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Comparative Study on the use of Reverse Osmosis and Adsorption Process for Heavy Metals Removal from Wastewater in Saudi Arabia

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Abstract: The main objective of this study was to remove heavy metals from wastewater by two different wastewater treatment methods namely reverse osmosis and adsorption (Saudi bentonite clay as adsorbent) process. The concentration levels of heavy metals such as Co, As, Cd and Cr in wastewater in Riyadh were above the maximum recommended limits for crop production. The comparison showed that the minimum removal efficiency of heavy metal ions was 88.89% with adsorption process (Saudi bentonite clay) and 87.92% by Reverse Osmosis (RO) method. Moreover, the concentration level of the heavy metals in the treated wastewater was within the recommended permissible limits for crop production. The study provided an excellent potential for using local adsorbent material such as Saudi bentonite clay for wastewater treatment on economical basis.

Key words: Wastewater, Reverse Osmosis (RO), Saudi bentonite clay, adsorption process, removal efficiency, recommended maximum concentration limits

INTRODUCTION

Main sources of heavy metals in wastewater especially the industrial wastewater are plastic water pipes, fertilizers, electroplating, paint pigments, catalytic processes, metal ceramics and alloys industries (Ajay *et al*., 2005; Brezonik, 1974; Patterson and Passino, 1987; Emsley, 1992). The heavy metals affect human health and cause serious diseases such as kidney failure, anemia, destroyed liver, cancer and brain damage when present above the permissible concentration levels (Ajay *et al*., 2005; Emsley, 1992; Abdulkarim and Abu Al-Rub, 2004).

In general, wastewater treatment processes such as chemical precipitation, extraction, reverse osmosis and adsorption methods are normally used in removing the heavy metals from wastewater. It has been observed that the adsorption method is an economically feasible and viable process especially using the natural material such as clay as an adsorbent. Many investigators used clay for the removal of cobalt, lead, cadmium, zinc and chromium ions from wastewater (Orumwense, 1996; Yadava *et al*., 1991; Pradas *et al*., 1994; Singh *et al*., 1992; Ceylan *et al*., 2005; Al-Jlil and Alsewailem, 2009).

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The Wastewater Treatment Plant (WTP) at King Abdulaziz City for Science and Technology (KACST) was established to treat wastewater from KACST for landscape irrigation in and around KACST compound.

An extensive review on the subject showed that a very little research and investigation have been carried on the removal of the heavy metals from sewage wastewater in Riyadh City. Therefore, the aim of this study was to remove a mixture of heavy metals from the sewage waste water in Riyadh City by using the available wastewater treatment plant at King Abdulaziz City for Science and Technology (KACST). Firstly, treatment of wastewater by using Reverse Osmosis (RO) unit and secondly, by replacing the RO-Unit in the sewage plant by adsorption unit using Saudi bentonite clay as an adsorbent. Then, the results will be compared for determining the heavy metals removal efficiency of RO-Unit and the adsorption method for economical evaluation.

MATERIALS AND METHODS

Materials

The Saudi bentonite clay from Jeddah city was used as adsorbent in the experiment. The chemical analysis of the Saudi bentonite clay was done by XRD, XRF and surface area analyzer. Mean chemical analysis is shown in Table 1 and 2. The XRD results verified the presence of montmorillonite as the major component with small amount of Kaolinite, quartz and illite minerals.

The adsorbates were a mixture of multi-components namely: copper, cobalt, zinc, lead, arsenic, cadmium and chromium ions in the wastewater of Riyadh City (Table 3).

