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Microscopic testing and analysis of drinking water filters after the final life cycle, using an experimental stand

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Abstract. The purpose of this paper was to develop a testing infrastructure, under laboratory conditions, for the drinking water filters used in the household. The mechanical filtration of existing nanoparticles in drinking water distributed to the large public is a very important aspect of ensuring a high level of drinking water quality, at the final consumer - the household user, regardless of the conditions of supply or its distribution. Moreover, the importance of increasing the quality of domestic drinking water is reflected by the need to encourage its consumption, to the detriment of bottled PET packaging (polyethylene terephthalate), which confers a number of disadvantages in relation to environmental protection and consumer's health. In order to achieve the proposed goal, a computer aided design (CAD) was developed and an experimental stand was designed and built to allow different categories of constructive and structural filters to be tested. The filters were chosen according to well established criteria. Their testing was aimed at identifying the potential and characteristics of mechanical filtration of existing nanoparticles in drinking water. Finally, using the atomic force microscopy technology (AFM), it was possible to microscopically investigate the nanofiltration results performed using the sample of tested filter elements and their classification according to the quality of the filtration obtained.

1. Introduction

A viable solution for increasing the quality of domestic drinking water is the purchase and use of water filters, to the detriment of the acquisition of bottled drinking water.

The necessity to purchase filters for drinking water provided by the public network has a dual role. On the one hand, it is achieved an increasing with regard to the quality of drinking water supplied from

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the public network, which is qualitatively affected during its supply along the distribution network. On the other hand, the population is discouraged from purchasing bottled water in Polyethylene Terephthalate (PET) packaging, which has direct and immediate negative effects on the environment [1-3].

In this sense, through the developed research it was proposed to identify the optimal filtering element, in order to improve the quality of life of the population and at the same time to support the environment in the context of sustainable development [4].

2. Materials and methods

In order to analyze the quality of water samples, two diametrically opposed test points were chosen, both having the regional operator - Someș Water Company, as the exclusive supplier. Therefore, for the research, the first test point was located in the Iris district on Muncii Boulevard from Cluj-Napoca and the second one was located in the Gilău villlage, on Braniște street. The reason for choosing these two areas consisted primarily in the fact that they are located at a considerable distance, more exactly 21 km from each other, which can lead to different water quality effects, both before and after mounting the filter elements.

On the current market, there are a variety of filters, such as ceramic, polypropylene, active carbon, textile material or washable material, etc., with particle filtering capacities ranging between 0.3 μm to 70 μm. However, their different structural properties have allowed Atomic Force Microscopy (AFM) to analyze only the ceramic and polypropylene filter elements, which are also the first two in the order of filtering capacity declared by the manufacturer [3, 5].

The CAD environment was used to design an experimental stand, which was built and utilized for testing the filters under laboratory conditions. Also, for the analysis of deposition results, the AFM technology was used, with which was performed the 3D scan of the tested samples [6].

After the experimental tests of the filters has been carried out, at the maximum life time using capacity of them, it was done a topological analysis of the filtering samples surfaces and a mechanical nanocharacterization of the polluting particles deposit. This was possible through the Atomic Force Microscopy, using the AFM Microscope XE 70 from the MINAS research laboratory (Micro and Nano Systems Laboratory), part of Technical University of Cluj-Napoca.

The tests were carried out for a relative humidity of 28 % at a room temperature of 23 °C. The topography determination and the nanocharacterization was performed using a PPP-NCHR cantilever which is defined by: thickness of 4 μm, width of 30 μm, length of 125 μm, resonance frequency of 400 kHz and force constant of 42 Nm^{-1}, also the tip height is 15 μm and radius is smaller than 10 nm.

The surface topography evaluation, in non-contact mode, supposed that a sharp tip placed on the top of the cantilever, vibrate near the surface of the sample, interacting with the sample trough the inter-atomic attractive forces principle [7, 8].

The roughness of filtering samples surfaces analyzed is directly influenced by the size and the distribution of deposited polluting particles, closely related to the filtration capacity and the filter element materials structure. The samples analyzed were taken from the same middle area of the tested filters, because due to the testing carried out on the experimental stand, the flow rate of the water was uniform and the filter section being constant [9].

