Performance Study of Some Reverse Osmosis Systems for Removal of Uranium and Total Dissolved Solids in Underground Waters of Punjab State, India.

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Abstract: Radionuclides (uranium, thorium, radium, radon gas etc.) are found naturally in air, water, soil and rock. Every day, we ingest and inhale these radionuclides through the air we breathe and through food and water we take. Out of the internal exposure via ingestion of radionuclides, water contributes the major portion. The natural radioactivity of water is due to the activity transfer from bed rock and soils. In our surveys carried out in the past few years, we have observed high concentrations of uranium and total dissolved solids (TDS) in drinking waters of some southern parts of Punjab State exceeding the safe limits recommended by national and international agencies. The main drinking water source is the underground water procured from different depths. Due to the highly saline taste, disorders in their digestive systems and other ailments, people are installing reverse osmosis (RO) systems in their houses. Some RO systems have been installed on commercial basis. The state government is also in the process of installing community RO systems at the village level. As high values of uranium are also undesired and may pose health hazards due to radioactivity and toxicity of uranium, we have conducted a survey in the field to study the performance of various RO systems for removal of uranium and TDS. Water samples from about twenty-five RO systems from Faridkot, Mansa, Bathinda and Amritsar districts of Punjab State were collected and analyzed. Our results show that some RO systems are able to remove more than 99% of uranium in the underground waters used for drinking purposes. TDS values are also reduced considerably to the desired levels. So RO systems can be used to avoid the risk of unduly health problems posed by high concentrations of uranium and TDS in drinking water.

Keywords: *Reverse Osmosis, Uranium, Total Dissolved Solids, Water, Punjab***.**

1. Introduction:

Water plays an important role in our life. It is indispensable and one of the precious natural resources of this planet. Excess or lack of minerals in water can hamper the normal functioning of the body organs and can give rise to various illnesses. It is also needed for the maintenance of proper body temperature. So pure water that contains all the essential minerals within the limits prescribed by various agencies should be consumed. Most of the sources of drinking water like hand pumps, tubewells, rivers etc are highly contaminated by the addition of undesireable substances which have rendered it unfit for consumption. Reverse Osmosis (RO) is one of the most popular methods for purifying the polluted water for drinking purposes. A significant advantage of RO over traditional water treatment technologies is that it also reduces the concentration of other ionic contaminants as well as dissolved organic compounds. A rejection of contaminant removal is a function of membrane type and pore size. [1-6]

Reverse Osmosis (RO) is a process for the removal of dissolved ions from water in which pressure is used to force the water through a semipermeable membrane element which will pass the water but reject most of the dissolved materials. Reverse osmosis occurs when the water is moved across the membrane against the concentration gradient, from lower concentration to higher concentration. To illustrate, imagine a semipermeable membrane with fresh water on one side and a concentrated aqueous solution on the other side. If normal osmosis takes place, the fresh water will cross the membrane to dilute the concentrated solution. In reverse osmosis, pressure is exerted on the side with the concentrated solution to force the water molecules across the membrane to the fresh water side.

Total dissolved solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in water. The total dissolved solids also measures the total amount of dissolved minerals in water. Concentrations of TDS from natural water sources have been found to vary from less than 30 mg/l to as much as 6000 mg/l, which strictly depends upon the solubilities of minerals in different geological regions [7]. Bureau of Indian Standards [8], Health Canada [9] and Environmental Protection Agency of USA [10] limits the amount of dissolved solids as 500mg/l for drinking water and WHO [11] has set a limit of 600mg/l for TDS in drinking water.

Apart from chemical toxic substances, radioactive elements may also be present in the drinking water which may also cause health hazards. One of such elements is the uranium that we have analysed in our present study. Due to its chemical toxicity and radioactive nature, high intakes of uranium through food and water can lead to harmful effects on the body, particularly different types of cancers as is evident from animal experiments. Animal studies, as well as studies of occupationally exposed persons, have shown that the major health effect of uranium is chemical kidney toxicity [12- 15]. Both functional and histologic damage to the proximal tubulus has been demonstrated [16 - 22]. In a study carried out by Zamora et al. [23] it is found that uranium intakes of 0.004μg/Kg to 9μg/Kg body weight, chronic ingestion of uranium in drinking water affects kidney function. Radio-toxicity also arises from irradiation of bone surfaces and red bone marrow by alpha particles emitted by uranium.