Methodology

The experiment was carried at the King Abdulaziz City for Science and Technology (KACST) during 2008-2009. The wastewater was passed through a series of treatment processes to obtain clean water for landscape development around KACST compound by reducing COD and BOD and the removal of heavy metals. The Wastewater Treatment Plant (WTP) at KACST consists of RO-Unit for advanced treatment of product water from biological treatment process where aeration, biofilters and activated sludge were used for the reduction of COD and BOD from domestic wastewater. The RO-Unit at the WTP facility was

Table 1: Chemical analysis of the bentonite clay by XRF

Element	Composition (wt. %)
Si	58.00
Al	20.00
Fe	5.17
Ca	2.00
K	1.00
S	-
Traces of other elements (Mg, Ti, Mn, etc.)	13.83

Table 2: Surface area and pore characteristics of bentonite clay

Element	Values
BJH adsorption cumulative surface area of pores between 17.000 Å and 3000.000 Å diameter ($m^2\ g^{-1}$)	47.740000
BJH adsorption average pore diameter (A°)	95.650000
BJH adsorption cumulative volume of pores between 17.000 Å and 3000.000 Å diameter ($cm^3\ g^{-1}$)	0.114157

Table 3: Heavy metals concentrations in wastewater in Riyadh City

	Heavy metal concentration ($mg\ L^{-1}$)						
Water type	Cu	Co	Zn	Pb	As	Cd	Cr
Raw water	0.012	0.14	0.162	0.165	0.972	6.36	0.149