3. Developing the testing infrastructure

For the testing of the filter elements, first was made a CAD model of the experimental stand, which is shown in Figure 1 (a). The CAD model has been implemented in practice, and the result is shown in Figure 1 (b).

The stand developed is composed by the following elements: 1) adjustable foot table; 2) network water inlet hose; 3) water quantity meter; 4) water pressure control valve; 5) water pressure indicator; 6) drinking water filter (consisting of a filter casing and a removable filter cartridge); 7) filtered water outlet hose; 8) water tap with double role (adjusting post filter flow and retaining post filter impurities on an auxiliary sieve).

(a) (b)

Figure 1. (a) CAD model of the experimental stand, (b) Experimental stand developed.

4. Carrying on the experimental tests and microscopic analysis

In this way, starting from the amount of minimum water required (indicated) to be consumed by a person over a day, correlated with the filter cartridge manufacturer's specification of their maximum lifetime, but also by the average number of water consumers into a family, the amount of total water consumed for each filter cartridge (intended for direct consumption or in the cooked preparations form) was determined using the calculus relation 1.

$$C_{water\_total} = C_{water\_i} \ x \ N_{days} \ x \ N_{consumers} \quad [\mathrm{m}^3] \tag{1}$$

After replacing in the calculus relation 1, it is obtained:

$$C_{water\_total} = 2 \ x \, 180 \ x \ 3 = 1080 \ \ [liters] \, \mathrm{x} \, 10^3 = 1.08 \ \ [\mathrm{m}^3]$$

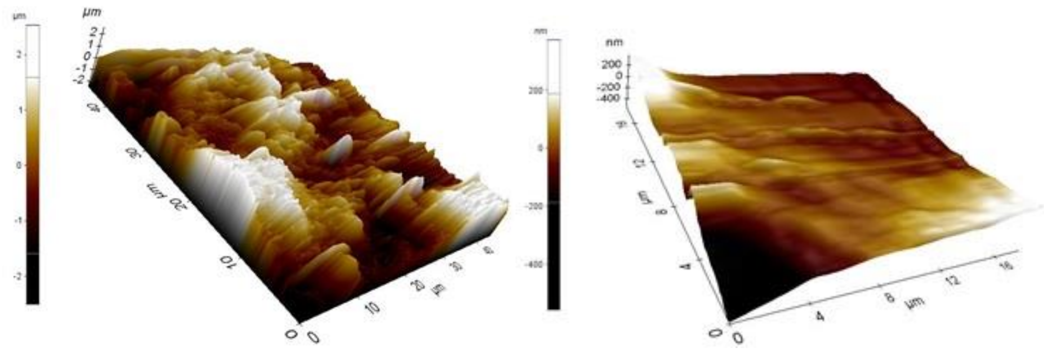
where:

- C_{water_total} is the amount of total water intended for self-consumption (water or cooked water) by the average number of people in a family for a period of 6 months;
- C_{water_i} represents the daily water consumption at the individual level;
- N_{days} represents the number of days from the analyzed period;
- $N_{consumers}$ represents the average number of people in a family (consumers).

Considering that the result reflects the minimum amount of water consumed for the specified activities during the life of the filter cartridges, but also the fact that the manufacturer additionally indicates the possibility of filtering up to 3 m^3 for one filter cartridge over the lifetime of the filters, to perform the experimental procedures, it was chosen to test them for the maximum amount of water admitted.

After the testing infrastructure was completed, the next step in the filtering test phase of the analyzed cartridges was to generate samples containing elements obtained by cutting the tested filter cartridges and subjecting them to microscopic analyzes. The microscopic analyzes have the role of determining the quality of drinking water filtration (in terms of types, geometry, size and density of impurities deposited in the structure of the experimentally tested filter elements) and these objective was possible with the help of AFM. From the results obtained, it can be said that the efficiency of the filters is directly proportional to the value of the microns number held by each one, for the filtration capacity [9, 10].