Most uranium from drinking water is eliminated from the body. However, a small amount is absorbed and carried through the blood streams. Once in the bloodstream, the uranium compounds are filtered by the kidneys, where they can cause damage to the kidney cells. The uranium concentration in most surface and near surface waters is highly variable, ranging from less than 0.1ppb(μg/l) to more than 1000ppb[24]. In natural waters, however, uranium concentrations greater than 100ppb are quite rare, and have generally been found only in acquifers containing uranium mineralization. The World Health Organization [25] has given a TDI (Tolerable Daily Intake values) of 30μg/l in drinking water above which it may not be safe.

Due to awareness in the public, nowadays, people are using water purifiers in their houses. There are two types of purifiers available in the market, simple purifiers and the systems based on RO (Reverse Osmosis) membranes. RO systems are also being installed by the state government in the villages for providing safe drinking water to the public. The water supply to the RO systems is the local underground water. So, in the present study we have investigated the performance of RO systems for the removal of uranium and TDS from drinking water.

2. Materials and Methods:

2.1 Sample Collection

In order to study the performance of RO (Reverse Osmosis) systems we have collected some water samples from Amritsar, Faridkot, Bathinda and Mansa districts of Punjab State. The RO systems belong to different brands. The water samples were collected with 1L-size plastic containers which have been previously washed and rinsed with nitric acid. In total we have studied 25 RO systems. Two water samples were collected from each RO system, the feed water and the purified water. The feed water samples were collected after at least 5-10 min of pumping to evacuate more than 3-5 times of the borehole storage volume [26, 27]. The collected samples were acidified with 0.01M of nitric acid to obtain a pH< 2 in order to avoid adsorption of the radionuclides on the walls of the container.

2.2 Experimental Procedure

2.2.1 TDS Measurements

The TDS in water samples was measured with TDS meter. TDS meters are, in reality, conductivity meters. They work by applying a voltage between two or more electrodes. Positively charged ions (e.g., sodium, Na^+; calcium, Ca^{++}; magnesium, Mg^{++}; hydrogen ion, H^+; etc.) will move toward the negatively charged electrode, and negatively charged ions (e.g., chloride, Cl^-; sulfate, SO_4^{--}; bicarbonate, HCO_3^-; etc.) will move toward the positively charged electrode. Because these ions are charged and on moving, they constitute an electrical current. The meter then monitors how much current is passing between the electrodes as a gauge of how many ions are in solution.

2.2.2 Uranium Estimation

Uranium content in water samples of Amritsar Faridkot, Bathinda and Mansa was measured by laser fluorimeter. The laser fluorimeter is an instrument for detection of trace quantities of uranium present in aqueous samples such as water. The instrument works on the principle of detection of fluorescence of uranium complexes in the sample. Under UV excitation uranium salts emit green luminescence, which can be measured by a sensitive PMT. Since the fluorescence yield is proportional to the intensity of excitation source and concentration of uranium in the sample, measurement of fluorescence give information about concentration of uranium, in the sample.

Since the fluorescence yield varies for different complexes of uranium an inorganic reagent (Sodium Pyrophosphate) is used to convert various complexes into single form having same fluorescence yield.

The water samples generally contain other impurities also. Most of the organic species present in natural water fluoresce mainly in blue region when excited by nitrogen laser. This fluorescence is blocked partially by using a long pass filter allowing light only above 450nm. However, this does not completely eliminate the fluorescence from organic matter. Under pulsed excitation, the fluorescence from the organic matter lasts only for few tens of nanosecond, whereas the uranium salts emit fluorescence for few tens of microsecond. By proper time gating of PMT, the remaining fluorescence from organic matter is completely eliminated.

2.2.3 Reverse Osmosis

Reverse Osmosis works by using a high pressure pump to increase the pressure on the salt side of the RO and force the water across the semi-permeable RO membrane, leaving almost all (around 95% to 99%) of dissolved salts behind in the reject stream. The amount of pressure required depends on the salt concentration of the feed water. The more concentrated the feed water, the more pressure is required to overcome the osmotic pressure. The schematic diagram showing the working of an RO system is shown in Fig 1.

