastewater by granular-media filtration does not remove nutrients (nitrates, phosphates and ammonia) to any appreciable degree. In other words, the effluent maintains satisfactory levels of nutrients required for plant growth as the effluent is reused for agricultural purposes. However, excessive application of effluents containing NH_3-N in irrigation may be detrimental and application rates should be carefully determined. More extensive tertiary treatment utilizing chemical clarification, biological nitroge removal, carbon adsorption and reverse osmosis are capable of producing effluent quality much better than can be accomplished by granular media filtration as practiced in Saudi Arabia but at considerably high cost. Granular media filtration coupled with chlorination removed about 99.9% of total coliforms and produced an effluent which satisfies the bacteriological quality for water reuse (Table 4). However, the treated effluent may contain viruses even though bacterial indicators are absent. Viruses, being very active at very low numbers, are considered the most dangerous among all other microorganisms and pathogens that might exist in the treated effluent used for irrigation. The removal or inactivation of these microorganisms is of utmost importance in any wastewater reclamation system.

ADVANCED TREATMENT PROCESSES

A major problem associated with water reuse applications is the level of the total dissolved solids (TDS) in the wastewater. For example, effluents from the Abu-Dhabi's wastewater treatment plant have a TDS of about 2000 mg/l (Table 4) which is relatively high for agricultural irrigation. Moreover, with increased industrialization, industrial wastewater effluents will reach municipal wastewater treatment plants. In fact, the city of Dubai is considering plans to build a new plant to treat combined domestic and industrial wastewater effluents nearby the industrial zone of the city. This may contribute a variety of new pollutants such as heavy metals and trace organics, as well as the common total dissolved solids, i.e. salts. Such pollutants cannot be removed by conventional wastewater treatment processes.

The reverse osmosis (RO) process has been the principal historic focus of water desalination but continuous development and refinement of RO membranes and hardware has now made it possible to implement the technology to advanced wastewater treatment. This separation process is usually used as a polishing step for the treatment of secondary and tertiary effluents. Application of RO treated water to landscaping and other agricultural purposes is receiving more attention in arid and semi-arid countries (Bowler et al., 1985).

The primary purpose of RO application in tertiary treatment of wastewater is removal of dissolved inorganic solids. This can be accomplished with 90% reduction to a TDS level of about 100 mg/l and recovery of approximately 85% of the applied water (McCarty, 1982). In addition, membranes reject the high-molecular-weight polymeric substances that represent the majority of organics as measured by the COD test (Hamoda et al., 1973). The COD reductions are about 90% resulting in permeate COD concentrations of less than 2 mg/l (McCarty and Reinhard, 1980). Removal of a wide range of organic priority pollutants such as chlorinated hydrocarbons, high molecular weight organics and pesticides ranged between 45 and 99% (McCarty and Reinhard, 1980). Nonionic organic compounds of low molecular weight are poorly removed by RO. The process shows excellent removal of nutrients such as ammonia, nitrite and nitrate-nitrogen as well as total phosphorus when treating secondary municipal effluent. Moreover, its efficiency is very high in removing enteroviruses and bacteria (McCarty, 1982).

The two common membrane materials for RO are cellulose acetate and aromatic polyamide. Cellulose acetate membranes have a high flow rate per unit area and are commonly used to form tubes of spiral-wound flat sheets. In contrast, polyamide membrane have a relatively lower specific flow rate and are manufactured in the form of hollow fibers to achieve the maximum surface area per unit volume. Recent developments of thin film composite membranes resulted in a new generation of low pressure RO membranes. The thin film composite type, primarily polyamide materials, can operate at considerably lower pressure (17 bar vs. 31 bar) than the conventional cellulose acetate membranes while giving a high flux rate. Several pretreatment processes, physical and/or chemical, are usually implemented on secondary wastewater effluents prior to pumping the feed to the RO membranes in order to reduce or remove hazardous and undesired constituents from the feed.

