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The usefulness of ascorbic acid degradation to analyze the effectiveness of water filtration in household water filter jugs

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ABSTRACT

Introduction: This study aimed to determine whether the degradation of ascorbic acid in aqueous solutions could be used to compare the filtration efficiency of various household water filter jugs.
Materials and methods: Based on absorbance measurements of ascorbic acid, a new water quality coefficient (WQC) parameter was defined. Differences between the WQC were determined for 4 different water filters commonly used in household water filter jugs in Poland. In addition, correlations between the WQC, the amount of filtered water (AFW), and a number of other parameters were examined for all 4 filters.
Conclusions: Significant differences were found in WQC among the 4 filters. A decreasing efficiency of calcium ion removal from the water was observed with the ongoing use of all 4 filter cartridges. Overall, this method could be a sensitive, simple, fast, eco-friendly, and relatively inexpensive tool for determining the effectiveness of water purification in household water filter jugs, which of course requires further research.
Keywords: ascorbic acid; drinking water; filtration; household water filter jugs; water quality; water pollution.

INTRODUCTION

The quality of water against the background of the developing intensity of human economic activity has been widely discussed for many years. Water, as an inherent element of the ecosystem, is being polluted as a result of human activity, and rapid purification processes are not fully effective. The degradation of the natural environment has led to considerable reductions in good quality water [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]. The issue of water quality, regardless of geographic location, remains a highly relevant topic. Its impact on our health is enormous because good quality water is crucial for the supply of essential micronutrients to our body. However, the consumption of impure water is associated with the risk of intaking a variety of pollutants which may have a negative impact on our health; for example, via the accumulation of heavy metals in tissues or the induction of carcinogenic effects [15, 16, 17, 18, 19, 20]. In addition, poor water quality may cause diarrhea, resulting in numerous deaths worldwide, particularly among children in countries with a low economic status [3, 6, 8, 9]. Furthermore, water purity is significant for the quality of consumed food products [11, 16, 18].

Consumers require that the water supplied directly to the access points is clean, tasty, and healthy; yet unfortunately, primarily due to the poor condition of the water supply system, this is often not the case. To overcome this issue, household water filters were developed, with a wide range of these filters available on the market, varying in capacity, the type of particles they are able to filter, and cost. The most popular – probably due to the relatively low cost of purchase and operation, simplicity of use, and availability – are free-standing filter jugs. Their operation is extremely simple: the jug is filled with tap water which flows by gravity through the filter cartridge. The filter cartridges offered by individual manufacturers differ slightly in their composition and principle of operation. Most devices available on the Polish market consist of an ion exchange resin and activated carbon (both in granular form). The ion exchange resin allows the capture of compounds that cause scaling (i.e. magnesium and calcium salts) and reduces the concentration of metal ions (e.g. lead and copper); while the activated carbon absorbs chlorine, pesticides, and organic pollutants, as well as improves the taste, smell, and color of water [20, 21, 22, 23, 24, 25, 26, 27, 28, 29].

The problem of maintaining the quality of tap water is rather complicated, because clean water may contain traces of substances that do not go beyond the established standards. Unfortunately, interactions (e.g. with food) and the long-term consumption of water from one source can lead to the accumulation of a specific component (e.g. aluminum), resulting in adverse health effects [19, 30]. Furthermore, tap water may contain small amounts of pharmaceuticals that can potentially cause mutations in organisms living in water [30, 31]. Therefore, new methods for determining water quality, as well as the effectiveness of individual methods of water purification, remain highly sought after.

In highly developed countries, water is taken directly from the sources into the water supply network, and purified to strict control values to ensure it meets legally specified quality requirements. Access to good quality water is not always possible in countries with a water deficit (mainly Asian and African countries), with the situation even more difficult in developing countries due to poor or even lacking infrastructure [1, 2, 5, 7]. Although water that is distributed through a water supply network is the cheapest solution, and usually the safest to consume, this is not the norm. Indeed, some inhabitants of poorer regions may be forced to use other water sources, making long trips in search of an available well or using the services of door-to-door water sellers, which puts them at risk of consuming water without any quality guarantee. A number of organizations are involved in the issues around water supplies for cities, such as WHO, UNICEF and the World Meteorological Organization (WMO). Therefore, there is a need to develop simple and fast methods for water filtration as well as quality assurance for use in these regions.