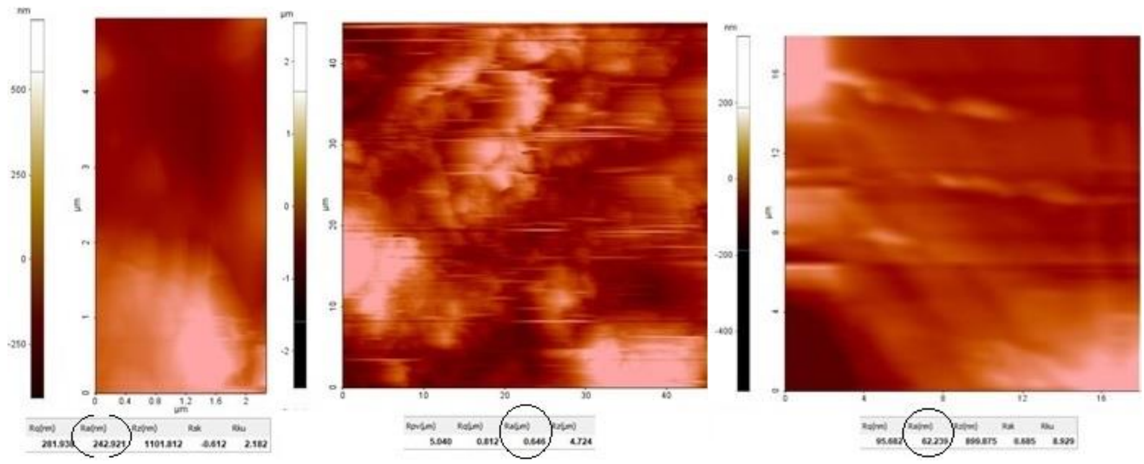
The scanned area for topography of the ceramic sample is the maximum permissible of 40 μm x 40 μm, and for the topography of the polypropylene sample due to a small dispersion of the determined particles, it was enough to analyze a surface of only 16 μm X 16 μm. From Figure 2 (a) results an increased density of particle agglomeration, with approximate heights of 2000 nm, while Figure 2 (b) shows a much lower particle density agglomeration, with mean heights up to 1000 nm.



(a) (b)

Figure 2. (a) Ceramic filter topography – deposits, (b) Polypropylene filter topography.

The samples surface scanning reflects more roughness parameters, but an important one called R_a, is the arithmetic average height of roughness. R_a high values, shows the influence of the polluting particles deposit in relation to a standard filtrating surface and also the quality of the filter with regard to itself filtration capacity. In Figure 3 (a), it is observed the surface roughness of the standard sample of ceramic material, where $R_a = 0.242$ μm. In Figure 3 (b), it is observed the roughness of the ceramic surface of the tested filter element, where $R_a = 0.646$ μm. Figure 3 (c) shows the roughness of the polypropylene surface of the tested filter element, where $R_a = 0.062$ μm.

