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Assessment of the reverse osmosis system's effectiveness in eliminating impurities and enhancing dialysis water quality

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Abstract

This study sought to assess the chemical and physical characteristics of dialysis water as well as the effectiveness of a reverse osmosis plant in eliminating impurities in the summer and winter. Several important parameters, including pH, electrical conductivity, total dissolved solids, phosphates, alkalinity, turbidity, total hardness, chloride, and heavy metals (Fe, Pb, Cr, Cd, Zn, Ni), were measured as part of the analysis.

The pH levels, which ranged from 7.6 to 8.2 in the source water and from 7.9 to 8.0 after treatment, were found to be within acceptable bounds. In summer and winter, electrical conductivity significantly decreased from 358 and 253 $\mu\text{S}/\text{cm}$ to 2.9 and 4.5 $\mu\text{S}/\text{cm}$, respectively. Additionally, total dissolved solids levels dropped from 175 and 124 ppm to 1 and 2 ppm, resulting in excellent removal efficiencies of 98.39% and 99.43%, respectively.

In terms of the other metrics, turbidity dropped from 9.8 and 0.9 NTU to 0.1 and 0.07 NTU with efficiencies of 98.98% and 92.22%, while alkalinity dropped from 138 and 92 ppm to 3 and 8 ppm with efficiencies of 97.83% and 91.30%. Chloride levels dropped from 19 and 16.2 ppm to 7.1 and 3.5 ppm with efficiency of 62.63% and 78.40%, while total hardness dropped from 188 and 162 ppm to 20 and 12 ppm with removal rates of 89.36% and 92.59%.

Regarding the other parameters, alkalinity decreased from 138 and 92 ppm to 3 and 8 ppm with efficiencies of 97.83% and 91.30%, while turbidity decreased from 9.8 and 0.9 NTU to 0.1 and 0.07 NTU with efficiencies of 98.98% and 92.22%. Chloride levels dropped from 19 and 16.2 ppm to 7.1 and 3.5 ppm with efficiency of 62.63% and 78.40%, while total hardness dropped from 188 and 162 ppm to 20 and 12 ppm with removal rates of 89.36% and 92.59%.

These results demonstrate the efficiency of the reverse osmosis facility in removing dissolved contaminants and physical traits. Due to its poor efficacy in removing certain heavy metals, particularly lead and cadmium, additional treatment procedures must be put in place to ensure the safety of dialysis water.

Keywords: Reverse osmosis, dialysis water, hemodialysis, HPI, CKD

Introduction

Water is also an essential ingredient of most of the basic processes and is particularly noteworthy in terms of health, such as the renal dialysis process of those with kidney illness ^[1]. Dialysis is the main compensatory process of patients with renal failure to get rid of toxins and metabolic waste products accumulated in their blood, which is based on the principles of diffusion and filtration, and utilizes a semipermeable membrane that allows the passage of specific molecules and ions ^[2]. This process requires the presence of water and as the kidney dialysis patient will be subjected to between 90 and 190 liters of water during one dialysis session; the purity and quality of this water becomes a very important consideration to the patient ^[3].

The semipermeable membrane allows the easy passage of heavy metals and other chemical pollutants present in dialysis water to the circulation where they can build up in body tissues and lead to significant health effects with the most notable being metal poisoning ^[4]. Consequently, several health agencies including the American Association of Advancement of Medical Devices (AAMI) and the International Organization of Standardization (ISO) have come up with strict regulations and specific thresholds of each component or contaminant in water ^[5, 6].

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Monitoring the quality of water in general and dialysis water in particular in scientific research in relation to the analytical component is important due to the high quality of water cleanliness and devoid of any chemical pollutants that may lead to a health problem or worsen the patient condition. Some of the most important of these substances or contaminants include heavy metals, sodium, potassium, chlorides and sulfates [7]. To achieve this, several complex chemical analysis methods are employed which may include spectroscopy, electrical conductivity testing, pH testing and atomic absorption spectroscopy. For accurately determining elemental and contaminant concentrations, these analytical chemistry techniques are crucial [8, 9].

Reverse osmosis removes a great quantity of dissolved salts, organic matter, and heavy metals in the water with the help of semi-permeable membranes; that is why it is considered one of the most significant technologies applied in dialysis plants to treat water [10]. This technique is mostly applied in a combined system that incorporates pre-treatment steps such as filtering, dechlorination and softening to protect the reverse osmosis membranes and enhance their overall performance [11].

