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Effectiveness of domestic water filters

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ABSTRACT

A laboratory study was carried out to determine the best domestic water filter with respect to cost, volume of treated water, and effectiveness in improving the quality of potable water. Six types of filters were tested including sand, five micron cartridge, ceramic, carbon block, ultra violet (UV) sterilization unit, and reverse osmosis combined filters. Water samples were collected upstream and downstream of each type of filter. These samples were analyzed for pH, EC, TDS, TSS, turbidity, TOC, chlorine concentration, and various bacteria. Also, the volume of treated water produced by each type of filter was measured. The laboratory results indicated that inlet water had low salinity (TDS value 275–438 mg/l), low TSS (0–7 mg/l), chlorine (0.13–0.78 mg/l) contents, and high content of bacteria (1–1212 MPN/100 ml). The results revealed that the membrane of the RO combined filter set was exposed to severe damage by the residual chlorine in the water, rendering the membrane unable to reduce water salinity effectively and causing high total bacteria counts in the filtered water. Additionally, a biological slime layer formed at the surfaces of cartridge filters, and produced high values of TSS and bacteria in the filtrate samples. The results showed that the best type of filter was the five micron filter on the basis of cost, volume of filtered water, and improvement in water quality.

Keywords: Potable water; Ceramic filter; UV sterilization unit; Residual chlorine; Total coliform bacteria; RO combined filter

1. Introduction

In Kuwait, freshwater supplied from the desalination plants is generally stored in overhead tanks at consumer premises before it is used. The stagnancy, the quality of freshwater supply (quantity, types of salts and chlorine concentrations), and contribution of pollutants such as dust particles from the surrounding environment through aeration outlets may contaminate freshwater stored in tanks. Therefore, this water should be treated before it used for drinking purposes, and different types of water filters are used for this purpose. Commercial water filters are used in the private houses and government buildings. The treatment includes removal of suspended solids, organic matter, microorganisms including bacteria, fungi and algae as well as reduction of salinity of water. The suspended solids can be removed using the ceramic filters, sand filters and five micron cartridge filters. The organic matters and materials causing bad smell, and color of water in the storage tank can be removed using activated carbon filters and sand filters. The microorganisms including bacteria can be removed by sterilizing

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the water using ultraviolet (UV) filters. The reduction of salinity of fresh water is generally carried out using reverse osmosis through membrane filters. The selection of type of filters to be used depends on the capital and operation costs, the removal efficiency of pollutants from the freshwater, and the quantity of produced treated water. The current study aims to determine the best water filters for residential users that will produce good quality and adequate quantity of water economically under conditions prevailing in Kuwait.

There are more than 1,000 types of commercial water filters for use in the residential units and numerous branded and generic filters are available in Kuwait. These water filters can be classified into five filter groups according to the treatment techniques. The first group of filters use physical treatment for removal of sand, dust, and dirt in the water. Central sand filters and cartridge filters such as 5 micron, ceramic belong to this group. The particle sizes removed by this group range between one micron (e.g. ceramic filter) and 10 micron (e.g. sand filter). The second group of filters uses surface adsorption for removal of materials responsible for unwanted color, taste, and smell and also reduces levels of chlorine and organics. Block carbon and activated carbon filters are members of this group. The third group of water filters uses the effect of ultraviolet radiation to kill or reduce the contents of bacteria and other microorganisms in the water. The water sterilization units containing UV lamps belong to this group. The filter devices that reduce the water salinity comprise the fourth group. This group of filters includes reverse osmosis membranes, water distillers, and water softener filters. The last group of water filters is a combination of all the above types. The reverse osmosis combined filters is an example of this type. It consists of five filters, that include five micron, block carbon, activated carbon cartridges, reverse osmosis membrane, followed by UV sterilization unit. Some filters are costly and they require continuous supply of electricity, such as central sand filters and reverse osmosis combined filters. The cartridge filters are cheap and some varieties can be replaced or cleaned when the flow of water is reduced. The purpose of the study was to evaluate the performance of variety of filters available in Kuwaiti market.

