Evaluation of small home-use reverse osmosis units in Jordan

Odeh R. Al-Jayyousi*, Mousa S. Mohsen

*Civil Engineering Department, Applied Science University, Amman 11931, Jordan
Tel. +962 (6) 5237181; Fax +962 (6) 5232899; e-mail: jayousi@go.com.jo

Department of Mechanical Engineering, Hashemite University, Zarqa 13115, Jordan
Fax +962 (5) 3826613; e-mail: msmohsen@usa.net

Received 5 February 2001; accepted 19 February 2001

Abstract

This paper aims to evaluate the water quality of domestic RO units used in Jordan along with bottled and tap water. Analyses of the quality of water sources (RO, bottled and tap) and water cost are carried out. The methodology of this research is based on both lab experimental analysis and field survey of several RO units. It was concluded that all samples from the three sources are in compliance with Jordanian Standards. However, one type of bottled water and RO produced water are below the allowable limits with regard to all chemical properties. Tap water exceeds the allowable limit with regards to both total hardness and TDS, but is still below the allowable limits in case no better resource is available. However, with regard to pH and chloride concentrations, tap water is below the allowable limits. Based on quality and cost, it was found that RO produced water provides water within the allowable limits with a relatively reasonable price.

Keywords: Reverse osmosis; Jordan; Water quality; Bottled water

1. Introduction

Evaluation of water treatment system as a tool for protecting the public health requires an understanding of its role within the context of many measures for controlling health impacts in potable water systems.

Provision of a safe potable supply begins with the crucially important step of source selection. Selection involves three fundamental considerations, the first of which is that water must be

*Corresponding author.

sufficient in quantity and adequate in quality. There are relative measures of quality in a water supply system. Health suitability depends upon the statistical probability of adverse impacts. In evaluating health risks water supply professionals tend to be conservative because of heavy responsibility for protecting the health of large segments of the public. Accordingly, standards for protecting water quality typically begin with selection of the best source among those available, within reasonable economic constraints. Where alternative sources are both adequate in quantity and entirely satisfactory in quality, the third important consideration is total cost.

The public health standards consider drinking water to be safe for human consumption when it contains a maximum of 500 CFU/ml of HPC, when it is free from coliforms, and when nephelometric turbidity is less than 2. Drinking water should not contain any bacteria indicative of fecal pollution or any pathogenic microorganisms. Contamination is the most common and widespread health risk associated with drinking water, either directly or indirectly, by animal or human excreta, and particularly by feces [1].

In developing countries, more than 250 million new cases of waterborne diseases are reported annually. This has resulted in high morbidity and mortality rates, especially in young children. The pathogenic agents may cause diseases that vary in severity from mild gastroenteritis to severe and sometimes fatal diarrhea, dysentery, hepatitis, or typhoid fever [2-6].

Surface waters may contain pathogenic (disease-producing) organisms, suspended matter, or organic substances. Except in limestone areas, ground water is less likely to have pathogenic organisms than surface water, but may contain undesirable tastes and odors or mineral impurities limiting its use. Some of these objectionable characteristics may be tolerated temporarily, but it is desirable to raise the quality of the water to the highest possible level by suitable treatment.

In those instances where the nearly ideal water can be developed from a source, it is still advisable to provide the necessary equipment for treatment to ensure safe water at all times.

Although the Ministry of Water and Irrigation conducts a comprehensive set of lab tests for water quality [7], in summer 1998, a serious water pollution problem took place in Amman, Jordan. This water crisis in Jordan led to the spread of small and medium Reverse Osmosis (RO) units in the market. Vendors currently sell and/or distribute treated water on demand. In Amman City alone, more than 120 small businesses are in operation. Many households have installed small RO units to ensure adequate quality of drinking water. The capacity of these units are in the range of 5–15 m³/d [8].

This paper aims to assess the quality of treated water from domestic RO units used in Jordan and to compare it with tap and bottled water in Amman. The methodology of the research is based on both lab experimental analyses and field survey of several RO units. Cost of production of 1 m³ of treated water and affordability will be addressed for various types of treated water in Amman City.

1.1. Water properties and Jordanian standards

In this section a brief description of Jordanian standards for drinking water is presented.