A number of past studies have been done to investigate quality of water used in dialysis machines and effectiveness of reverse osmosis systems to eliminate various contaminants [12]. Some study [13] has shown that when used and appropriately maintained, reverse osmosis machines can extract a considerable level of salts and heavy metals in water. The functionality of these systems, however, may be influenced by numerous factors, including the quality of the raw water fed into the system, the effectiveness of the pre-treatment stages, the state of the membranes installed to it, and the level of their maintenance per year [14]. According to other studies, the lack of proper water treatment systems can cause the rise of certain elements in dialysis water, which can cause illness to patients and predispose them to dialysis-related problems [15].

Consequently, analytical studies should be undertaken on a periodical basis to determine the effectiveness of water treatment systems in renal dialysis centers, more so where they use varying water sources that could possess varied physical and chemical characteristics [16]. This is because the quality of water should be continuously checked to ensure that it is of approved health standards [17].

Thus, the research problem is that there is a necessity to analyze the quality of the water used in dialysis units and the effectiveness of the treatment systems, especially reverse osmosis systems, to eliminate different chemical pollutants and provide the water with appropriate levels to be used in medicine.

This research is intended to perform a chemical and analytical assessment of the water quality of dialysis units within the dialysis center in Hawija District, Kirkuk Governorate in 2025. This will be achieved by comparing the results with international criteria for the quality of water used in dialysis, as well as by analyzing a range of physical and chemical properties of the water both before and after treatment at the reverse osmosis plant. This will be useful in offering scientific data that will enhance the quality of care given to kidney failure patients in the area and enhance the efficiency of water treatment systems.

Materials and Methods

Study Site

This research was carried out in 2025 in the hemodialysis unit of Hawija District, Kirkuk Governorate, Iraq. The unit has a reverse osmosis (RO) water treatment device to generate high purity water to be used in dialysis solution.

Collecting Samples

Water samples were collected prior to and after the treatment using the RO system. The samples were collected in 1-liter sterile and clean bottles, kept under appropriate conditions, and transported to the lab as soon as possible to conduct chemical and physical analyses to exclude possible changes in their properties.

Physical and chemical tests

A Shimadzu AA-6200 atomic absorption spectrometer was used to measure heavy metals. A Jenway 3310 (Japan) was used to monitor pH. An EC meter BC 3020 (Singapore) was used to detect electrical conductivity (EC) and total dissolved solids (TDS).

A HACH DR3900 visible light spectrometer was used to measure additional chemical characteristics. The TNTplus 10239 method was used to test alkalinity, the TNTplus 10291 method to measure chlorides (Cl^-), and the TNTplus 10293 method to measure total hardness. The Persulfate UV Oxidation 8007 technique was used to measure phosphate (PO_4). The turbidity was tested by a turbidity meter and the results are presented in NTU.

The following formula was used to compare the concentrations of variables before and after treatment in order to determine the reverse osmosis system's contamination removal efficiency:

$$\text{Removal Efficiency(\%)} = \frac{C_{\text{before}} - C_{\text{after}}}{C_{\text{before}}} \times 100$$

Where C_{before} denotes the concentration of the element prior to treatment and C_{after} signifies its concentration subsequent to treatment.

The Heavy Metal Pollution Index HPI is an index procedure which calculates the extent to which water supplies are generally contaminated by heavy metals. The two important criteria used to compute this index [18, 19] were the standard allowable limit (Si) of each heavy metal [6] and unit weighted (Wi) of each individual metal which used the following equation:

$$HPI = \frac{\sum_{i=1}^n WiQi}{\sum_{i=1}^n Wi}$$

where (n) is the number of parameters taken into consideration, (Wi) is the unit weight, and (Qi) is the sub-index of the (i) parameter.

Results

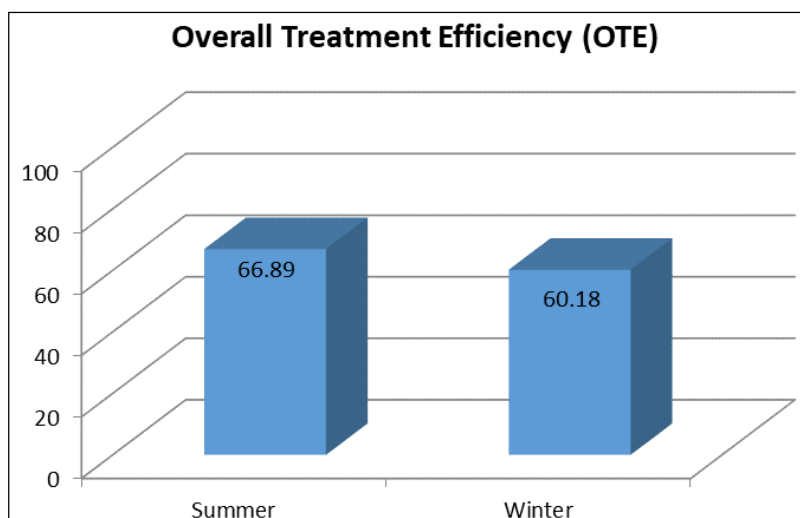
Table 1 presents the results of the physical and chemical properties of dialysis water prior to and following the treatment at the reverse osmosis plant. All pollution removal capacity of the reverse osmosis plant is presented in Table 2. The overall statistics of the efficacies of the treatment plant during summer and winter are presented in Figure 1. Figure 2 shows the index of heavy metal pollution (HPI).

