FABRICAÇÃO E TESTE DO NÍVEL INTERMEDIÁRIO DE FILTROS DE DESFLUORIZAÇÃO BASEADOS EM ALUMINA ATIVADA

FABRICATION AND TESTING OF INTERMEDIATE LEVEL ACTIVATED ALUMINA BASED DEFLUORIDATION FILTERS

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RESUMO

Dois filtros de desfluorização de alta capacidade e alta taxa com 10 e 25kg de alumina ativada foram fabricados e testados com água de posso local contaminada com flúor. Diversos parâmetros de qualidade da água como pH, TDS, F^-, Cl^-, SO_4^{2-}, NO_3^-, dureza de Ca^{2+} e Mg^{2+} e dureza total foram monitorados através do proceso de filtração e foi detectado que esses valores estão dentro dos padrões permitidos. A performance do filtro foi avaliada através da determinação do volume de água padrão (<1.5 ppm), capacidade de adsorção de flúor, taxa de vazão, tempo de contato, capacidade de água do filtro, tempo antes da primeira regeneração e custo do filtro. Baseado em uma discussão detalhada frente a esses parâmetros, o filtro com 10kg de alumina foi considerado melhor se comparado ao de 25kg.

Palavras-chave: *Activated Alumina, Defluoridation, Fluoride, Water Filter*

ABSTRACT

Two high capacity, high flow rate defluoridation filters with 10 and 25kg Activated Alumina have been fabricated and tested with local fluoride contaminated ground water. Various water quality parameters like pH, TDS, F^-, Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+} Hardness, Mg^{2+} Hardness, Total Hardness have been monitored throughout the filtration process and it has been found that these values are within the permissible limits. The filter performance has been evaluated by determining the volume of safe water (<1.5 ppm), fluoride uptake capacity, flow rate, empty bed contact time, water capacity of filter, time before first regeneration, capital and recurring cost of filter. On basis of detailed discussion on these parameters the filter with 10 kg AA is considered to be a better filter as compared to the one with 25 kg AA.

Keywords: *Activated Alumina, Defluoridation, Fluoride, Water Filter*

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INTRODUCTION

In many parts of the world high concentration of fluoride occurs naturally in ground water and causes wide spread fluorosis, a disease which mainly affects the bones and teeth [1-6]. About 95% of fluoride ingested the body is deposited in hard tissues like bones and teeth weaking their structure and making them brittle[7,8]. Other problems which arise due to the excessive intake of fluoride are low heamoglobin levels, excessive thirst, headache, skin rashes, nervousness, depression, gastrointestinal problems, urinary tract malfunctioning, low IQ, weakening of muscle [1 4]. In India, excess fluoride is present in ground water in many states for example in parts of Andhra Pradesh, Rajasthan etc[9-11].There are several methods of defluoridation like Precipitation Method, Nalgonda Technique, Adsorption, Ion Exchange Mechanisms etc[12]. Excess of fluoride in ground water have been treated using Activated alumina (AA) based defluoridation filters earlier[13-21]. As a part of Department of Science and Technology, Government of India sponsored project to design, develop and test, low cost defluoridation filters for rural use, we have recently studied the kinetics of fluoride removal from local ground water using AA[22] and described the fabrication and testing of four small domestic fluoride level filter fitted with single or double ceramic cartridge with different quantities of AA (2.5, 3, 3.5 kg) and one or two ceramic cartridges [24,25] .We found that the flow rate of defluoridated water from these filters was less, (2 lit./hr.) and the filter needs to be refilled 3-4 times at least, per day to obtain approximately 20 liter of water to meet the water needs of an average household. The AA needs to be replaced or regenerated every 2-4 months. In continuation the above study we have fabricated AA based fluoride filters with high flow rates and high capacity and was tested them in the lab using fluoride contaminated ground water from a nearby village (Bhooma Chota), and in this paper we present the results of our study.

EXPERIMENTAL

Four holes of 1 cm diameter were made at the bottom of a 51 liter HDPE water storage container. Four similar holes of 1 cm diameter were made on top lid of a 50 liter HDPE drum so that both the set of holes were centro-symmetric. Four ceramic cartridges were fitted on the base of the top container with their outlets protruding through the holes into bottom container (fig. 1 and 2). 10 kg and 25 kg water washed activated alumina (DF-101, M/s Siddhartha Industries, Surat, and Gujarat, India) was poured from the top.

A tap was fitted 2 cm above the base of the bottom of drum. Fluoride contaminated ground water from the village Bhooma Chota (middle tubewell) was brought by water tankers and stored in 1000 and

500 liters drums in the lab. The water was pumped into the upper container every day. Periodically various water quality parameters were analysed as follows: Water from the outlet tap was analysed for fluoride using a Fluoride Ion Selective Electrode (Orion Thermo Scientific, USA) and TISAB III buffer. Calcium and Magnesium hardness using EDTA method, Carbonate and Bicarbonate by titrating with standardised H_2SO_4, and Chloride by titrating with silver nitrate. Sodium and Potassium were analysed by Flame Photo Meter. Duly calibrated electronic pH and TDS meter were used for determining pH and TDS of untreated and treated water.