The desalinated water that is demineralized or deionized, is called permeate (or product) water. The water stream that carries the concentrated contaminants that did not pass through the RO membrane is called the reject (or concentrate) stream.

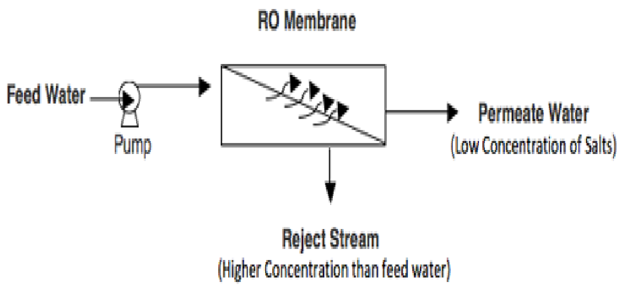

Figure 1: Schematic diagram showing the working of an RO system.

As the feed water enters the RO membrane under pressure (enough pressure to overcome osmotic pressure), the water molecules pass through the semi-permeable membrane and the salts and other contaminants are not allowed to pass and are discharged through the reject stream (also known as the concentrate or brine stream), which goes to drain or can be fed back into the feed water supply in some circumstances to be recycled through the RO system to save water. It is important to understand that an RO system employs cross filtration rather than standard filtration where the contaminants are collected within the filter media. With cross filtration, the solution passes through the filter, or crosses the filter, with two outlets: the filtered water goes one way and the contaminated water goes another way. To avoid build up of contaminants, cross flow filtration allows water to sweep away contaminants build up and also allow enough turbulence to keep the membrane surface clean.

3. Results and Discussion:

The results of our present study are presented in Tables 1 & 2. The TDS values in the feed water samples vary from 316mg/l to 1650mg/l. According to USEPA , BIS and Health Canada specifications, TDS upto 500mg/l is highest desirable for drinking water purposes [8,9,10]. Based on this guideline of TDS, 52% of the samples have TDS values above the prescribed limit in the feed water. WHO [11] has recommended the safe limit of 600mg/l, while there is no strict adherence on desired TDS value of drinking water. Taking into consideration this limit, 40 % of the water samples has TDS value above 600mg/l. The TDS values in the RO treated water is observed in the range of 10 mg/l to 126mg/l which are well within its prescribed limits. In case of Faridkot, Bathinda and Mansa districts the TDS values in feed water vary from 656mg/l to 1650mg/l and in the treated water from 21mg/l to 84mg/l. About 87.57% to 97.01% of the TDS is removed by the RO systems. In case of Amritsar the values of TDS vary from 316mg/l to 890mg/l in the feed water and from 10mg/l to 126mg/l in the treated water that means about 76.31% to 97.48% of TDS is removed by RO systems. A comparison of TDS in the feed water and RO treated water as a bar diagram is shown in Figs. 2 & 3.

Uranium concentration in feed water samples ranged from 7.0µg/l to 405.3µg/l. From the tables, we see that 32% of the total water samples have uranium concentration higher than 30µg/l, the Maximum Contamination Level (MCL) as recommended by World Health Organization [25] and 60µg/l as recommended by India´s Atomic Energy Regulatory Board [28]. The RO treated water has a minimum uranium concentration from $\leq$ 0.01µg/l (Below Detection Limit) to a maximum value of 5.16µg/l which are well within the safe limits. In case of Faridkot, Bathinda and Mansa districts the uranium concentration in the feed water ranges from 49.50µg/l to 405.3µg/l and in the treated water it varies from 0.58 µg/l to 5.16 µg/l that is about 93.70% to 99.81% of the uranium is removed. In case of Amritsar uranium concentration in the feed water is observed in the range of 7µg/l to 25.9µg/l and in the treated water it is observed in the range $\leq$0.01µg/l to 4.5µg/l that means 71.33% to 100% is removed by the RO systems. Bar diagram (Figs. 4 & 5) gives the comparison of uranium concentration in the feed water and the RO treated water.