Pretreatment largely depends on feed water quality, membrane type and configuration, measures arranged for fouling prevention, cleaning frequency, designed recovery ratio and product water quality. Long-term application of RO has been successfully demonstrated (Kirkpatrick and Asano, 1986) in the Water Factory 21 (Orange County, California) which is designed to reclaim unchlorinated effluent from biological treatment of municipal wastewater containing a low proportion of industrial wastes at a uniform flow rate of about 57,000 m^3/d. The RO plant is limited to a design flow rate of 19,000 m^3/d since demineralization of one-third of the wastewater is adequate to provide a blended effluent of suitable quality.

The RO process has been tested in a number of wastewater treatment plants in the GCC countries. In the U.A.E., the RO process was applied (Hamoda, 1995) to upgrade existing tertiary treatment at Al-Ain municipal wastewater treatment plant. The tertiary treatment receives settled wastewater after biological treatment by the extended aeration process. It comprises eight granular-media, gravity filters treating a total flow of about 25,000 m^3/d. Each filter contains a surface layer of anthracite coal overlaying sand and garnet to provide effective in-depth filtration. The filtration rates are in the range of 25 to 32 m^3/m^2.d with filter runs of one day. Chlorine gas is injected as a water disinfectant prior to and following gravity filtration. The effluent quality after filtration and chlorination treatment is shown in Table 6. The existing Granular-media filtration is an economical and widely used pretreatment step for RO. Moreover, chlorination could effectively remove bacteria to protect the RO membranes from bacteriial aattack but residual chlorine was removed by dechlorination to prevent membrane fouling. A cartridge filter was added prior to the RO unit as a preliminary polishing step commonly used in almost every RO process. The cartridge filter can remove small particles in the 5 to 25 um range. The RO unit used in the field trials employs Du Pont Permasep B-9 membranes for brackish water desalination. It comprises hollow fiber membranes which were operated at a feed pressure of 25 bar and 80% recovery with a nominal production of 1300 m^3/d. There has not been any cleaning of membranes during field trials that lasted for two months at an average water temperature of 30?C. A synthetic salt solution was mixed with the feed to the RO unit in order to simulate the expected quality of wastewater when industrial effluents are discharged to the plant. The average characteristics of the RO treated effluent are shown in Table 6. The results clearly indicate the potential for effluent quality improvement by the RO process. The demineralized water produced is adequate to provide a blended effluent of suitable quality for reuse in irrigation. However, implementation of the RO process in the existing tertiary treatment is not required at the present time but it might be necessary in the future when industrial wastewater effluents are introduced to municipal plants for combined treatment.

Table 6 . Effluent Characteristics after Reverse Osmosis Tertiary Treatment at Al-Ain Plant, U.A.E. (Hamoda, 1995)(1)

Parameter	Feed Water to Membranes	Treated Water
COD (mg/l)	15	2
NO_3-N (mg/l)	20	3.5
PH	7.4	7.2
TDS (mg/l)	1,450	130
Chlorides (mg/l)	360	25
Sulphates (mg/l)	290	20
Phosphates (mg/l)	15	1
Calcium (mg/l)	188	12
Magnesium (mg/l)	80	6
Fecal Coliform (MPN/100 ml)	2	0

(1) Based on field testing with DuPont Permasep B9 membranes.

Table 7. Effluent Characteristics after Reverse Osmosis Tertiary Treatment at Ardiya Plant, Kuwait (Abdel-Jawad et al., 1996 (1)

Parameter	Feed Water to Membranes	Treated Water
pH	7.0	5.73
Conductivity (µS / cm)	1670	47
TDS (mg/l)	970	25
Chloride (mg/l)	265	12.5
Sodium (mg/l)	145	10.5
TSS (mg/l)	6.1	<0.5
VSS (mg/l)	1.5	<0.5
COD (mg/l)	20	2
BOD (mg/l)	4	0.1
NH3 (mg/l)	21	0.7
PO4 (mg/l)	10	0.2
Turbidity (NTU)	3.75	0.0
F. Coliform (MPN/100 ml)	ND	0.0
Coliform (MPN/100 ml)	ND	0.0
Salmonella (MPN/100 ml)	ND	0.0
F. St. Cocci (MPN/100 ml)	ND	0.0

(1) Based on field testing with filmtec polyamide membranes.