RESULTS AND DISCUSSION

We were unable to use the same water container for both the upper and the lower chamber because of the two reasons. Firstly we found that four ceramic cartridges could not be fitted at the base of available 50 liter drum, therefore it could not be used as the top container. Secondly the 51 liter water container used had coagulated cover which could not support the weight of water filled container (approx. 53kg). Therefore the present arrangement of two different water containers has been used. In the beginning of our experiments we filled 10 kg activated alumina in the lower chamber after covering the inlet of the tap with layer of nylon cloth having 0.16 mm mesh size. We however found after one week the particles of AA choked the nylon cloth and flow of water stopped from the filter. Therefore we transferred the AA from the bottom drum to the upper container. Hence in the second filter we filled 25 kg AA in the upper container from the beginning of the experiment itself (Fig 3).

The costs of the various components of the filter are given in Table 1. We found that the maximum component of cost is that of AA Rs. 1160/- for 10 kg and Rs. 2900/- for 25kg. The diameter of the top container was 41 cm at the top and base 32 cm at the base. The cask shaped bottom container was 30.5cm at the top and 29.5 cm at the base in diameter.

The filter can be fabricated easily by an unskilled labor with only few drilling of holes and tightening of wing nuts of the ceramic cartridge is required. The water capacity of the filter was found to be 40 liter for 10 kg and 16 liter for 25 kg AA. The bed volume of 10 kg AA is 13.5 lit. and 25 kg AA is 33.78 lit. Average elution rate of defluoridated water from the filter was 20.6 lit./hr. for 10 kg and 9.3 lit/hr for 25 kg (Figure 4 and 5). This difference is partly due to the less water capacity of the filter filled with more quantity of AA and more resistance to the flow of water by AA in the 25 kg AA filter than with 10 kg AA. (Empty Bed Contact Time) EBCT for 10 kg AA filter is 39.35 min. and 56.3 min. for 25 kg AA) Table 2.

If the 10 kg filter is filled once a day it produces sufficient water for two days (assuming water can supply of 20 liter/day for a family of four people). For 25 kg AA filter needs to refill at least twice a day for two days to produce 64 liter of drinking water which is sufficient to meet drinking water requirements for three days. The fluoride concentration in treated water was monitored every 50 liters and depicted in (Fig 6 and 7). The volume of safe water yield (< 1.5 ppm) of the filter with 10 kg is 3300 liters and 3900 liters for 25 kg AA. Specific safe water yield is 330 mg F-/kg for 10 kg, 156 mg F-/kg AA for 25 kg AA. The Fluoride Uptake capacity of AA for AA in the filter with 10 kg AA is 722.7 and 396.24 for filter with 25 kg AA.

The higher volume of safe water in 25 kg filter than 10 kg filter can be explained in the larger amount of AA. This safe water volume is not, as expected 2.5 times, that that of 25 kg filter. The lower specific safe water yield and hence lower fluoride uptake capacity in the filter with 25 kg AA is ascribed to several reasons discussed as follows: a) lower than expected volume of safe water from the 25 kg AA filter than the 10 kg AA filter, b) the average bicarbonate concentration and the average TDS in raw ground water was 300 ppm and 100 ppm higher, when the 25 kg AA filter was being tested, as compared to the raw water with which 10 kg AA filter was tested.

The overall low FUC of AA in both the filters is due to a) their relatively high flow rates (20.6 and 9.3 liter/hours) as compared with single cartridge flow rate was 1.7lit./h and double candle filter flow rate was 3 lit. /h [23, 24] a) it is known that AA absorbs fluoride optimally at pH 5 [21, 25, 26, 27] the average pH of ground water being used for testing the filter was 9, and it is known that the fluoride adsorption capacity of the filter falls drastically after pH 8-8.5[27,29,30] c) very high concentration of bicarbonates in the raw water is also known to reduce the fluoride adsorption [21, 28].

AA surface has an amphoteric character. Removal of fluoride by AA is mainly due to ion-exchange and can be described by following equations

$$AlOH + F^- \rightarrow AlF + OH^- \quad (1)$$

$$AlOH_{2+} + F^- \rightarrow AlF + H_2O \quad (2)$$

Al represent solid alumina surface[30].

Notice that the fluoride removal from the ground water is nearly constant till 3000 lit. in the 25 kg AA while for the 10 kg AA filter the fluoride level fluctuates (Fig 6 and 7). Also notice the presence of four ceramic cartridges in the filter and occupying 270 cm^2 each of surface area protruding upwards from the base of the filter (Fig 2). Therefore the raw water comes into contact with AA to different extents before coming in contact with the surface of the ceramic cartridges. In the filter with 25 kg AA, the bed volume of AA is 2.5 times more than with 10 kg AA and the defluoridation is more uniform. Assuming a water usage of 20 lit. per day if used at domestic level, the 10 kg filter can be operated for 5 months 15 days and 25 kg filter can be operated for 6 months 15 days before it needs to be regenerated.

If the filter is shared at community level for example, between 5 households then the 10 kg AA filter can be operated for one month three days and 25 kgAA filter for one month and nine days. Considering the higher average flow rate of 10 kg AA filter and higher fluoride uptake capacity and specific safe water yield cost per liter of defluoridated water, the 10 kg filter is better than 25 kg AA filter

We now discuss the other water quality parameters monitored in the raw and filtered water during the defluoridation process. The maximum permissible limit of pH according to BIS standard is 6.5 to 8.5[31].The average pH of raw water is 9.03, 9.18 while for average treated water pH is 9.1, 9.01 for 10 and 25 kg (fig. 8). The average carbonate of raw water is 171.6 and 122.4 ppm and average treated water carbonate is 194 and135ppm for 10 kg and 25 kg (fig 9). The average bicarbonate of raw water is 1349.7, 1662.8 ppm and the average bicarbonate of treated water is 1075.6 and 1278.9 ppm (fig. 10). (The max. permissible limit for total alkalinity is 600 ppm (fig.11) [31]

For chloride, the permissible limit is 1000 ppm[31]. The average chloride of raw water is 644.2, 533.45 ppm and average chloride of treated water is 709.85 and 490.50 ppm for 10 and 25 kg (fig. 12). For calcium the maximum permissible limit is 200 ppm[31]. The average calcium of raw water is 9.6 and 10.8 ppm and average calcium of treated water is 7.4 and 7.1 ppm for 10 and 25 kg (fig. 13).