Table 1: Shows the physical and chemical properties of dialysis water

No	Parameter	Standard AAMI [6]	Source	Summer	Winter
1	pH	6.5-8.5	In	8.2± 0.0493	7.6±0.0351
			Out	7.9±0.0950	8±0.0603
2	E.C μS/cm	-	In	358±2.6460	253±3.0622
			Out	2.9±0.9521	4.5±0.8443
3	T.D.S ppm	100	In	175±1.5280	124±1.8562
			Out	1± 0.0811	2±0.0741
4	PO ₄ ppm	-	In	1.7±0.1103	1.9±0.2028
			Out	1.1±0.0741	0.8±0.0136
5	Alkalinity ppm	-	In	138±2.0941	92±1.7420
			Out	3±0.5180	8±1.6302
6	Turbidity NTU	0	In	9.8±1.7392	0.9±0.3461
			Out	0.1±0.0236	0.07±0.01063
7	Total Hardness ppm	10	In	188±5.8293	162±6.9201
			Out	20±1.2094	12±1.0611
8	Chloride ppm	5	In	19±1.0961	16.2±1.1099
			Out	7.1±1.0821	3.5±0.9421
9	Fe ppm	0.1	In	0.2±0.0306	0.03±0.0008
			Out	0.1±0.0211	0.05±0.0009
10	Pb ppm	0.005	In	0.0173± 0.0015	0.0181±0.001
			Out	0.0143±0.002	0.0149±0.0021
11	Cr ppm	0.014	In	0.02±0.0051	0.019±0.0008
			Out	0.0083±0.0009	0.006±0.0002
12	Cd ppm	0.001	In	0.0236±0.0031	0.02477±0.004
			Out	0.0168±0.002	0.01767±0.007
13	Zn ppm	0.1	In	0.5538±0.0112	0.5806±0.0136
			Out	0.1923±0.0201	0.2016±0.0094
14	Ni ppm	0.004	In	ND	ND
			Out	ND	ND

Table 2: The reverse osmosis plant's pollution removal efficiency

Parameter	Summer	Winter
TDS	99.43 %	98.39 %
PO ₄	35.29 %	57.89 %
Alkalinity	97.83 %	91.30 %
Turbidity	98.98 %	92.22 %
Total Hardness	89.36 %	92.59 %
Chloride	62.63 %	78.40 %
Fe	50.00 %	- 66.67 %
Pb	17.34 %	17.46 %
Cr	58.50 %	68.42 %
Cd	28.81 %	28.66 %
Zn	65.28 %	65.28 %