(2) Not determined.

In Kuwait, the RO process was employed to reclaim tertiary treated wastewater from the Ardiya plant (Abdel-Jawad et al., 1996). The plant effluent received pretreatment (chemical coagulation and filtration) prior to the RO treatment. The RO unit was operated at a flow rate of 50 m^3/h and feed pressure of 8.5 bar using filmtec, BW 30-8040, polyamide membranes. The results obtained are displayed in Table 7, based on average values reported with over 50% recovery and 97.4% salt rejection. This shows that water with excellent quality can be produced by RO.

In continuous RO application to advanced wastewater treatment, the membranes employed require periodic cleaning to restore the water flux rate. The loss of productivity is a major problem of membrane separation in wastewater reclamation. The fouling layer consists primarily of bacteria that attach to the surfaces of the membranes, even though a combined residual is maintained in the feedwater. Of the cleaning solutions available, combination of detergents and enzymes appear to be most effective. Flushing is also used after cleaning to remove chemical solutions. Another problem arising from RO application is finding a suitable means for disposal of the reject brine.

TREATMENT COSTS

Economics of water reuse might be considered the most important factor in determining the feasibility of water reuse. Such economics could be influenced by several factors which include:

1. Level of wastewater treatment,
2. Water reuse markets,
3. Geographical location of users,
4. Size of wastewater treatment plant,
5. Elimination of wastewater disposal problems, and,
6. Cost of providing the water from alternative sources.

A cost/benefit analysis is an important test to verify whether an investment in wastewater reuse is justified financially, and in economic terms whether it represents an optimal investment in relation to other opportunities for investment in the water resources sector. Wastewater collection and disposal projects have a major impact on the social, financial and economic well-being of the public. A simple financial comparison of capital investment, operational costs and revenues or recovered costs and profits does not reflect all the factors and issues. There is a need to review, and quantify to the extent possible, wide ranging social, health and environmental aspects which are important not only to the immediate beneficiaries but also to society at large. Most of these benefits and costs have been generally accepted as indirect or external benefits and costs. A quantitative cost-benefit analysis for all issues and factors is extremely difficult to prepare but at least a qualitative analysis should be made. For a water reuse project, if viability on purely financial terms cannot be demonstrated, subsidies can become part of the financing to reflect the often considerable social and environmental benefits associated with such a project

Based on current cost figures from wastewater treatment plants and water desalination plants in the GCC countries the cost of producing tertiary-treated effluent (using filtration and chlorination for tertiary treatment) is about US$ 0.5/cubic meter. This represents about one-third of the cost of producing one cubic meter of desalinated water (using the MSF process) and demonstrates the viability of the wastewater reuse option. However, if reverse osmosis treatment is implemented, the cost of producing reclaimed water will be in the range of US$ 0.9 to 1.1 depending on the plant size and membranes used.

CONCLUSIONS

Water reuse has a great potential in the development of water resources since the wastewater quantities are increasing and the fresh water sources are depleting. The tertiary treated effluent produced at municipal wastewater treatment plants in the GCC countries is suitable for reuse in irrigation since the existing granular media filtration process is capable of removing residual suspended solids. It also reduces effluent quality variations and contributes to the stability of plant performance.

Reverse osmosis is an excellent advanced treatment process where high rejection of total dissolved solids, a broad range of organics and micropollutants and pathogens can be effectively achieved thus reducing health risks associated with reuse of treated wastewater effluents. It may become necessary to implement reverse osmosis in wastewater treatment plants as industrial effluents will be discharged into the municipal sewerage system. The treated effluent is currently produced for water reuse at about one third the cost of desalinated water by the MSF process. The wastewater treatment cost will be almost doubled as the reverse osmosis process is implemented.

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