For magnesium, the maximum permissible limit is 100 ppm[31]. The average magnesium of raw water is 18.1 and 22 ppm and the average magnesium of treated water is 13.9 and 5.1 ppm (fig. 14). The maximum permissible limit of TDS according to BIS standard is 2000 ppm in absence of any alternative source of water[31]. The TDS measured (indirectly based on conductivity) of raw water. The average TDS value is 1420 and 1532 ppm and in treated water average value is 1513.3 and 1613.3 ppm (fig. 15). The high concentration of various dissolved salts is reflected in the high TDS value of raw water. Na^+ concentration in raw water it was found to be 270.6 and 375.6 ppm and for treated water 348 and 309.14ppm, K^+ concentration in both raw and treated water varied from 13.7 and 11.8 ppm (fig. 16 and 17).

CONCLUSION

To conclude we have investigated the filter performance of the AA based filters filled with 10 and 25 kg AA. It was found that the filter with 10 kg AA was better, as it needed to be filled only once daily to be able to meet the water demands of a family. Also its initial capital cost was 60% lower than that with 25 kg AA. However, in terms of recurring costs of one liter water (if AA is discarded after single use) the filter with 25 kg AA is cheaper to operate by 15 % as compared to the filter with 10 kg AA. The higher efficiency of the AA in the filter with 10 kg AA reflected in its fluoride uptake capacity which was found to be double than that of 25 kg AA. With a high flow rate of 20 lit. /h, the filter with 10 kg AA is suitable for installation at a common place so that 5-6 household living close together can take benefit of the filter.

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Table 1. *Cost of Components of 51 liter Intermediate Filter with Ceramic Cartridge*

Filter Parameters	10 kg AA Four candle filter	25 kg AA Four candle filter
Activated Alumina @ Rs.116/$ 2.10 /kg	Rs. 1160/$ 21.09	Rs. 2900/$ 52.72
Drum @ Rs. 200/$ 3.63	Rs. 200/$ 3.63	Rs. 200/$ 3.63
Big Bucket @ Rs. 265/$ 4.81	Rs. 265./$ 4.81	Rs. 265/$ 4.81
Ceramic Cartridge @ Rs. 280/$ 5.09	Rs. 1120/$ 20.36	Rs. 1120/$ 20.36
Outlet valve @ Rs./$ 0.545	Rs. 30 /$ 0.545	Rs. 30/$ 0.545
Total Cost Rs./$)	Rs. 2775 /$ 50.454	Rs. 4515/$ 82.09

Table 2. *Characteristics of filters with different quantities of activated alumina*

AA (kg)	10	25
Capacity (lit.)	40	16
Depth of A.A covering ceramic cartridge	7.4 cm	27.6 cm
Depth of A.A in upper chamber	16.7 cm	36.5 cm
Bed Vol. (lit)	13.5	33.78
EBCT (min)	39.35	56.3
Diameter of upper chamber	40.6/32 cm	41/32 cm
Time (min)for emptying of the filter (brimful)	116 min	103 min
Liters per hour	20.6 lit/h	10 lit/h
FUC (mg/kg)	722.7	396.24
No. of refills required per day water	1/2	2
Vol. of safe water (lit.) (1st Cycle) @2.4 ppm F	3300	3900
No. of filter refills of safe water	82.5	243.75
Time before 1st regeneration	5 months 15 days	4 months 10 days
Capital Filter Cost (Rs./$)	2775/50.454	4515/82.09
Cost of defluoridated water per liter (for 1st cycle) in Rs/$ (Consider capital cost of the filter)	0.84/0.015	1.15/0.0209
Recurring cost of 1 liter water (if AA is discarded after Single use in paisa/$)	35.15/0.0063	29.74/0.0054

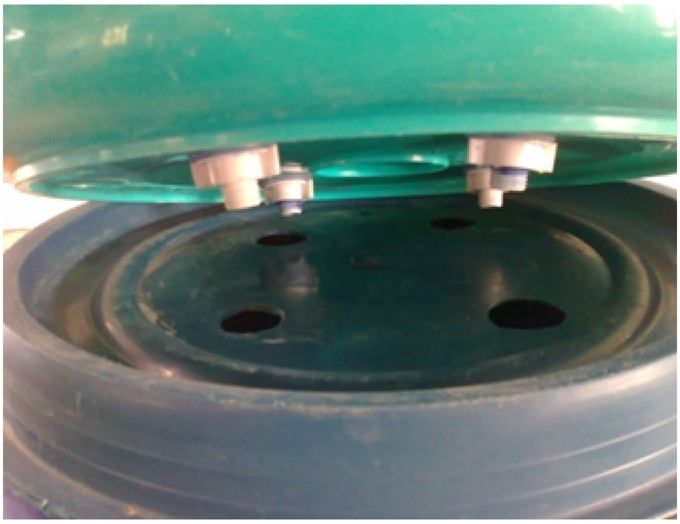

Figure 1. *Photograph of Middle Portion of the Filter*

Figura 2. *Photograph of the inside of the filter with four ceramic cartridges (without the AA)*