2. Methodology

Six house water filters were tested in this study. These are combined reverse osmosis filters, carbon filter, ceramic filter, five micron (μ) cartridge filter, sand filter, and UV filter. The fresh water from main water supply was pumped daily to a 2000 L tank and fed to all filters simultaneously. All the pipes, flittings, unions, water tapes, sockets, and adapters were made of 19 mm PVC to reduce the problem of corrosion. The design and setup of house water filters is presented in Fig. 1. The specification and cost of the types of filters used in this study is presented in Tables 1 and 2. The flow of water passing through each type of filter was measured using accumulative flow meters. All filters were arranged parallel to each other in the following order:

(1) Central sand filter.
(2) Five micron cartridge filter.
(3) Ceramic filter.
(4) Carbon filter.
(5) UV sterilization unit.
(6) Reverse osmosis combined fitters.

Prior to sampling, parameters like pH, and electrical conductivity (EC) were measured at the site at the time of collection of the samples using portable meters supplied with electrodes. Also, the growth of algae and fungi were reported for each filter, and this was done through observing the biological clogging layer through the transparent casings of water filters, especially of cartridge type. Water samples were collected from the inlet (fresh water tank) and from outlet points of each of the water filters in order to evaluate the efficiency for each type of filter. Water samples were collected on daily and weekly basis during four month period. The samples were collected in 1 L sterilized glass bottles, and kept in an ice box and transported to the Hydrology laboratory for analysis. The volume of water treated by each type of water filters was measured during sampling.

The first batch of experiments was carried out during July–September 2007, while the second batch of repeat experiments was carried out during October–November 2007. The program of cleaning and replacement of cartridges, membranes and UV lamps is presented in Fig. 2 and Table 3. The ceramic, 5 μ and carbon cartridges were replaced on weekly or biweekly basis due to the formation of slimy biological layers on the surfaces of cartridges causing blockage to movement of water inside the pipes. The slime layer from the ceramic cartridge was collected and analyzed for the determination of bacterial activities on 23 September 2007. The reverse osmosis combined cartridges, and membrane and UV lamps of the sterilization unit were replaced three times during the study due to formation of slimy layer on the surfaces of the cartridges and damages of RO membrane by chlorine (in August, September and October 2007). The fillings

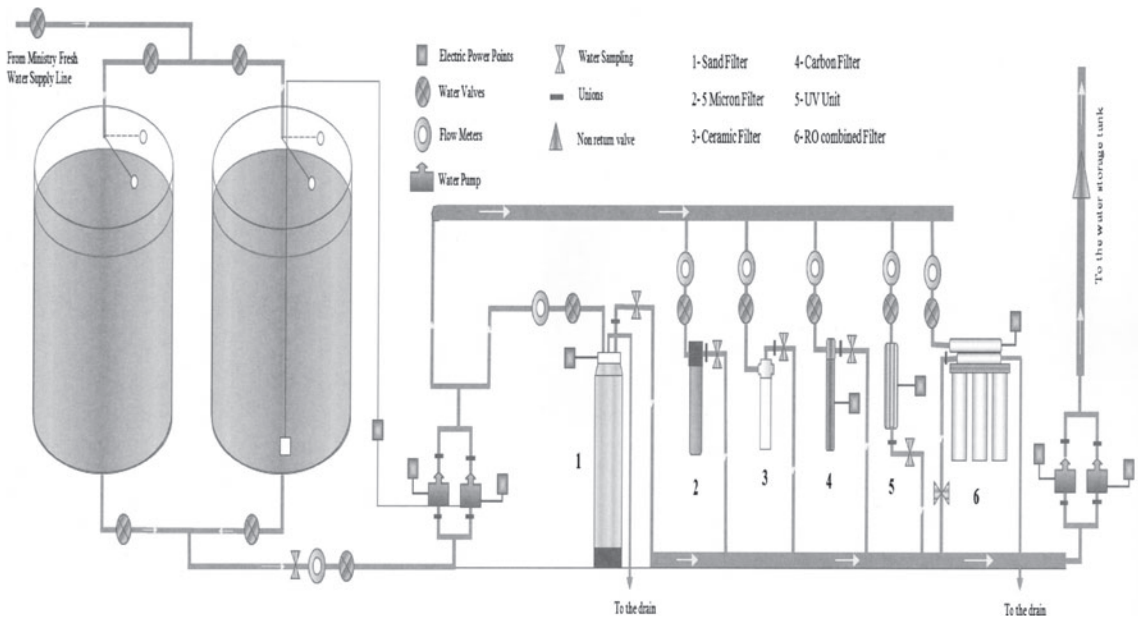

Fig. 1. Setup of house water filter experiments.