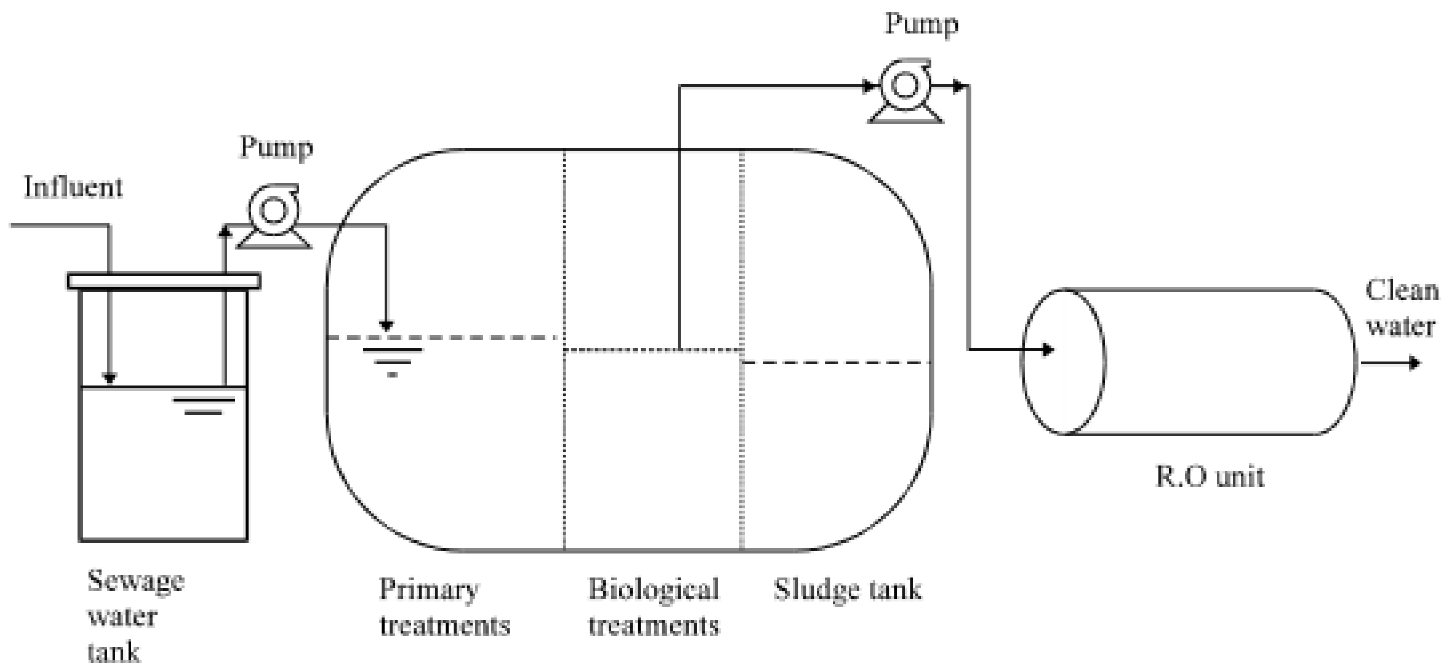

Fig. 1: Wastewater treatment plant with Reverse Osmosis Unit

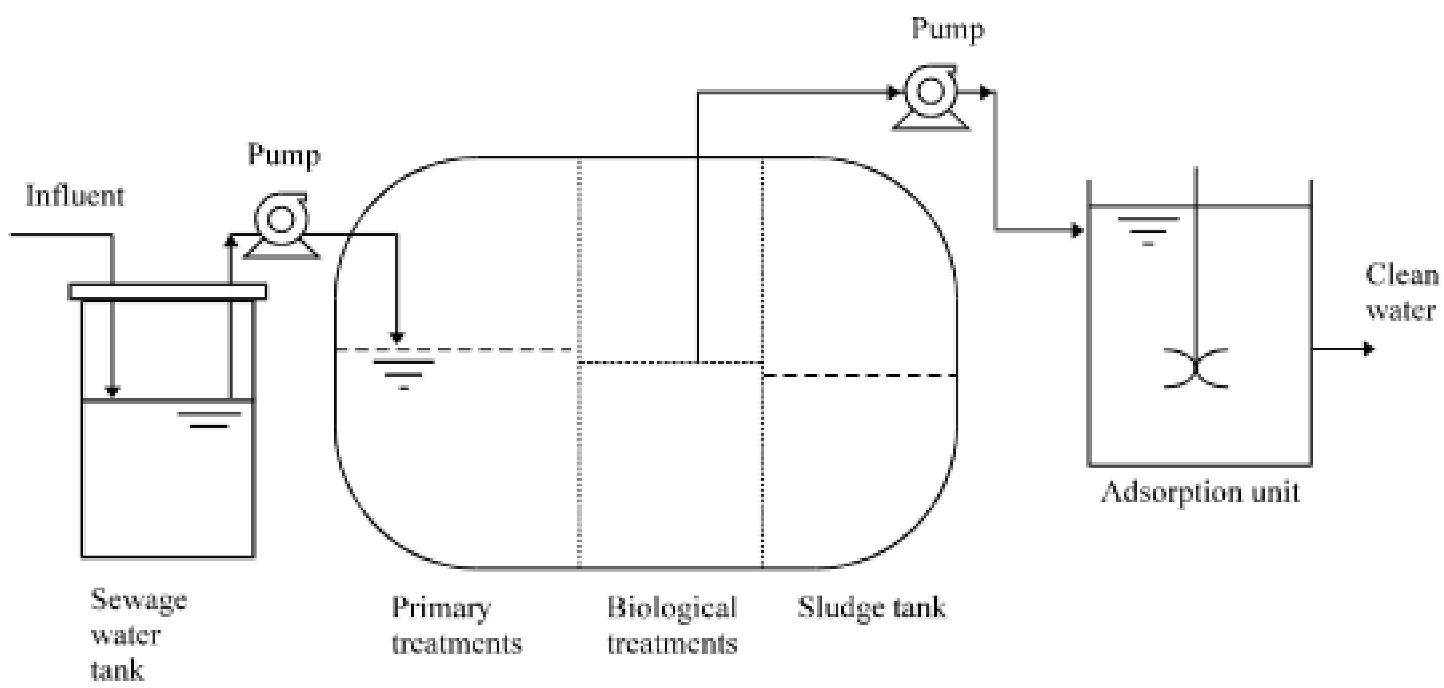

Fig. 2: Sewage wastewater treatment plant with Adsorption Unit

used for the removal of heavy metals from product water obtained from biological treatment process of WTP. Then, the RO-Unit was replaced by the Adsorption Unit using Saudi bentonite clay as an adsorbent for the removal of heavy metals. The results, from both the treatment techniques were compared for heavy metals removal efficiency and its economical feasibility.