**Fig 1:** Overall Efficiency for the Summer and Winter

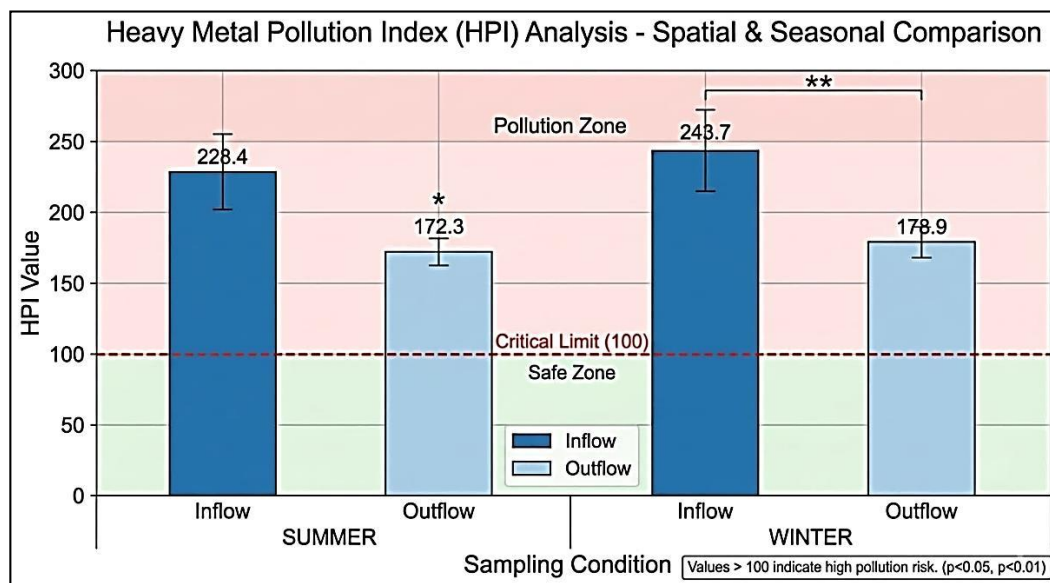


Fig 2: The Heavy Metal Pollution Index (HPI)

Discussion

The results in Table 1 shows that the physical and chemical properties of dialysis water treated with reverse osmosis technology have greatly improved. This shows the level of efficiency of the system in decreasing the levels of pollutants to a level that can be used in medicine. These results are especially significant as the renal failure patients are hypersensitive to any water quality alteration and such water directly flows into the blood during dialysis.

The findings made it clear that the ranges proved to be stable in internationally recognized ranges with pH values of 7.6 to 8.2 prior to treatment and 7.9 to 8.0 after treatment. This is in line with the recommendations put forward by the World Health Organization and the Association of Advancement of Medical Instrumentation which recommends that the pH should be maintained to be approximately at a neutral level. This stability is a very significant indicator that the treatment method did not cause any undesired changes in the chemical. Other researchers conducted in the past on the quality of dialysis water have also established that RO systems do not significantly affect the acid-base balance, and that the pH levels after treatment are within the acceptable values [20].

Electrical conductivity (EC) and total dissolved solids (TDS) were reduced significantly following treatment with TDS decreasing to 1-2 ppm, which means that virtually all the dissolved salts were eliminated. These results indicate the dissolving removal efficiency of 98.39-99.43 in Table 2. These findings are in line with a few studies that show that reverse osmosis is used to eliminate the total dissolved solids in dialysis plants [20, 21]. Nevertheless, they are contrasted with the previous works that demonstrated that it is not possible to use reverse osmosis plants to eliminate total dissolved solids effectively [22, 23].

Regarding turbidity, the outcomes indicated that the turbidity decreased significantly to very low levels (0.07-0.1 NTU) that is less than the global proportion of the recommended number (<1 NTU) by the World Health Organization. This decrease can be explained by the fact that the RO membranes are effective in removing small particles and suspended solids. This research established that a decrease in turbidity is a sure sign of better water quality and reduced possibility of microbial contamination [24].

In addition, alkalinity and total hardness results (Table 2) indicated a tremendous decrease in results post-treatment with the removal efficiencies of (91.30-97.83%) and (89.36-92.59%), respectively. This shows that the system is efficient in eliminating calcium and magnesium ions, which may cause hazardous build-ups in dialysis equipment. These findings coincide with a 2021 study of dialysis water hardness by a Libyan researcher who found that after treating water, a reduction of hardness and alkalinity is a requirement to the dialysis water quality based on AAMI standards [20].

The concentrations of chloride ions (Cl^-) decreased to safe concentrations within the recommended limits of the WHO (≤ 250 ppm) although the removal was only moderate (62.63-78.40%). These results were attributed to the selectivity of the reverse osmosis membranes, particularly, their permeability to some monovalent ions, which are more difficult to eliminate than divalent ions. The findings of the new study do not correspond with all the previous studies [25] but it does not agree with most of the previous studies [23, 26] that found the concentrations of the chloride to be exceeding the permissible levels.

The effectiveness of heavy metals removal is also greatly different as the data in Tables 1 and 2 demonstrates. Having a modest degree of removal, iron (Fe) levels were reduced to amounts of less than acceptable limits (≤ 0.3 ppm, as advised by the WHO) [25]. Table 2 indicates that lead (Pb) was the least effective at removal (approximately 17%), with Table 1 indicating that lead concentrations were in excess of what was permitted. Considering its great toxicity even in very low doses, it was observed in all models during the summer as well as during the winter. A maximum concentration of 0.01 ppm is advised by the WHO. According to a study on lead toxicity in hemodialysis, long-term lead exposure in dialysis patients might cause major problems that call for better removal methods. The results obtained in the present study are consistent with other studies in the other fields [27, 28].