Table 1
Specification of commercial house water filters

Filter type	Specification
Sand	10 inch central sand filter complete with backwash timer. Made in USA. Fillings from bottom 20 kg fine sand, 10 kg pebbles and 3–4 kg gravel
Cartridge	5 μ cartridge water filter. Made in USA
Ceramic	Ceramic filter of kitchen type, 0.9 μ. Made in USA
Carbon	Block carbon filter, 5–10 μ. Made in USA
UV	Ultraviolet sterilization unit supplied with UV lamps. Made in USA
RO	Reverse osmosis combined with five filters (5 μ cartridge, activated and block carbon cartridges, RO membrane and UV unit). Made in USA

Table 2
Cost of commercial house water filters

	Price (KD)				
Filter type	Sand filling	Cartridge	Lamp	Membrane	Complete filter
Sand	40.0	–	–	–	290.0
5 μ	–	10.0	–	–	20.0
Ceramic	–	10.0	–	–	20.0
Carbon	–	10.0	–	–	20.0
UV unit	–	–	10.0	–	20.0
RO combined	–	–	–	15.0	465.0

Note: 1 KD = 3.7 USD.

of central sand filter was replaced only at the beginning of the experiments and on 21 October 2007.

3. Laboratory analysis

Water samples were collected and analyzed in order to carry out the following investigations; general parameters including total dissolved solids (TDS) and total suspended solids (TSS), major ions (Ca, Mg, Na, K, Fe, Cl, SO_4, HCO_3, NO_3, NH_3, PO_4) free chlorine, sulfide, organic parameters including chemical oxygen demand (COD), biochemical oxygen demand (BOD), total organic carbon (TOC), bacterial parameters including total bacteria counts (TBC), heterotrophic bacteria count (HPC), FS, total coliform bacteria, fecal coliform bacteria, *Escherichia coli*, fecal streptococcus, salmonella, and sulfate reducing bacteria (SRB). The chemical analyses were carried out as quickly as possible and within one week from time of collection of the samples. The methods recommended by APHA [1] were followed for the determination of these parameters. Also, blank and duplicate samples were collected and analyzed randomly to ensure that the analysis results are reliable. Parameters such as Ca, Mg, Na, K, Cl, SO_4, HCO_3, NO_3, NH_3, PO_4, sulfide, COD, BOD, and SRB were measured only during the first month of sampling.

4. Evaluation of laboratory results

The change in the quality of freshwater after passing through different types of house water filters was evaluated. The water samples were analyzed for water quality parameters before and after passing each type of water filters. The effect of different types of water filters on the physical, chemical, organic, and bacterial water parameters was evaluated separately. The volume of treated water obtained after passing through each type of water filters was recorded.

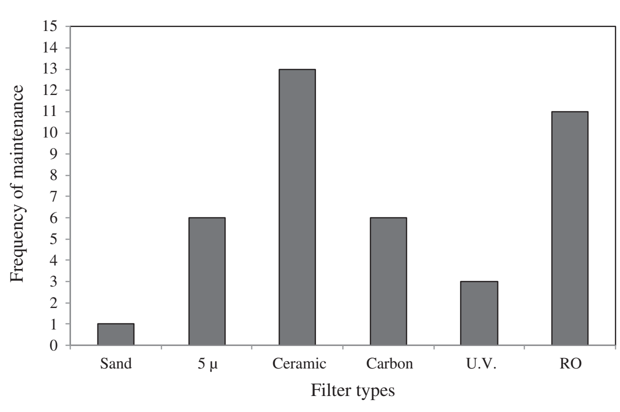

Fig. 2. Frequency of replacement of water cartridges, filling, lamps, and membrane during the study period.