Table 1. TDS and uranium removal study by RO systems in drinking water systems of Faridkot, Bathinda & Mansa Districts of Punjab state, India.

Sr. No.	RO Systems	TDS (mg/L)			Uranium Concentration (µg/L)		
		Feed Water	Treated Water	Percentage Removal	Feed Water	Treated Water	Percentage Removal
1	WBR-LA	703	21	97.01	64.30	0.58	99.09
2	WBR-VS1	656	61	90.70	49.50	3.10	93.7
3	WBR-KM	1210	72	94.04	73.03	3.10	95.75
4	WBR-AF	1137	66	94.19	235.0	1.0	99.57
5	WBR-VS2	721	26	96.39	85.80	0.60	99.30
6	WBR-AA	963	70	92.73	194.33	5.16	97.31
7	WBR-VS3	1650	57	96.54	405.3	0.77	99.81
8	WBR-ZR	676	84	87.57	153.33	0.65	99.60

Table 2. TDS and uranium removal study by RO systems of drinking water systems in Amritsar District of Punjab State, India.

Sr. No.	RO Systems	TDS (mg/L)			Uranium Concentration (µg/L)		
		Feed Water	Treated water	Percentage Removal	Feed Water	Treated Water	Percentage Removal
1	FR-PR	476	34	92.86	19.45	0.2	98.9
2	FR-AGR	505	19	96.23	20.9	3.0	85.65
3	FR-WV	677	25	96.31	10.5	2.87	72.66
4	FR-DL	890	62	93.03	15.7	0.08	99.49
5	FR-OP	316	29	90.82	9.53	0.62	93.49
6	FR-AGU	508	35	93.11	14.5	0.04	99.71
7	ASR-AGR1	322	19	94.09	11.43	0.16	98.6
8	ASR-AGR2	360	24	93.33	25.9	(BDL)	~100
9	ASR-ZR	360	16	95.55	25.9	(BDL)	~100
10	ASR-WG	340	18	94.70	8.08	(BDL)	~100
11	ASR-AGU1	340	20	94.11	8.08	(BDL)	~100
12	ASR-AGU2	398	10	97.48	17.5	(BDL)	~100
13	ASR-KRS	410	14	96.58	12.8	(BDL)	~100
14	ASR-AGR3	384	19	95.05	15.2	(BDL)	~100
15	ASR-KNT	532	126	76.31	15.7	4.5	71.33
16	ASR-KMF	372	18	95.16	7.0	(BDL)	~100
17	ASR-AGU3	424	46	89.15	7.69	1.6	79.19