Figura 3. *Photo of the fabricated filter with four ceramic candles with Activated Alumina*

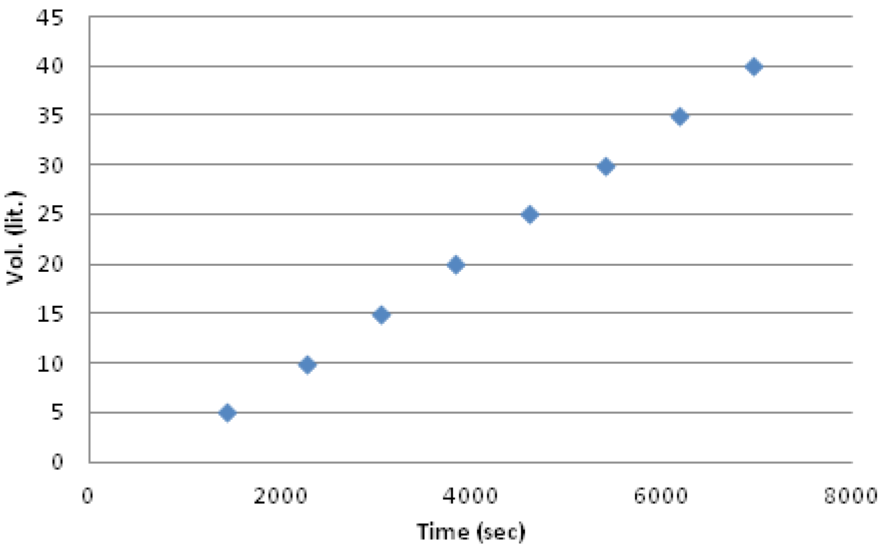

Figura 4. *Flow rate of filter with 10 kg AA*

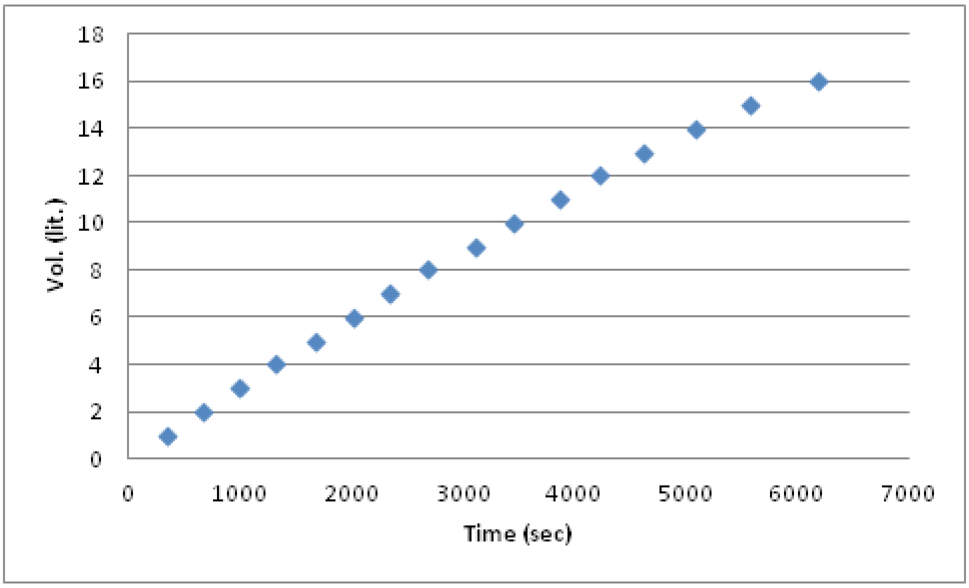

Figura 5. *Flow rate of filter with 25 kg AA*

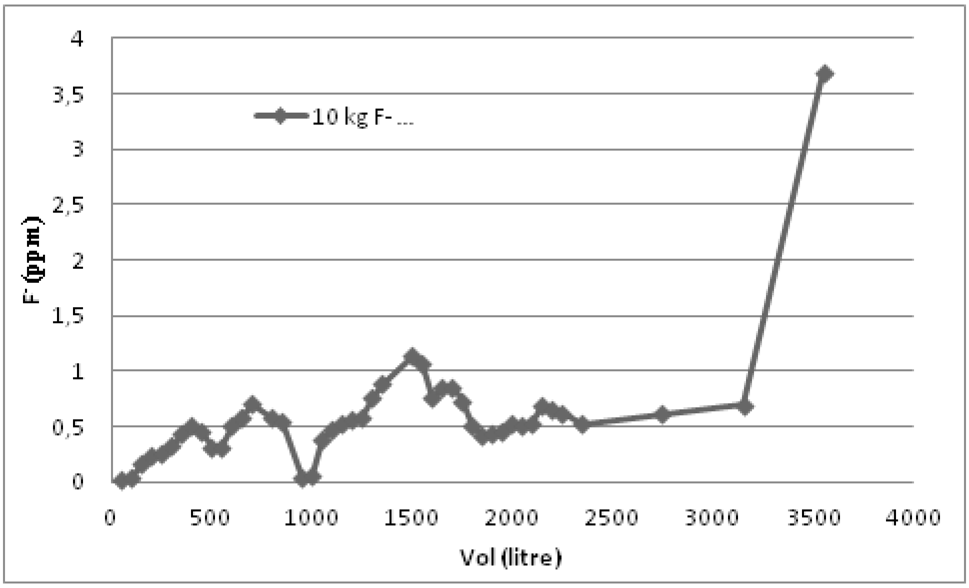

Figura 6. *Breakthrough profile of filter with 10 kg AA @ average inlet fluoride conc. 2.94 ppm*