4.1. pH

The pH of the inlet (freshwater tank) ranged between 7.58 and 8.04. The pH of the water after passing water filters is the same as the pH of the inlet. Slight increase in pH in 21 October 2007 was observed due to cleaning the water filter system with sodium hypochlorite.

4.2. Electrical conductivity

The EC of the inlet water ranged between 511 and 663 µS/cm. The EC values of the water filters are the same as those values for inlet water except for the reverse osmosis combined filter. The EC of the outlet water from the latter was reduced and ranged between 136 and 438 µS/cm due to the removal of a part of the salt in solution by the filter. The EC removal efficiency of the reverse osmosis combined filter ranged between 34 and 79%.

4.3. Major cations, anions, and water salinity

It was observed at the beginning of the experiments that all water filters with exception of reverse osmosis combined filter had no effect on removing major cations (Ca, Mg, Na, K) and anions (Cl, SO_4, HCO_3, NO_3) from the inlet water. Therefore, the effect of water filters on water salinity expressed as TDS was used instead of major cations and anions. Chemicals such as ammonia and phosphate were not detected in any of samples collected from both the inlets and outlets of all water filters. The TDS of the inlet water ranged between 275 and 438 mg/l. The concentration of the TDS in the inlet and outlet points of water filters were the same except for samples from the reverse osmosis combined filter. The TDS removal efficiency ranged between 29 and 78% with mean values 49% for the reverse osmosis combined filter. A stage of stabilization followed by a decline in TDS removal efficiency with time was observed. Chlorine in the inlet water could be one of the causes that affected the efficiency of the membrane to reduce the salinity. Also, low concentration of dissolved iron was observed in the inlet (0.004–0.024 mg/l) and outlet (0.00–0.124 mg/l) samples of water filters. In general, none of the water filters used in these experiments was able to remove the low concentrations of iron (Fig. 3).

Table 3
Schedule for water filter maintenance

Date	Water filter maintenance
08/07/2007	Testing the system
14/07/2007	5 μ and ceramic cartridges were replaced
22/07/2007	5 μ cartridges in both 5 μ filter & in RO combined filters were replaced
04/08/2007	All cartridges were replaced except RO & UV Unit
12/08/2007	All cartridges were replaced including RO & UV Unit
25/08/2007	Ceramic cartridges were cleaned and inserted in the casing filter
02/09/2007	Ceramic cartridges were cleaned and inserted in the casing filter
09/09/2007	Ceramic cartridges were cleaned and inserted in the casing filter
16/09/2007	Ceramic cartridges were cleaned and inserted in the casing filter
23/09/2007	Ceramic cartridges were cleaned and replaced, sampling from that filter
27/09/2007	Ceramic cartridges were cleaned and replaced
30/09/2007	Ceramic cartridges were cleaned and replaced
16/10/2007	Cleaning the system with chlorine and repetition of experiments
17/10/2007	Flushing the system to remove chlorine
18/10/2007	Remove fillings from sand filter and all cartridges, membrane and UV lambs
21/10/2007	Refilling sand filter and sampling started
28/10/2007	Ceramic cartridges were cleaned and replaced
30/10/2007	Ceramic cartridges were cleaned and replaced
04/11/2007	5 μ, ceramic and carbon cartridges were replaced, sampling was completed

4.4. TSS and water turbidity

The turbidity and TSS of the inlet water ranged between 0 and 2 NTU and between 0 and 7 mg/l, respectively. Measurable values of turbidity and TSS were observed in the outlets samples of all types of water filters except for the 5 μ filter cartridge. These values were generally low (turbidity: 0–8 NTU and TSS: 0–9 mg/l) for the outlet samples. Complete removal efficiency (100%) for TSS and turbidity was obtained with 5 μ water filter. It may be noted that the slime layer formed on the cartridge filter had high TOC values (26.0 mg/l) and bacteria counts (125 mpn/100 ml), indicating that the suspension that forms on the surfaces of the water cartridges are due to biological and bacterial activities.