The allowable limit in Jordanian standards for TDS is 500 mg/l and 1500 mg/l in case no better resource is available. Dissolved substances may be organic or inorganic in nature. Inorganic substances which may be dissolved in water include minerals, metals, and gases. The TDS is expressed as mg/l on a dry-mass basis. An approximate analysis for TDS is often made by determining the electrical conductivity of the water. The ability of water to conduct electricity, known as the specific conductance, is a function of its ionic strength. Specific conductance is measured by a conductivity meter employing the Wheatstone bridge principle. The standard procedure is to
Table 1

Limits of drinking water physical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Allowable limit</th>
<th>Maximum allowable in cases where no better resource is available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taste</td>
<td>Acceptable to most consumers</td>
<td></td>
</tr>
<tr>
<td>Odor</td>
<td>Acceptable to most consumers</td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>10 units estimated by platinum cobalt measure</td>
<td>15 units</td>
</tr>
<tr>
<td>Turbidity</td>
<td>One (1) unit estimated by Jackson candle apparatus, or the equivalent</td>
<td>5 units</td>
</tr>
<tr>
<td>pH</td>
<td>Shall be no less than 6.5 and no more than 9</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Shall preferably range from 8–25°C</td>
<td></td>
</tr>
</tbody>
</table>

Measure the conductivity in a cm³ field at 25°C and express the results in millisiemens per meter (mS/m) by using a conductivity meter [9].

The range of natural pH in fresh waters extends from around 4.5–10. Jordanian standards determine the range of pH within the limit of 6.5–9.0 for the drinking water. Jordanian standards set the allowable limit to be 100 mg/l as CaCO₃ and in case no better resource is available 500 mg/l as CaCO₃. The total calcium and magnesium content of the water is considered to constitute the total hardness when expressed as CaCO₃.

Chlorides in reasonable concentrations are not harmful to humans. At concentrations above 250 mg/l they give a salty taste to water, which is objectionable to many people. For this reason chlorides are generally limited to 250 mg/l in supplies intended for public use. Because sewage is a source of chloride, a high concentration of chloride may indicate pollution of a water by a sewage affluent. Jordanian standards specify the allowable limit as 200 mg/l and 500 mg/l in case no better source is available.

The physical properties shall not exceed the limits shown in Table 1. The toxic substances counts in water shown below shall not exceed the limits as presented in Table 2.

The counts of substances that have a health or water acceptability effect, or that are considered an indicator to pollution, shall not exceed the limits shown below in Table 3.

The most probable number of colonial bacteria should not exceed 2.2/100ml from tested water using the multi-tube method, and equal to zero when using the filtration membrane method. The tested 100 ml sample should be free of fecal colonial bacteria. In case non-fecal colonial bacteria is present in the sample then another test can be performed by looking for other indications such as fecal germs and clostridium germs. Concentration should be made on testing samples from places where germal tests indicate that total bacterial count equals more than 1000 m. The residual free chlorine shall be no less than 0.2 mg/l, and preferably no more than 0.8 mg/l when water supply reaches the consumer.

Table 2

Limits of toxic substances for drinking water

<table>
<thead>
<tr>
<th>Substances</th>
<th>Maximum limit, mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead, Pb</td>
<td>0.05</td>
</tr>
<tr>
<td>Selenium, Se</td>
<td>0.01</td>
</tr>
<tr>
<td>Arsenic, As</td>
<td>0.05</td>
</tr>
<tr>
<td>Total chrome, Cr</td>
<td>0.05</td>
</tr>
<tr>
<td>Cyanide, Cn</td>
<td>0.1</td>
</tr>
<tr>
<td>Cadmium, Cd</td>
<td>0.005</td>
</tr>
<tr>
<td>Mercury, Hg</td>
<td>0.001</td>
</tr>
<tr>
<td>Antimony, Sb</td>
<td>0.01</td>
</tr>
<tr>
<td>Silver, Ag</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Table 3
Limit of substances that have a particular effect on water acceptability

<table>
<thead>
<tr>
<th>Substance</th>
<th>Allowable limit, mg/l</th>
<th>Maximum allowable in case no better resource is available, mg/l</th>
<th>Type of effect within the maximum limit shown in this Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dissolved salts, TDS</td>
<td>500</td>
<td>1500</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Total hardness, TH (CaCO₃)</td>
<td>100</td>
<td>500</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Detergents, ABS</td>
<td>0.5</td>
<td>1.0</td>
<td>Pollution indicator</td>
</tr>
<tr>
<td>Aluminum, Al</td>
<td>0.2</td>
<td>0.3</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Iron, Fe</td>
<td>0.3</td>
<td>1.0</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Manganese, Mn</td>
<td>0.1</td>
<td>0.2</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Copper, Cu</td>
<td>1.0</td>
<td>1.5</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Zinc, Zn</td>
<td>5</td>
<td>15</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Sodium, Na</td>
<td>200</td>
<td>400</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Nickel, Ni</td>
<td>0.05</td>
<td>0.1</td>
<td>Health</td>
</tr>
<tr>
<td>Chloride, Cl</td>
<td>200</td>
<td>500</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Fluoride, F</td>
<td>1.0</td>
<td>1.5</td>
<td>Health</td>
</tr>
<tr>
<td>Sulfite, SO₄</td>
<td>200</td>
<td>500</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Nitrate, NO₃</td>
<td>45</td>
<td>70</td>
<td>Health</td>
</tr>
</tbody>
</table>

1.2. Typical small RO system

The idea of RO has been known for over 200 years, however, the practical application is a recent development. In 1962 the US Government funded the first RO plant which processed 1000 gallons clean water per day. Today, there are more than 3000 large RO treatment plants, each producing more than a million gallons of drinking water each day.