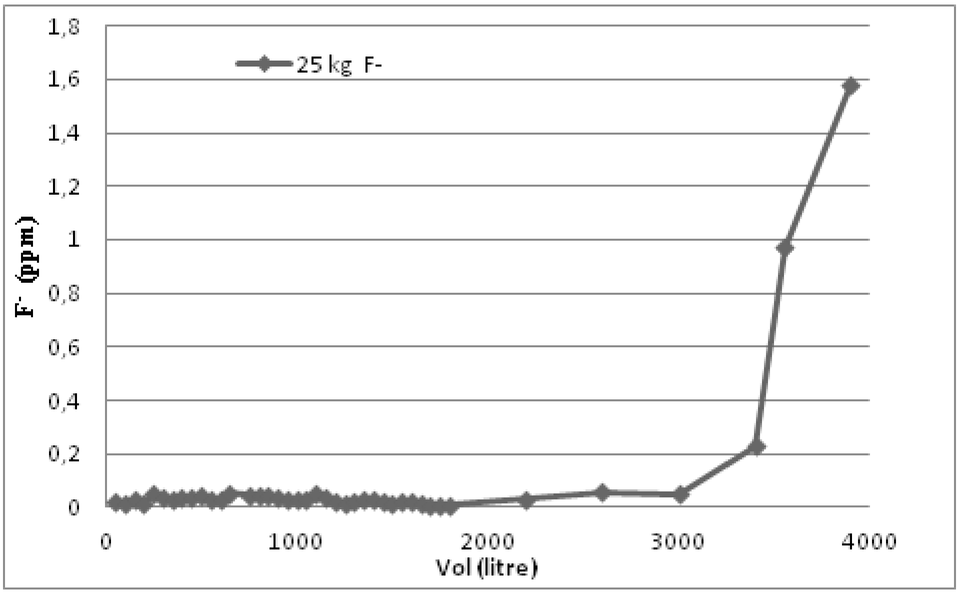

Figura 7. *Breakthrough profile of filter with 25 kg AA @ average inlet fluoride conc.3.29 ppm*

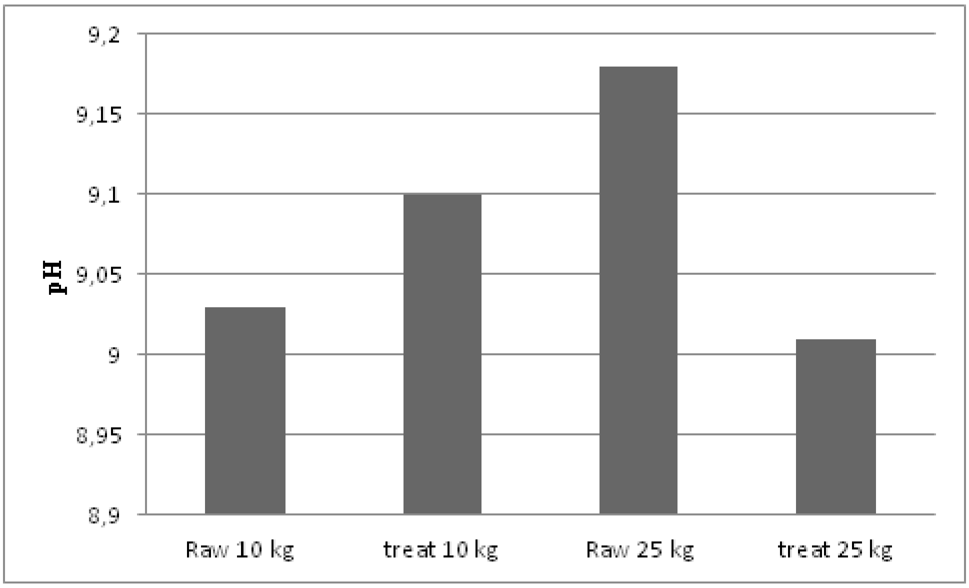

Figura 8. *Comparative average pH values of raw and treated water from filters with 10 and 25 kg AA*

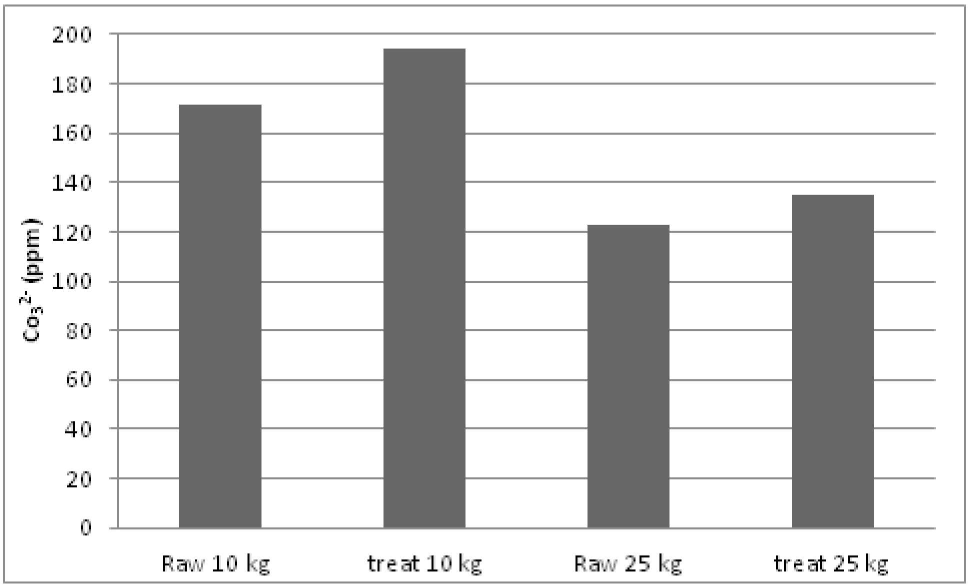

Figura 9. *Comparative average Carbonate values of raw and treated water from filters with 10 and 25 kg AA*