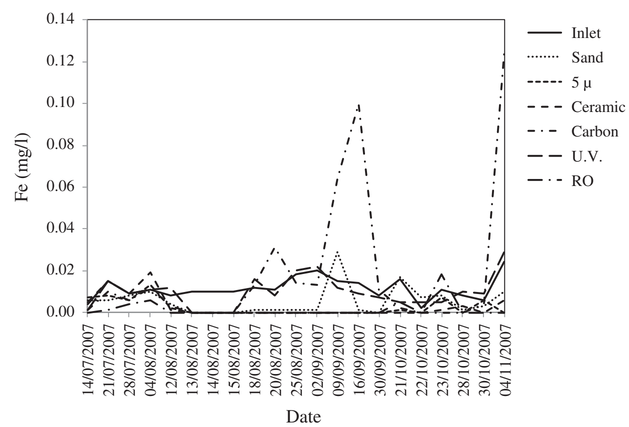

Fig. 3. Variation in Fe concentration before and after passing water filters.

4.5. Total organic carbon

The TOC concentration in the inlet water ranged between 0.33–4.7 mg/l (Fig. 4). High concentration of TOC was observed during the first week of the experiments at the inlet and outlets of the water filters, and this was due to the use of PVC cement glue during the installation of PVC water pipes. The smell of PVC glue could be detected in all the water samples during this period. After this period, the TOC concentrations at the inlet and outlets were the same. It means that after installation of filters, the water should be drinkable after one week. The TOC removal efficiency during the first week ranged between 50 and 88%. The average TOC removal efficiency was found to be 18.1 and 38.7% for central sand filter and RO combined filters, respectively.

4.6. Chlorine

The chlorine levels in the inlet water ranged between 0.13–0.78 mg/l (Fig. 5). Except for the reverse osmosis combined filter, the chlorine concentrations observed at the outlets of all water filters were either the same or slightly lower than that in the inlet water.

The chlorine removal efficiency ranged between 31 and 100% with the average value of 89.9% with the use of reverse osmosis combined filters. Presence of low chlorine concentrations in the water after passing through the water filters is good from health perspective.

4.7. Bacteria

Bacterial parameters, such as total coliform bacteria, fecal coliform bacteria, *E. coli*, salmonella, and SRB were not detected either in the inlet or in the outlet samples for any of the filters. It means that sewage and pathogenic bacteria that cause health problem to humans were not present in the supply water. Other bacterial parameters such as TBC, HPC, and faecal streptococcus, therefore were targeted in this study.

4.8. TBC

The TBC of the inlet water ranged between 1 and 10,000 MPN/100 ml (Fig. 6). It means that the amount of chlorine (0.13–0.78 mg/l) in the storage tanks and in supply lines is not enough to kill these bacteria. The TBC were detected in all types of water filters. The minimum number of TBC with outlet samples was found in water passing through 5 μ cartridge filter, while the maximum value of this parameter was found in water passed through reverse osmosis combined filter. Bacteria were hypothesized to be growing and regenerating on the surfaces of the cartridges forming biological slime layer. To confirm this idea, the slime layer that formed on the surfaces of ceramic cartridge was washed with deionized water and analyzed for TBC. The TBC concentration in the slime layer was found to be about 125 MPN/100 ml with TOC value of 26.0 mg/l. The concentrations of the TBC of the 5 μ cartridge water filter ranged between 0.1 and 11 MPN/100 ml whereas concentrations of these bacteria in the reverse osmosis combined filter ranged between 0.0 and 10,000 MPN/100 ml. The highest removal efficiency for TBC was obtained with 5 μ, ceramic, carbon cartridges, and UV water filter. The value of bacteria count (0.1MPN/100 ml) represents absence of bacteria in the outlet samples.