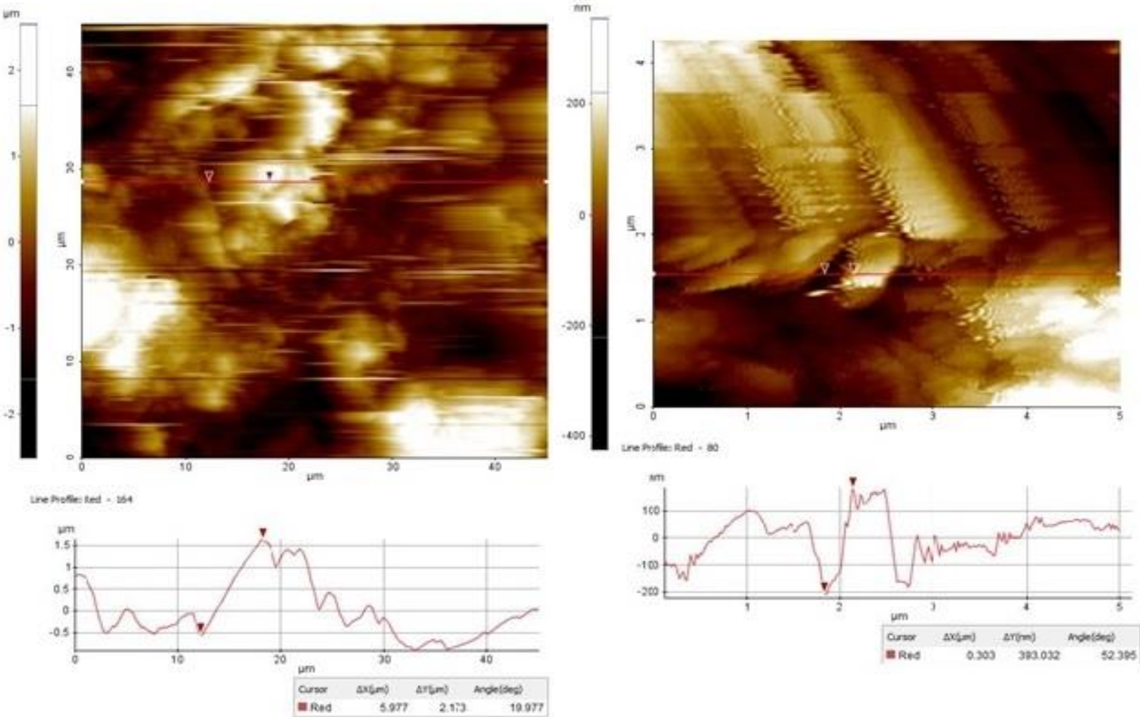


(a) (b) (c)

Figure 3. (a) Ceramic standard filter roughness, (b) Ceramic used filter roughness, (c) Polypropylene used filter roughness.

Corroborating the results of the topographic analyzes with those of the roughness of the scanned surfaces, it is observed that the highest density of particles retained by filtration is found on the ceramic sample. This density, through the particle deposition process, results in an increase of roughness R_a with 0.4 μm in the case of ceramic sample. On the opposite side, the low surface roughness of polypropylene is reflected by the lower filtration capacity of the tested filter, as can be seen also from the particle density agglomeration, highlighted in the topography from Figure 2 (b).

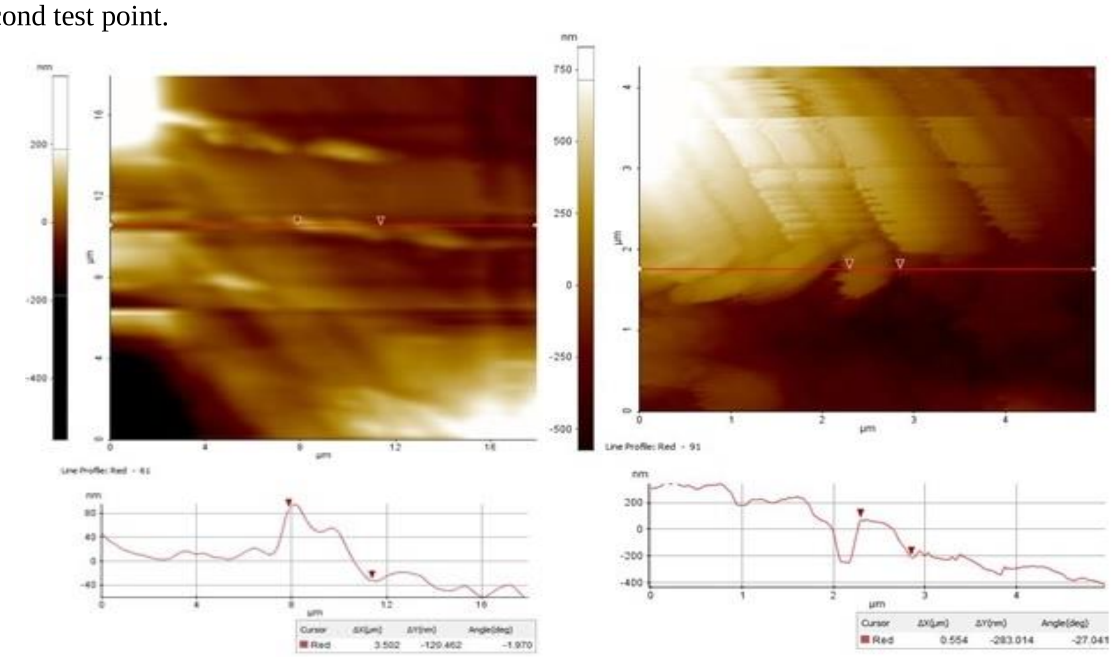
Farther, it was made the individual analysis of the most dimensional relevant particles, deposited on the surfaces of scanned ceramics and polypropylene samples. For this, the samples taken from the two test points were analyzed. For ceramic samples, from Figure 4 (a) results that the particle height size is 2173 nm for the first test point, while from Figure 4 (b) results a height size of 393 nm in the case of the second test point.