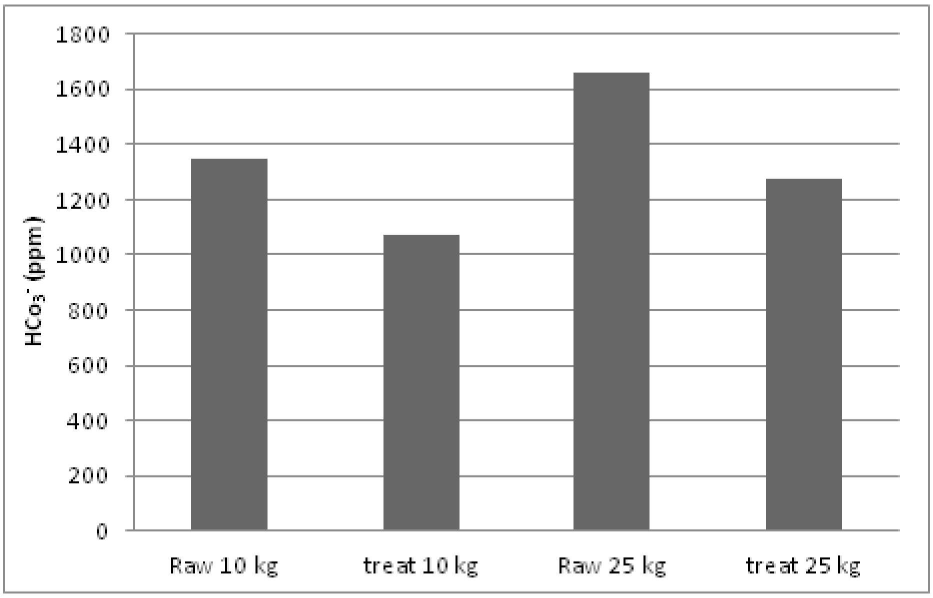

Figura 10. *Comparative average Bicarbonate values of raw and treated water from filters with 10 and 25 kg AA*

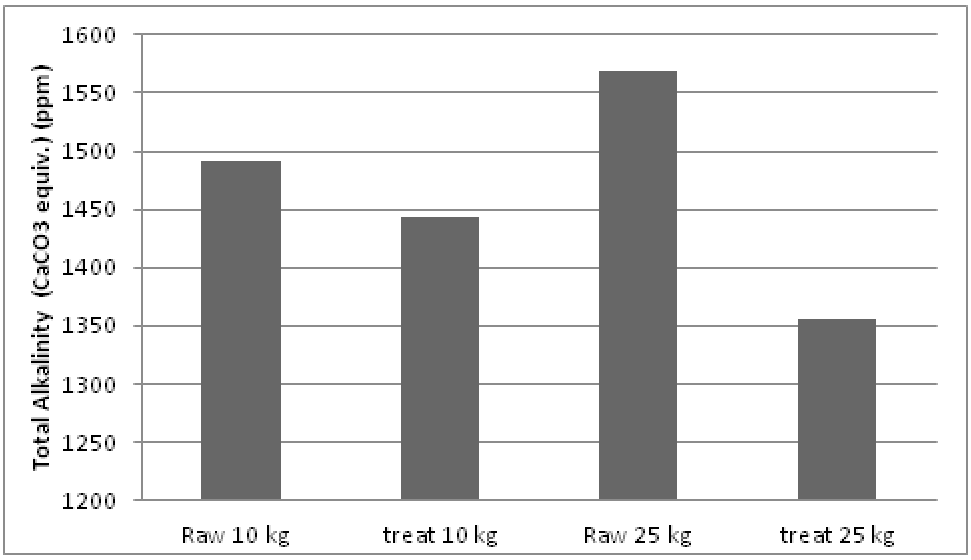

Figura 11. *Comparative average Total Alkalinity values of raw and treated water from filters with 10 and 25 kg AA*