4.9. HPC

The HPC of the inlet water ranged between 0 and 7 MPN/100 ml. The HPC were detected in the outlet samples from all types of water filters except 5 μ and ceramic filters. It appears that bacteria were growing and regenerating on the surfaces of the fillings and cartridges. The maximum number of these bacteria was found in the water treated by central sand, carbon, and reverse osmosis combined filters. The backwash water sample of the sand filter showed presence of high level of HPC.

4.10. Fecal streptococcus

The fecal streptococcus of the inlet water ranged between 0 and 1 MPN/100 ml. These bacteria were detected only in water treated by three types of water filters. These were central sand, carbon, and reverse osmosis combined filters. The maximum number of fecal streptococcus was observed in the water associated with reverse osmosis combined filters where its concentration ranged between 0 and 216 MPN/100 ml. The fecal streptococcus bacteria are

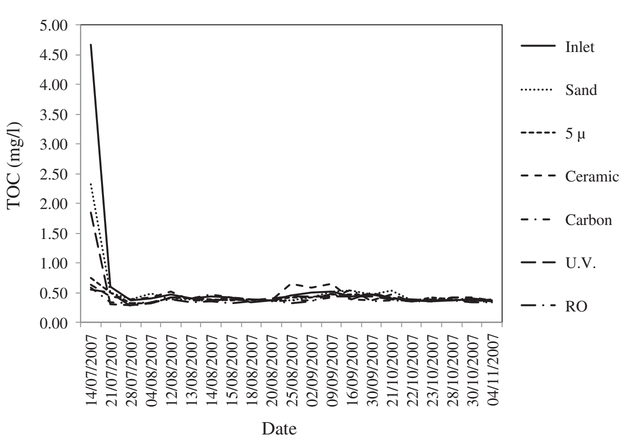

Fig. 4. Variation in TOC concentration before and after passing water filters.

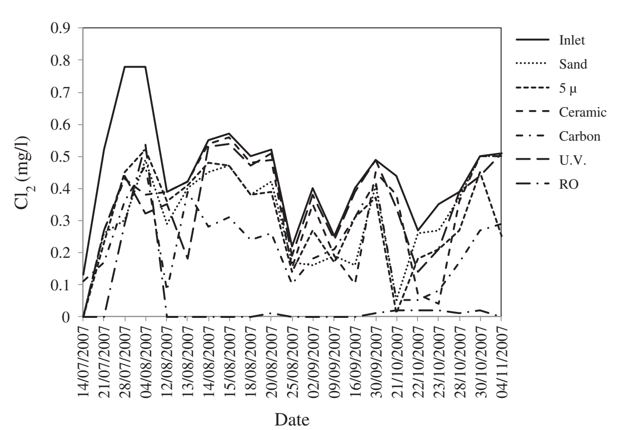

Fig. 5. Variation in Cl_2 concentration before and after passing water filters.

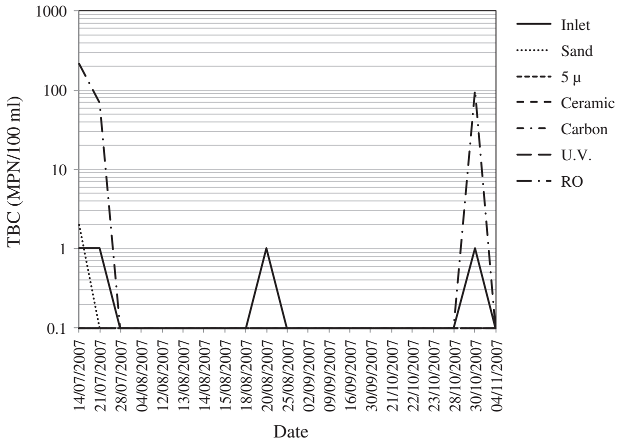

Fig. 6. Variation in TBC concentration before and after passing water filters.

probably regenerating on surfaces of the cartridges of RO combined filters. Water filters such as 5 μ, ceramic and UV, showed excellent removal efficiencies for these types of bacteria. Further studies are needed to determine the source of this type of bacteria in the inlet and on the surfaces of filter cartridges. The statistics values of the water quality before and after passing water filters (Table 4).