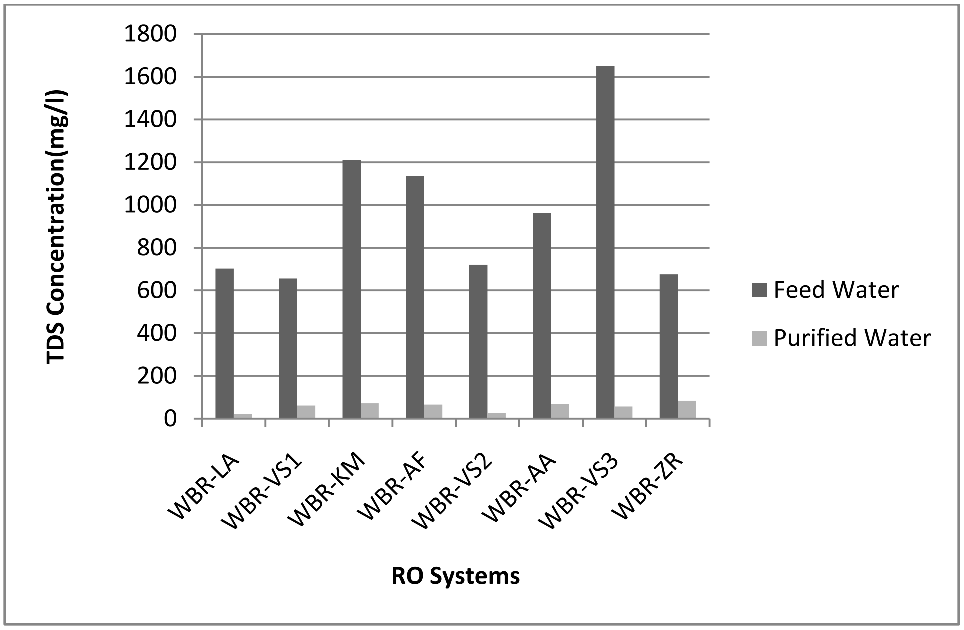

Figure 2: A comparison of the TDS values in the feed water and the RO purified water of Bathinda, Mansa and Faridkot districts of Punjab state, India.

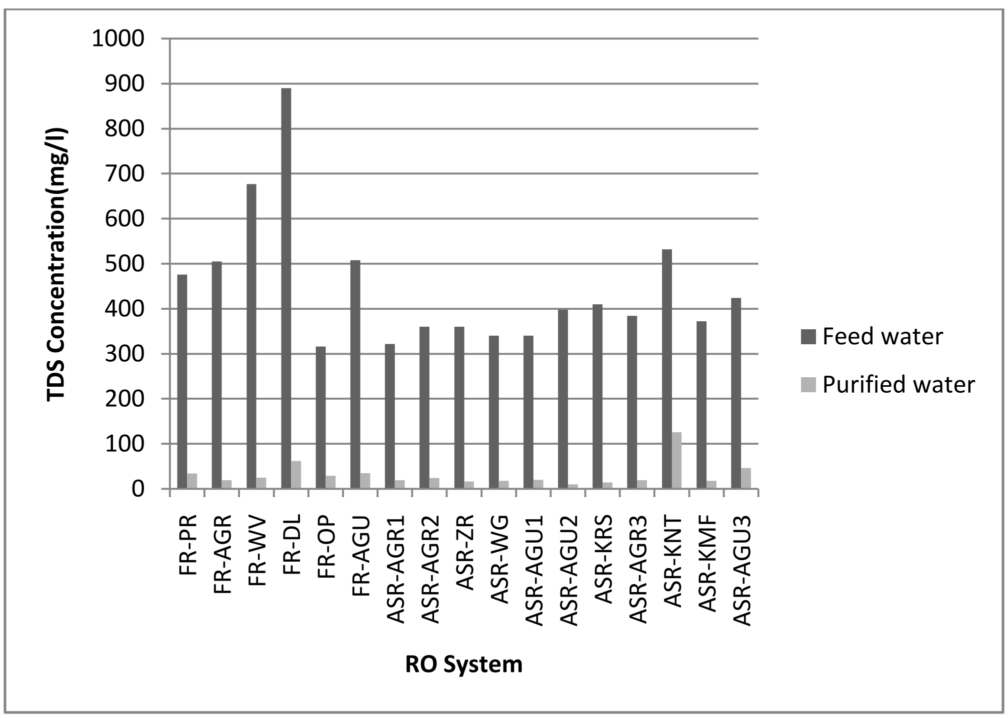

Figure 3: A comparison of TDS values in the feed water and the RO purified water of Amritsar district of Punjab state, India.