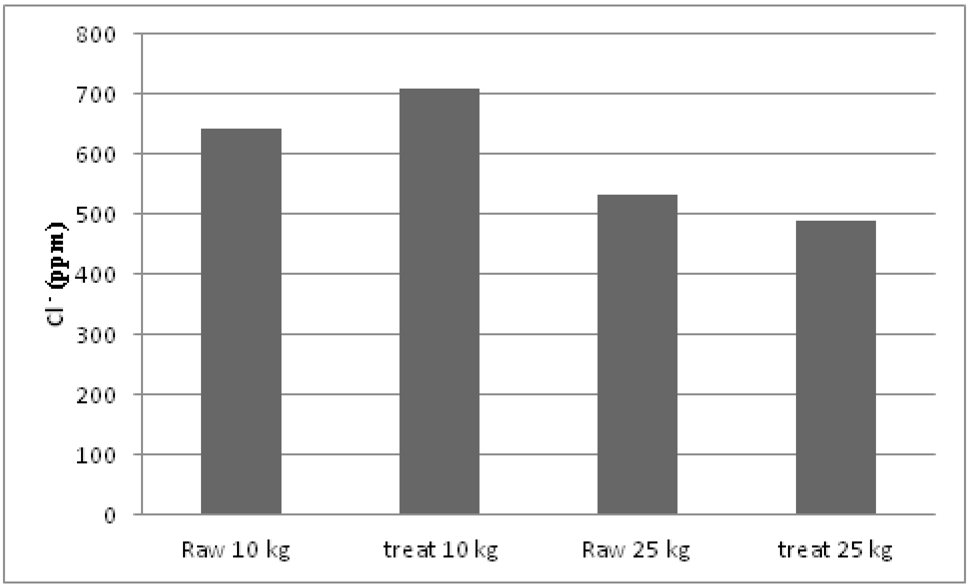

Figura 12. *Comparative average Cl- values of raw and treated water from filters with 10 and 25 kg AA*

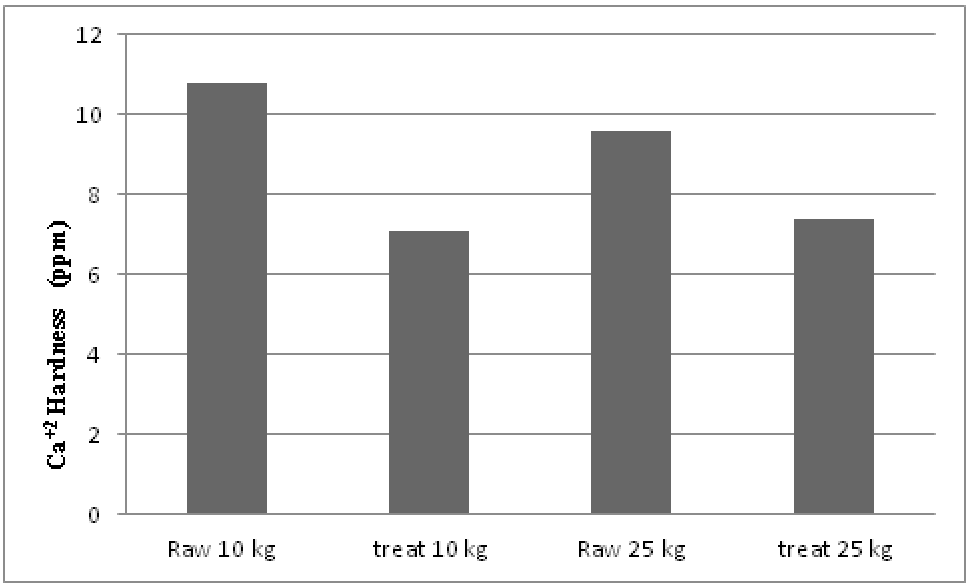

Figura 13. *Comparative average Ca+2 Hardness values of raw and treated water from filters with 10 and 25 kg AA*

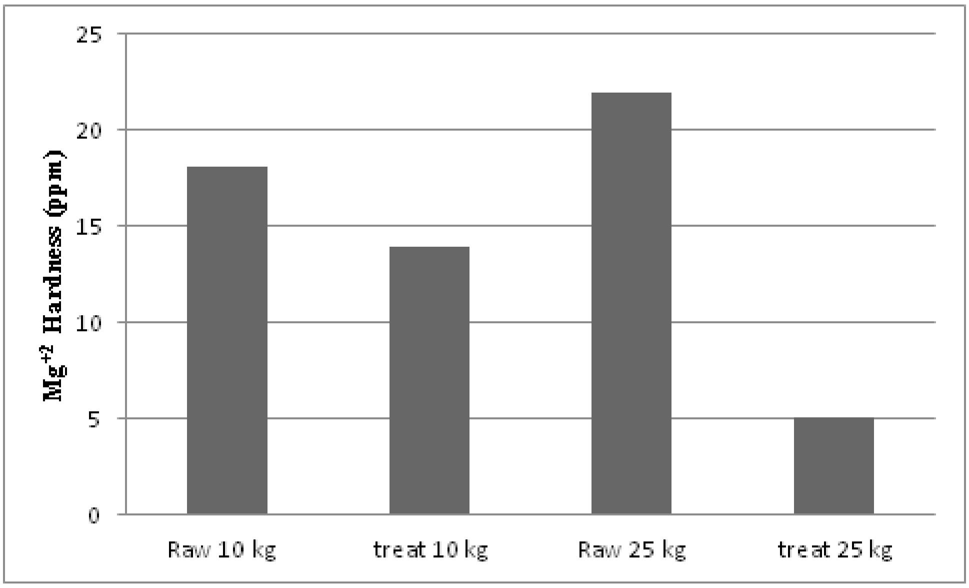

Figura 14. *Comparative average Mg+2 Hardness values of raw and treated water from filters with 10 and 25 kg AA*