5. Volume of treated water

The maximum amount of water was treated by central sand filter, whereas the minimum amount of water was treated by the reverse osmosis combined filter. The amount of treated water produced by central sand filter was 68% of the total volume of water supplied from the tanks whereas outputs from other types of filters were only 1–8% of that volume (Fig. 7). Moreover, the flow of water was not continuous through these water filters because of development of biological slime layer on the surfaces of the cartridges (ceramic, 5 μ, block carbon and activated carbon) and membranes. Whenever the flow of water through the filters stopped during experiments, the cartridges, or membranes either had to be cleaned or replaced by new ones.

6. Comparison of water filter performance

The factors that need to be considered in the selection of commercially available water filters for residential use are the effectiveness in improving the water parameters such as salinity, TSS, turbidity, and bacteria counts with respect to the potability of water; the volume of water treated and the operation and capital cost. The cost of filtered water (KD/m^3) was calculated by dividing the total cost for each type of water filter (Table 2) over the total treated volume (Table 5). Since, water supplied from the desalination plants is generally of low salinity (about 500 mg/l), the improvement in salinity is not a major concern in Kuwait. Rather the removal of suspended solids (mostly derived from iron rust in the supply line) and bacteria that may contaminate water supply due to leakage in the network or lack of proper protection of storage tanks at the residences are of more importance in Kuwait. The cost of producing one cubic metre of water using the sand filter and UV sterilization unit is small compared to the 5 μ cartridge filter (Table 5). However, the cost and maintenance of hydrostatic

Table 4
Minimum, maximum and average values of water quality before and after passing water filters

Parameter		Inlet	Sand	5 μ	Ceramic	Carbon	UV	RO
TDS (mg/l)	Minimum	275	293	286	286	284	273	68
	Maximum	438	428	444	430	435	434	284
	Average	344	346	345	345	342	344	176
TSS (mg/l)	Minimum	0	0	0	0	0	0	0
	Maximum	7	6	0	7	4	3	9
	Average	1.048	0.857	0.000	1.000	0.619	0.524	0.571
TOC (mg/l)	Minimum	0.333	0.355	0.326	0.355	0.324	0.284	0.274
	Maximum	4.664	2.316	0.754	0.654	0.583	1.844	0.543
	Average	0.623	0.51	0.4	0.4	0.4	0.5	0.382
Cl_2 (mg/l)	Minimum	0.13	0	0	0	0.05	0	0
	Maximum	0.78	0.5	0.52	0.56	0.47	0.54	0.54
	Average	0.447	0.310	0.301	0.336	0.229	0.349	0.045
TBC (MPN/100 ml)	Minimum	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Maximum	1	2	0.1	0.1	0.1	0.1	216
	Average	0.271	0.19	0.1	0.1	0.1	0.1	18.467

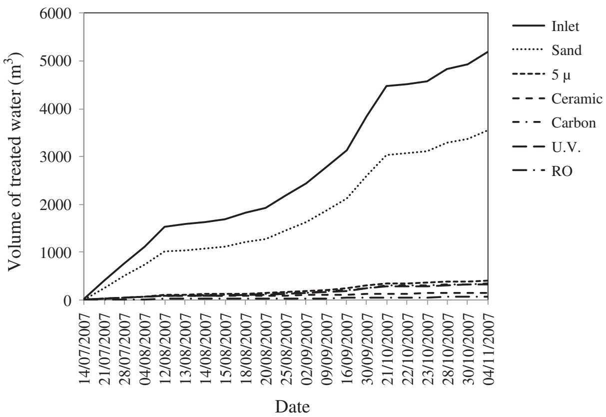

Fig. 7. Comparison of volume of treated water produced from different filters.

water pumps and cost of electricity needed for the automatic backwash of the sand filter and UV sterilization unit have not been accounted for in Table 6. Removal efficiency percent value was calculated by subtracting average inlet concentration from average outlet concentration divided by average inlet concentration. It is apparent that 5 μ cartridge filter exceeds in performance in removing the turbidity, suspension, and bacteria over the performance of other types of filters. Except for the sand filter, the 5 μ cartridge filter has also better performance in the volume of water treated and is relatively cheap. On the basis of above considerations, it is recommended that this filter is used in the residential units in Kuwait.