A brief description of a typical medium RO Plant used in Jordan is shown in Fig. 1.

A primary treatment is performed on tap water. First tap water flows from storage tank or the municipal line. Then tap water flows through a 5-micron cellulose filter. This filter is made of matted fibers or materials compressed to form a matrix that retains particles by random adsorption or entrapment. This filter is usually used as prefiltration because it is an economical way to remove 98% of suspended solids, dirt, rust and other sediment. It also protects elements downstream from fouling or clogging. After that, the water is stored in Tank A as shown in Fig. 1. Next, water flows through another 5-micron cellulose filter to ensure effective filtration. Water is split into two paths; in the first path water flows to the softener. The softener has a small tank full with NaCl, the softener function is to replace Mg²⁺ and Ca²⁺ with Na⁺, and this process is called Ion Exchange. In this stage the hardness of water is reduced and the water becomes soft. The other advantage of the softener is that it lengthens the life of components downstream.

Then, water flows to activated carbon filter, which is made from cool, coconut, lignite and wood. In the next stage of the process, water flows to the RO membrane system. RO membranes are capable of rejecting practically all particles, bacteria, and viruses.

In water purification systems, a pump with 14bar will provide enough pressure for RO application, pressure will be applied to the concentrated solution to counteract the osmotic pressure. Pure water is driven from the concentrated solution and collected downstream of the
membrane. Different feed water may require different types of RO membranes. Also, to increase the amount of water another membrane is used, that increases the capacity of the system. Water pressure also affects the quantity and the quality of the water produced. In the second path water flows to 2 series of activated carbon filters. These filters remove chlorine, sulfur, volatile organics and the remaining bad taste and odors from water.

Water from the first path and the second path meet in tank B as shown in Fig. 1. In this tank B water from 2 paths is mixed. This mixing will increase TDS value to be around 300 mg/l to give the water adequate test.

A post treatment is performed to ensure a better quality of water. A small pump (3 bar) pushes the water to 3 series filters. The first one is 5-micron cellulose filter, the second one is an activated carbon filter, and the third one is 1-micron cellulose filter. These 3 filters are installed to ensure the quality of water. They perform another treatment to remove the last remaining traces of resin fragments, carbon fines, colloidal and microorganisms.

Finally, water flows to an ultraviolet unit, UV, where radiation is used as a germicidal treatment for water. Mercury low-pressure lamps generating 254 nm UV light are used. Later, water flows to 1 micron cellulose filter. Finally, water is stored in tank C as shown in Fig. 1 for domestic use.
2. Methodology

The methodology adopted in this research is based on lab analyses of chemical, physical and biological properties of water and field survey of RO units. Specifically, the following steps were performed: selection of water sources, setting up criteria and test procedures, sample collection, performing tests, and data analysis. Samples were taken from 3 types of water:

1. Bottled water: samples were taken from two commercially available bottles in the local market (referred to as G and F). Acronyms were used to keep results anonymous.
2. Water from a medium RO unit in Amman City: samples were taken from a local water supplier (referred to as N).
3. Tap water from a medium income household in west Amman which is supplied by water from Zai-Dabouq system.

Water quality was monitored by taking weekly samples for a total period of 14 weeks representing water quality in summer and winter. A sample collection was carried out in two periods:

- Summer samples from 1st of July 1999 to 19th of August 1999 by taking a sample each week; a total of 8 samples were taken.
- Winter samples from 1st of November 1999 to 6th of December 1999 by taking a sample each week; a total of 6 samples were taken.

The volume of samples tested were 1.51 from various sources, except of the sample F which was 3.781.

3. Results and discussion

Figs. 2–5 show the results of the water chemical properties: hardness, chloride, pH and TDS, for all sources, bottled G, bottled F, RO produced water N, and tap water, respectively. The results are shown with respect to standards documented by the supplier, average experimental
Fig. 5. Experimental results of tap water properties.

data, and the allowable limits of the Jordanian standards. The experimental data represent water quality in summer and winter.