The treatment process using RO-Unit consists of the following steps:

- Primary treatment stage i.e., screening, aeration and sedimentation in clarifiers
- Biological treatment stage includes two processes:
  - Activated sludge tank treatment process
  - Bio-filters tank
- Reverse Osmosis (RO) Unit for removing heavy metals
- Chlorination (disinfection)

The whole experiment was repeated three times to obtain reliable data.

The schematic diagram of Wastewater Treatment Plant (WTP) is presented in Fig. 1.

The second treatment process was the Adsorption Unit for removing heavy metals instead of RO-Unit. This treatment process is identical to the first process except that the RO-Unit was replaced by the Adsorption Unit as shown in Fig. 2.

Determination of Equilibrium Time for Metal Adsorption

Equilibrium time for Saudi bentonite clay was determined by using a constant mass of adsorbent (3 g) in 50 mL of wastewater in 250 mL capacity glass bottles and placed on a constant agitating shaker. The particle size of the adsorbent was 0.25 mm and the temperature was maintained at 25°C.

The adsorbed metal ions and the adsorbent system reached to equilibrium after 1 h which was based on the run experiments at different time intervals. For this reason, the equilibrium process was left for 3 h to ensure that the adsorption process has reached the state of equilibrium.

Determination of the Concentration of the Collected Cobalt Ions Solution Samples

The sample from adsorption unit were collected after 3 h and filtered. After this, the absorbance of samples from adsorption unit and RO-Unit was measured by atomic absorption spectroscopy. Then the absorbance of samples was converted to concentrations directly using calibration curve for each metal ion. The removal efficiency of the metal ions adsorption on the bentonite clay and after reveres osmosis was obtained from the following equation:

$$\text{Removal efficiency } (\%) = \frac{(C_o - C_f)}{C_o} \times 100 \quad (1)$$

where, C_o is the initial concentration of metal ions (mg L^{-1}) and C_f is final concentration of the metal ions (mg L^{-1}) from Adsorption Unit and from RO-Unit.

RESULTS AND DISCUSSION

The concentration of heavy metals (Co, As, Cd and Cr) in the sewage wastewater of Riyadh city was above the permissible limits (Table 3) as compared to the recommended permissible limits for these metal ions for crop production (Table 5). For example, the concentration of Cd and As 6.36 and 0.972 mg L^{-1}, respectively which was above the permissible limits as shown in Table 5. It is well known that Cd and As, being toxic metals, can cause human health and environmental hazards. Therefore, wastewater treatments such as adsorption process and reverse osmosis were applied to remove the heavy metals from the sewage wastewater. In the Adsorption Unit, Saudi bentonite clay was used as a low cost adsorbent, whereas in the RO-Unit polyamide membrane was used for water treatment.

The concentration of heavy metals were less in the treated water by the two techniques than the recommended permissible limits for crop production (Table 4).

The concentration of heavy metals decreased significantly in the treated water when compared to the untreated wastewater. The results, showed that the Saudi bentonite clay and RO-Unit were very effective for the removal of heavy metals from the wastewater. Mean minimum removal efficiency of heavy metal ions was 88.89% by Saudi bentonite clay and 87.92% by RO-Unit as shown in Table 4. In conclusion, the Saudi bentonite clay and RO-Unit showed an excellent potential for the removal of some heavy metals from the sewage

Table 4: Effect of treatments on heavy metals concentrations in waste water in Riyadh City

	Metal removal (ppm)					
	Treated by reverse osmosis unit			Treated by adsorption unit		
Heavy metal type	Concentration before treatment	Concentration after treatment	Treatment efficiency (%)	Concentration before treatment	Concentration after treatment	Treatment efficiency (%)
Cu	0.012	0.000	100.00	0.012	0.000	100.00
Co	0.140	0.000	100.00	0.140	0.000	100.00
Zn	0.162	0.015	90.74	0.162	0.018	88.89
Pb	0.165	0.000	100.00	0.165	0.000	100.00
As	0.972	0.000	100.00	0.972	0.000	100.00
Cd	6.360	0.009	99.86	6.360	0.010	99.84
Cr	0.149	0.018	87.92	0.149	0.011	92.62