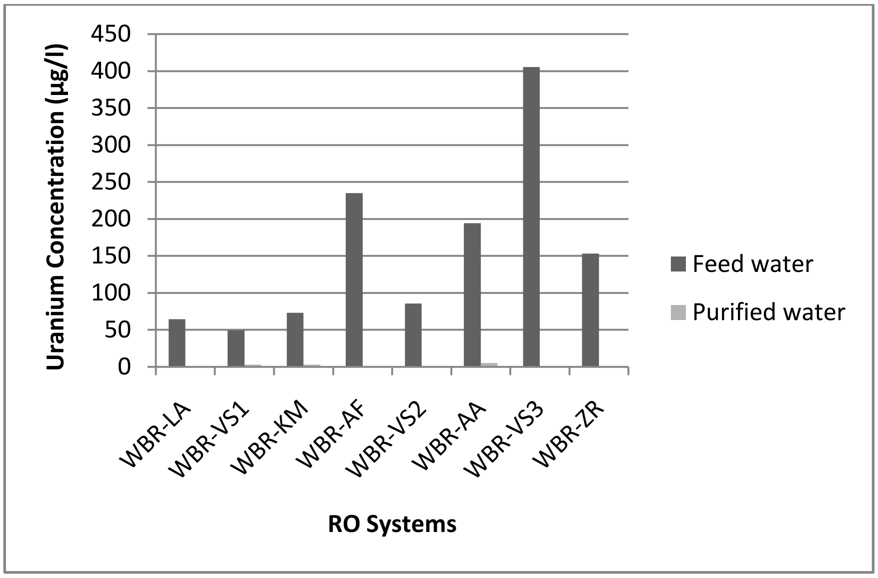

Figure 4: A comparison of the uranium concentration in the feed water and the RO purified water of Bathinda, Mansa and Faridkot districts of Punjab state, India.

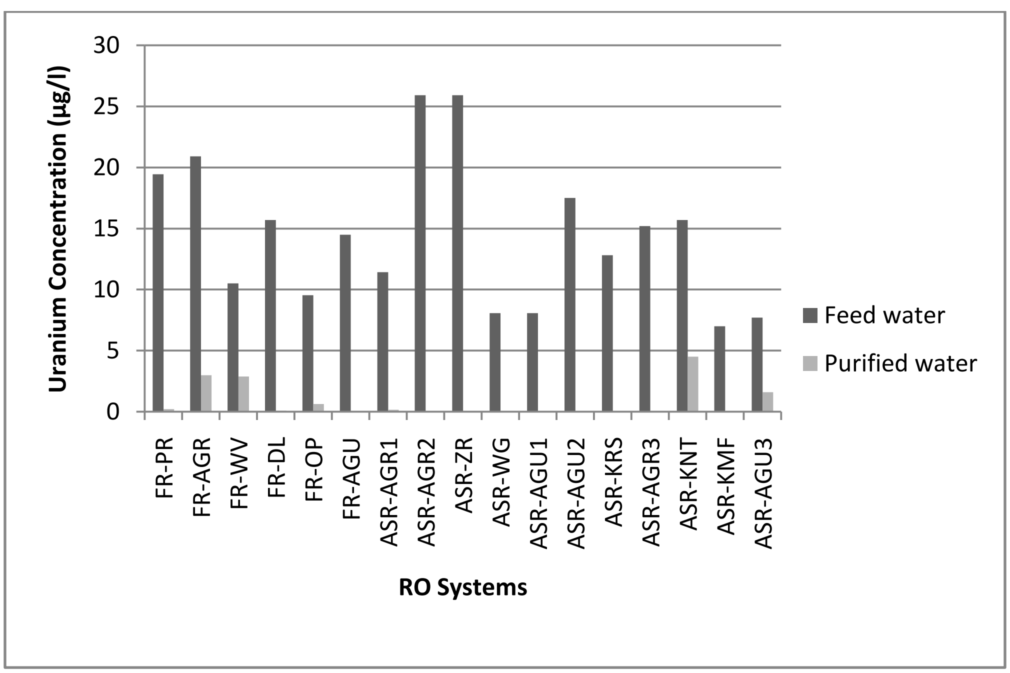

Figure 5: A comparison of uranium concentration in the feed water and the RO purified water of Amritsar district of Punjab state, India

4. Conclusions:

The RO systems can considerably reduce the TDS value and uranium concentration. Some of the RO systems are able to remove TDS by 97% and uranium by nearly 100%. TDS is an important indicator for predicting the essential mineral content in RO treated water. RO system removes the TDS value very effectively. As some of the untreated water samples are having high uranium content, it must be considered anomalous in terms of natural radioactivity. Uranium being a radioactive and chemically toxic element, such water is unsafe for drinking purposes.

Reverse Osmosis (RO) technique removes almost all the uranium from source water, which fulfils the purpose of our study. Hence, RO systems installed in the individual houses of the people and the RO systems installed by the state government that we have studied in the present investigations are working well. So, it is concluded that in the areas where water has high TDS and uranium concentrations and is not suitable for drinking purposes in such areas water purification is a necessity and RO systems can play an important role.

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