(a) (b)

Figure 4. (a) Ceramic sample Test Point 1 (Cluj-Napoca), (b) Ceramic sample Test Point 2 (Gilău).

For the polypropylene samples, from Figure 5 (a), it was observed a 120 nm particle height size for the first test point, while Figure 5 (b) shows a particle height size of 203 nm found in the case of the second test point.



(a) (b)

Figure 5. (a) Polypropylene sample Test point 1 (Cluj-Napoca), (b) Polypropylene sample Test point 2 (Gilău).

5. Conclusions

Using the experimentally developed stand, there was made tests at the two test points, on the ceramic and polypropylene filter cartridges up to the maximum usage time of 3 m^3. Subsequently, samples of these filters were taken which were subjected to microscopic AFM analysis. The results of experimental tests and microscopic analyzes indicate an increased particles retention capacity for the ceramic filter cartridge, much higher than the polypropylene filter cartridge. This is highlighted on the one hand by topography and surface roughness analysis, resulting into an increased agglomeration density of particles deposited on the ceramic sample, leading in an increase of the surface roughness value with R_a= 0,4 µm.

On the other hand, from the dimensional analysis of the relevant particles, it is found that in the case of the ceramic sample, the structure of the material and its roughness allows to retain a much higher number of particles with dimensions up to 2173 nm, and the characteristics of the polypropylene material, although they allow the retention of particles with dimensions up to 203 nm, their number is much lower.

In conclusion, it is noted that the best filtration efficiency is owned by ceramic cartridge, which is one of the best indicators for both, producers and household consumers who want to purchase a water filter with superior characteristics.

6. References

[1] Webster K 2017 *The Circular Economy: A Wealth of Flows* - 2nd Ed. (Ellen MacArthur Foundation Publishing) 102
[2] Howe K H, Hand D W, Crittenden J C, Trussel R R and Tchobanoglous G 2012 *Water Treatment: Principles and Design* – 1nd Ed. (Wiley) 321
[3] Gray N F 2010 *Water Technology IWA Edition: An Introduction for Environmental Scientists and Engineers* – 3nd Ed. (IWA Publishing) 28
[4] Peng Z and Chen S 2011 *Phys. Rev.* E **83** (5) 051915
[5] Eftekhar B, Skini M, Shamohammadi M, Ghaffaripour J and Nilchian F 2015 *J. of Dent.* **16** (3) 278-81
[6] Lobontiu N and Garcia E 2004 *Mechanics of Microelectromechanical Systems* (Springer-Verlag, New York)
[7] Kemp R and Volpi M 2008 *J. Clean. Prod.* **16** 14-21
[8] Knauss W G, Chasiotis I and Huang Y 2003 *Mech. of Mater.* **35** (3) 217-31
[9] Bellitto V 2012 *Atomic Force Microscopy – imaging, measuring and manipulating surfaces at the atomic scale* (Naval Surface Warfare Center, United States of America)143
[10] Briggs G and Briscoe B 1977 The effect of surface topography on the adhesion of elastic solids *J. of Phys. - Appl Phys.* D **10** (18) 2453