Table 5: Comparison of heavy metals concentration in the treated wastewater for crop production

Elements	Recommended maximum concentration (mg L^{-1})*	Maximum concentration after treatment by reverse osmosis (mg L^{-1})	Maximum concentration after treatment by the adsorbent (mg L^{-1})
Cu	0.20	0.000	0.000
Co	0.05	0.000	0.000
Zn	2.00	0.015	0.018
Pb	5.00	0.000	0.000
As	0.10	0.000	0.000
Cd	0.01	0.009	0.010
Cr	0.10	0.018	0.011

*Source: Pescod (1992)

Table 6: Cost of Saudi bentonite clay as compared to reverse osmosis module

Type	Price by $ per Kg of Saudi bentonite clay	Price by $ per membrane module
Reverse osmosis module*	-	2666
Saudi bentonite clay**	0.134	-

*Price according to the National Water Company, Saudi Arabia, **Selling price by Dirah Drilling and Heavy Equipment Company, Saudi Arabia

wastewater. The study findings agree with the results of Al-Jlil (2010), who found that the removal of heavy metals was 97% by using bentonite clay and Saudi roasted pits. Similar results were reported by Erdem *et al*. (2004) who studied the adsorption behavior of natural (clinoptilolite) zeolites with respect to Co^{2+}, Cu^{2+}, Zn^{2+} and Mn^{2+} in order to consider its application to purity metal finishing wastewater. Their results showed that natural zeolites hold great potential to remove cationic heavy metal species from industrial wastewater.

Adsorption Mechanism of Metal ions on Saudi Bentonite Clay

The metal ions adsorption on Saudi bentonite clay is due to the electrostatic attraction between the negative sites of clay and the positive sites of heavy metal ions. The number of negative sites formed on the bentonite surface is mainly due to the presence of silica (Elliott and Huang, 1981). Similar results were reported by many investigators who used clay for the removal heavy metals such as cobalt, lead, cadmium, zinc and chromium ions from wastewater (Orumwense, 1996; Yadava *et al*., 1991; Pradas *et al*., 1994; Singh *et al*., 1992; Ceylan *et al*., 2005).

Brief Economic Study

A rough economic study regarding the removal of heavy metals using RO-Unit in the WTP, KACST and Adsorption Unit using Saudi bentonite clay as an adsorbent was estimated. The cost is estimated by dollar kg^{-1} of bentonite clay and per membrane module (Table 6).

The data in Table 6 showed that Saudi bentonite clay is the least expensive adsorbent as compared to the reverse osmosis module which in very expensive. In addition to above, since the Saudi bentonite clay is not expensive, its regeneration may be not required after the adsorption process as it would be for the other expensive adsorbents. The reason is that the Saudi clay do not need regeneration because it is natural, locally available and cheep adsorbent suitable for heavy metals removal. On the other hand, the RO-Unit needs frequent cleaning due to fouling on the membrane pores. This will increase the cost of using RO-Unit for removing the heavy metals from wastewater.

CONCLUSIONS

The concentration of heavy metals in the sewage wastewater in Riyadh city were above the permissible limits for crop production. The heavy metals concentration in the treated water were within the permissible limits for crop production. The mean minimum removal efficiency for the adsorption of metal ions on Saudi bentonite clay and reverse osmosis method were 88.89 and 87.92%, respectively.

The economical evaluation of the study showed that Saudi bentonite clay is the least expensive adsorbent as compared to RO-Unit. Also, Saudi bentonite clay do not regeneration after the adsorption process. Whereas in the case of RO Unit, the membrane module needs frequent cleaning due to fouling and is very expensive.

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