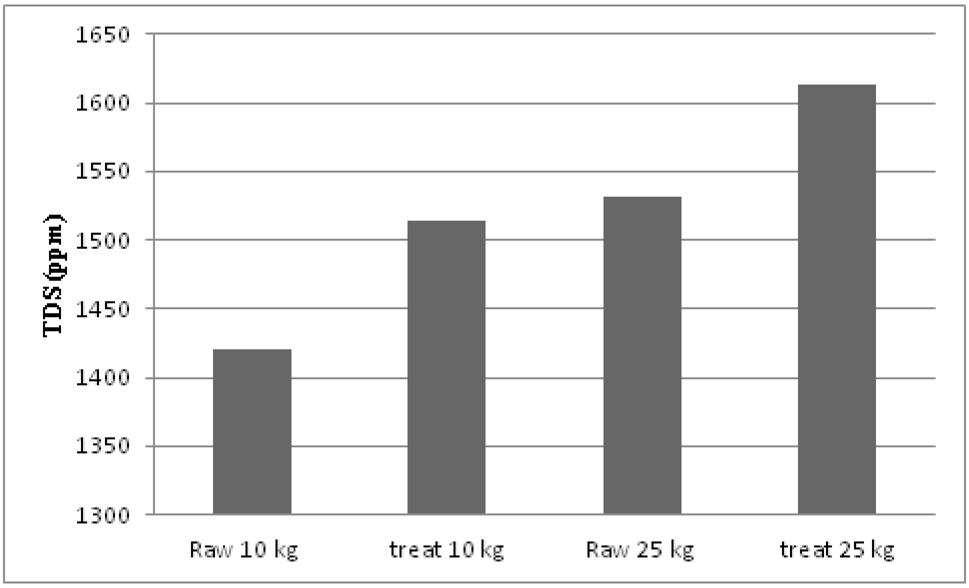

Figura 15. *Comparative average TDS values of raw and treated water from filters with 10 and 25 kg AA*

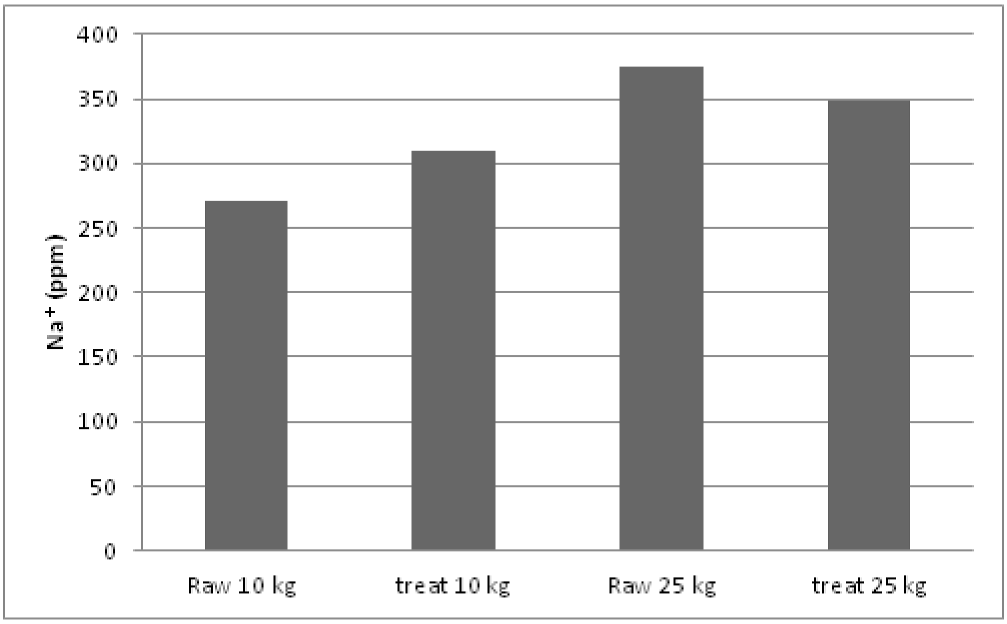

Figura 16. *Comparative average Sodium values of raw and treated water from filters with 10 and 25 kg AA*

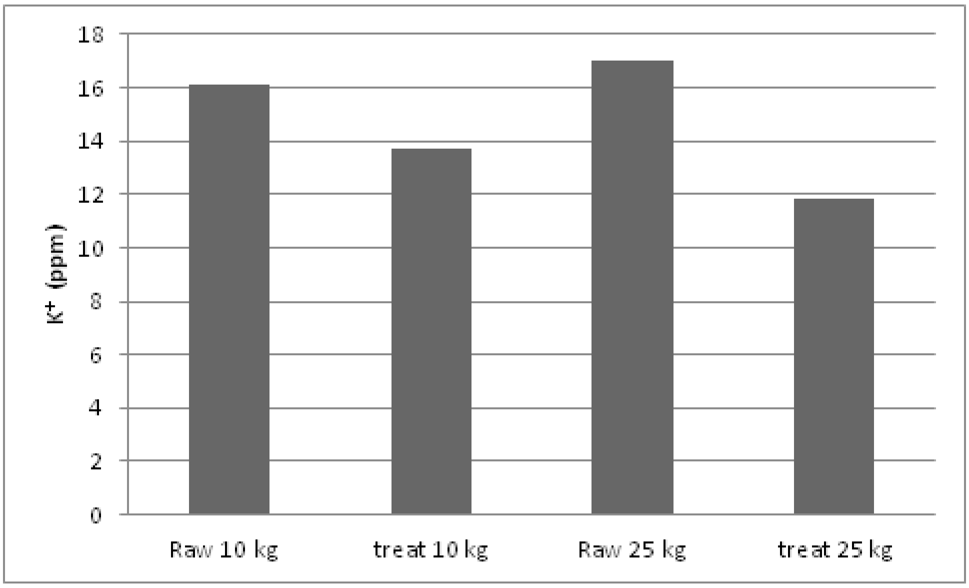

Figura 17. *Comparative average Potassium values of raw and treated water from filters with 10 and 25 kg AA*