In terms of TDS, shown in Fig. 6, the experimental results in summer and winter for bottled water F have the lowest values compared to other water sources; 134 mg/l and 128 mg/l for summer and winter, respectively, both values are lower than standards documented by the supplier and the Jordanian standards. The second sample is the RO produced water N; it has TDS values of 168 mg/l and 201 mg/l for summer and winter, respectively, followed by bottled water G. All samples have TDS values less than the Jordanian standards allowable limit. For tap water the TDS values are 628 mg/l and 609 mg/l for summer and winter, respectively. It is clear that these values are greater than both the Jordanian standards allowable limit and the claimed test results given by the Dabouq Reservoir Authority, although they are less than the maximum allowable limit, which is 1500 mg/l.

Fig. 7 compares the results of water pH value for all sources. For all samples, pH values fall within the allowable range of the Jordanian standards, which are 6.5–9. The highest value recorded by bottled water G sample with a pH of about 8.
Chloride concentrations for all samples are shown in Fig. 8. All concentrations are below the Jordanian standards allowable limit which is 200 mg/l. The lowest value was recorded for bottled water F that is 19 mg/l while the highest was for tap water, which was about 181 mg/l.

Fig. 9 shows the results of total hardness of all samples. Both bottled water G and tap water have hardness values that exceed the Jordanian standards allowable limit which is 100 mg/l; with winter experimental data of tap water having a value of 305 mg/l, which is the highest among all samples, but both samples have hardness values less than the maximum allowable limit. Bottled water F and RO produced water N have hardness values lower than the Jordanian standards allowable limit, with an average value of 51 mg/l for bottled water F.

The results of microbiological tests are shown in Table 4, the tests included coliforms, membrane filtration procedure for fungi testing and membrane filtration procedure for other bacteria (inhabitants) in water. All water sources proved to be in compliance with Jordanian standards. Moreover, all results do not exceed the maximum rate of coliform bacteria, which is 4 coliform bacteria/100 ml of water.

With respect to water affordability and cost of 1 m³ of water, the actual selling price of one m³ of different sources was calculated and is shown in Fig. 10. It was shown, that tap water is the least expensive with a price of 0.337 JD/m³ ($1=JD0.70), and bottled water G is the most expensive with a price of 167 JD/m³. The price of RO produced water N was estimated to be 50 JD/m³. This price is lower than both samples of bottled water, but still higher than the price of tap water by about 148 times.

4. Conclusion

The following can be concluded regarding water quality assessment of this study:
Fig. 8. Chloride concentration for all samples.

Fig. 9. Total hardness concentration for all samples.
Table 4
Experimental results of coliform, fungi and other bacteria tests for all samples

<table>
<thead>
<tr>
<th>Sample source</th>
<th>Coliforms tests tube</th>
<th>Sabouroud dextrose agar # of colony/100 ml</th>
<th>Plate count agar # of colony/100 ml</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td>MNP for 100 ml</td>
<td>Plate # Results</td>
</tr>
<tr>
<td>I-Schools</td>
<td></td>
<td>BGBL E.C.</td>
<td>1 2 3 Results</td>
</tr>
<tr>
<td>II-Filtered water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tap water</td>
<td>-ve -ve -ve -ve -ve</td>
<td>&lt;2.2</td>
<td>/</td>
</tr>
<tr>
<td>Reverse osmosis</td>
<td>-ve -ve -ve -ve -ve</td>
<td>&lt;2.2</td>
<td>/</td>
</tr>
<tr>
<td>G</td>
<td>-ve -ve -ve -ve -ve</td>
<td>&lt;2.2</td>
<td>/</td>
</tr>
<tr>
<td>F</td>
<td>-ve -ve -ve -ve -ve</td>
<td>&lt;2.2</td>
<td>/</td>
</tr>
</tbody>
</table>

Fig. 10. Price of 1 m³ for various water samples.

1. All water samples from various sources proved to be in compliance with Jordanian standards for drinking water.
2. Bottled water F and RO produced water N are below the allowable limits with regard to all chemical properties.
3. Bottled water G exceeds the allowable limit for total hardness but is still below the maximum allowable limit in case no better resource is available. However, it is below the allowable limits in all other chemical properties.
4. Tap water exceeds the allowable limit with regard to both total hardness and TDS, but is still below the allowable limits in case no better resource is available. However, with regard to pH and chloride concentrations in tap water it is below the allowable limits.
5. There is no significant difference in water chemical properties between summer and winter results.
6. Experimental results for bottled water F and G were found to be close to company standards.
7. Bottled water F showed the best results with regard to chemical water properties.
8. With respect to biological properties, it is concluded that all water sources proved to be in compliance with the Jordanian standards.
9. Based on the cost of 1 m³, it is found that tap water is the cheapest source of water (0.337 JD's) and bottled water G is the most expensive (166.7 JD's).
10. Overall, in terms of quality and cost, it is found that RO produced water N unit provides water within the allowable limits of the Jordanian standards, with a relatively affordable reasonable price.

References