7. Summary and conclusion

The laboratory results indicated presence of low concentrations of TDS (275–438 mg/l), TSS (0–7 mg/l) and chlorine (0.13–0.78 mg/l), and presence of high concentration of bacteria (1–10,000 MPN/100 ml-TBC) in the inlet water. All the tested types of water filters indicated absence of chemical reactions between filter materials and water as supported by stable readings of the pH values. The reverse osmosis combined filters produced low salinity water (EC of 136–438 μS/cm and TDS of 68–284 mg/l) with high concentration of bacteria. The water salinity was not affected when

Table 5
Cost of producing cubic meter of water using different water filters

Cost parameters	House water filters					
	Sand	5 μ	Ceramic	Carbon	UV unit	RO comb.
No. cartridge replacement	–	6	13	6	–	7
No. UV lamp replacement	–	–	–	–	3	2
No. membranes replacement	–	–	–	–	–	2
No. sand filling replacement	1	–	–	–	–	–
Cost of original unit (KD)	290	20	20	20	20	465
Cost of components replacement	40	60	130	60	30	120
Total cost (KD)	330	80	150	80	50	585
Cost of filtered water (KD/m^3)	0.09	0.20	1.05	0.23	0.15	9.24

Note: 1 KD = 3.7 USD.

Table 6
Comparison of water quality parameters with respect to water filters

Filter type	Total treated volume (m^3)	Need of electricity (Y/N)	Cost (KD/m^3)	Effectiveness in improving water parameter (%)				
				TDS	TSS	TOC	Cl_2	Bacteria
Sand	3,549	Yes	0.09	0	18.2	18.1	30.6	29.9
5 μ	406	No	0.20	0	100	35.8	32.7	100
Ceramic	143	No	1.05	0	9.4	35.8	24.8	100
Carbon	344	No	0.23	0	40.9	35.8	48.8	100
UV unit	335	Yes	0.15	0	50.0	19.7	21.9	100
RO comb.	63	Yes	9.24	49	45.5	38.7	89.9	0

other types of water filters were used. Some suspended solids were detected in water filtrate from ceramic, block carbon, activated carbon filters, and in the sand filter fillings. Biological slime layer was clearly observed on the surfaces of cartridge filters (5 micron, ceramic, block carbon and activated carbon) and on the fillings of sand filter. This slime layer was responsible for regeneration of bacteria and production of suspensions, in the above types of filters.

Low organics (TOC) and chlorine removal efficiencies characterized all types of water filters tested. Bacteria parameters, such as TBCs, HPC, and fecal streptococcus were found in all types of water filters except for 5 μ cartridge filter. The maximum number of bacteria (0–10,000 MPN/ 100 ml-TBC) was found in water filtrate of reverse osmosis combined filters. Largest volume of treated water was produced with central sand filter.

Although RO technology is well defined and proven technology in desalination, the RO combined system that is widely used in the household is not effective in improving the quality of potable water with respect to TSS, TDS, and TBC. Besides, the use of RO combined systems in a household requires frequent maintenance and monitoring.

Considering, however, the low cost of 5 micron cartridge filter, easy replacement of cartridges, no requirement for electricity, best efficiency for removal of TSS and bacteria, as well as reasonable efficiency for water treatment, this type of filter was recommended for installation in the houses for purification of potable water. Based on the results of the laboratory study, the following recommendations are forwarded:

(1) The quality of fresh water supplied by service provider should be monitored, especially for the chlorine content and the bacteria counts.
(2) Public should be educated about the advantages and disadvantages of different types of house water filters available commercially.
(3) The casing of the house water filters should be transparent to allow the inspection of suspensions accumulated on the surfaces of cartridges to determine the time for cleaning or replacement.
(4) Additional types of water filters and different combinations such as 5 micron filter attached with carbon filter should be tested for their efficiency and cost.
(5) Similar study should be carried out over a longer period and for a wider range of water parameters such as trace elements and other contaminants.

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