As per the studies on heavy metals in reverse osmosis, where it was proposed that the size of ions, as well as their charge, and their interaction with organic compounds, could influence the removal process, chromium (Cr) and cadmium (Cd) too showed moderate to poor removal efficiencies [25]. Nickel (Ni): on the other hand, the presence or absence of

nickel (Ni) was not detected, which implies that the metal was present or absent in the amounts below the detectable limit, whereas zinc (Zn) showed excellent removal ability (approximately, 65%). The results of the current study are consistent with the findings of other studies on the efficacy of reverse osmosis to remove zinc, cadmium and chromium [25, 28].

On the whole, these findings indicate that the reverse osmosis system is compliant with the World Health Organization (WHO) and Association of the Advancement of Medical Instrumentation (AAMI) standards in most parameters particularly in regard to dissolved salts, turbidity, and alkalinity [6, 25].

But the fact that certain heavy metals, especially lead and cadmium, are not removed by the system very well implies that either routine maintenance or that more advanced processing processes, such as ion exchange or adsorption, are required to enhance the system.

The total removal efficiency of the plant was recorded in 66.89% in the summer and 60.18% in the winter as indicated in Figure 1. Though reverse osmosis systems are considered to be one of the most effective ways to treat dialysis water, these findings are not surprising compared to the many studies conducted before them that demonstrated that they might require additional support to completely remove certain negative elements [25, 26]. In order to guarantee patient safety and reduce the health hazards connected with using non-compliant water, this study suggests ongoing water quality monitoring and rigorous adherence to international standards.

Both the inlet and outflow water of the two seasons show high pollution levels in both seasons as indicated by the Heavy Metal Pollution Index (HPI) in Figure 2. All values were evidently higher than the critical limit (100) that defines water as highly contaminated [27]. The HPI value of the intake water was 228.4 in the summer period which decreased to 172.3 after treatment and 243.7 to 178.9 after treatment in the winter period.

Overall, these findings reveal that the reverse osmosis system employed satisfies most of the World Health Organization (WHO) and Association of the Advancement of Medical Instrumentation (AAMI) criteria in the various indicators, especially the dissolved salts, turbidity, and alkalinity. Taking these findings with the data in Tables 1 and 2, it becomes evident that the low efficiency of removing some heavy metals, namely lead (Pb) and cadmium (Cd), is the main reason of the steady high HPI levels. According to the results, both the removal efficiency of lead (~17%) and cadmium (~28%) was low (Table 2). The presence of these elements, even in relatively low concentrations, significantly enhances the index value since HPI index takes into consideration the relative weights and concentrations of harmful metals [28].

Additionally, both before and after therapy, HPI readings were greater in winter than in summer. Heavy metals' higher solubility or a shift in the sources of pollution during the rainy season could be the cause of this [29]. The efficiency of the RO system in reducing a significant percentage of the heavy metal burden is however evidenced by the change in relative decrease in HPI after treatment that is similar to the significant decrease in concentrations of metals such as zinc (Zn) and chromium (Cr) as shown in Table 1. The achievement of acceptable levels is however limited by the poor total eradication of some of the harmful components.

Thus, it can be said that employing reverse osmosis by itself might not be enough to ensure that dangerous heavy metals are completely eliminated. In order to ensure that the HPI levels are reduced to a level below the critical limit (100) and obtain the full compliance with the international standards, one can suggest adding such advanced stages of the treatment process as activated carbon adsorption or ion exchange to the basic operations of the membrane maintenance.

Altogether, the data presented in Figure 2 and Tables 1 and 2 indicate that the quality of dialysis water still remains to be enhanced in terms of the ability to eliminate heavy metals despite the treatment to ensure patient safety and minimize the risks of long-term issues.

Conclusions

The results of the study prove the effectiveness of a reverse osmosis technology in increasing the quality of dialysis water. It significantly increased the quality of the water and made it suitable to specific medical purposes by enhancing most of the physical properties of the water and reducing the chemical contaminants like dissolved salts, turbidity, hardness and alkalinity. The results bring us to the conclusion that reverse osmosis can be rather effective to remove the typical impurities and improve the major properties of water. Not always was the elimination of heavy metals successful, however. Though the method was effective in reducing some of the heavy metals it was not effective in removing other metals that are hazardous to the health. This implies that employing reverse osmosis by itself might not be enough to ensure that all microcontaminants are eliminated. It was also observed that seasonal changes also influence the effectiveness of the treatments, which highlights the importance of continuous monitoring of the operational conditions and water quality received. Hence, though reverse osmosis is a simple and efficient step in dialysis water treatment process, to achieve the maximum level of safety, it is necessary to provide further levels of treatment, improved maintenance, and frequent monitoring procedures to ensure that the quality of water meets the needed health criteria.

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