This study aimed to show the possibility of using research on ascorbic acid degradation in aqueous solutions to compare the filtration efficiencies of household water filter jugs. Based on measurements of the absorbance of ascorbic acid, a new water quality coefficient (WQC) parameter was defined. The differences between the WQC for 4 different household water filters were then determined. In addition, the correlations between the WQC and the amount of filtered water (AFW), the levels of calcium/iron/copper ions, the concentration of chlorides and sulphates, the pH, and conductivity (i.e. the degree of filter wear) were calculated. The proposed method is sensitive, simple, fast, eco-friendly, and relatively inexpensive.

MATERIALS AND METHODS

A method for determining water quality had previously been developed based on changes in the absorbance of ascorbic acid solutions [32]. To apply this method in determining the effectiveness of water filter jugs, measurements of the decay rate of ascorbic acid were performed in aqueous solutions for tap water and filtered water.

Popular filter jugs (filters I and IV) in Poland and their cheaper substitutes (filters II and III) were examined. All 4 filter cartridges consisted of active carbon and ion exchange resins. Based on [32], solutions of ascorbic acid (Polskie Odczynniki Chemiczne, Gliwice, Poland) at 1 mg/100 mL were prepared. Measurement of absorption spectra of ascorbic acid in an aqueous solution was performed by UV spectroscopy using a Spectroquant Prove 300 spectro-photometer (Merck) in 10 mm quartz cuvettes at 260 nm wavelength (corresponding to the absorption max.).

The changes in the max. absorbance of the solutions over time were determined for tap water before and after filtering, i.e., for a new filter and then after filtering 40, 80, 120, and 160 L, which corresponds to a 4-week period of use. The manufacturers state that the period of filtration effectiveness is exactly 4 weeks, hence the measurements during this period should show the same filtration effectiveness. All measurements were made in quadruplicate and taken at room temperature (20°C).

A definition for a new parameter termed the WQC was proposed:

$$WQC = A_1/(A_1 - A_{20})$$

where A_1 and A_{20} are the absorbance values after the 1st and 20th min from the moment of preparing the ascorbic acid solution, respectively.

$$\Delta WQC = WQC_F - WQC_T$$

where WQC_F was determined for filtered water and WQC_T for tap water. In general, a faster decrease in absorbance over time (low WQC values) suggests greater water pollution, and a slow decrease in absorbance over time (high WQC values) indicates high purity water.

In addition, the levels of calcium, iron and copper ions, as well as chloride and sulphate content, pH, and conductivity σ were determined for both tap and filtered water. Ion levels were assessed using colorimetric test kits (Merck: 1144140001 Cu, 1.10083.0001 Ca, 1.14753.0001 chlorides, 1.14411.0001 sulphates, 1144030001 Fe). Measurements of conductivity σ and pH were made using a laboratory conductivity meter GLP31 (Crison) and a pH-009(I)A pH meter, respectively. All measurements were made for both tap and filtered water to avoid the influence of periodic changes of physical and chemical properties of water taken from the water supply network on the test results.

To show a statistically significant difference in the WQC for individual filters, Mann–Whitney U tests were made. All correlations between the analyzed parameters were examined using Spearman' correlation, with $p < 0.05$ considered statistically significant. All analyses were performed using Statistica v13.3 software (StatSoft, Polska).

RESULTS

Table 1 presents the means and standard deviations of ΔWQC depending on AFW for all 4 water filters tested, with p-values for the differences between the tested filters presented in Table 2. The difference between particular filters was considered statistically significant at $p < 0.05$. Table 3 shows the correlations between the ΔWQC and the AFW, the ΔWQC and the change in calcium ion level before and after filtering (ΔCa), and the AFW and the ΔCa. There were no statistically significant correlations between the ΔWQC and the other indicators tested, including changes in the levels of iron ions (ΔFe), copper ions (ΔCu), pH (ΔpH), conductivity (Δσ), or chlorides and sulphates content, before and after filtering. Finally, the average differences of individual physico-chemical parameters for the different filters, depending on the AFW, are presented in Table 4. The concentrations of chlorides and sulphates in the water before and after filtration remained exactly the same.

Due to the chemical structure of ascorbic acid, it is highly soluble in water. However, it also oxidizes quickly and is very

TABLE 1. Changes in the water quality coefficient for the tested household water filters, depending on the amount of filtered water

AFW (L)	Mean (standard deviation) ΔWQC			
	I	II	III	IV
0	2.8 (1.29)	0.0 (0.07)	0.1 (0.1)	−0.2 (0.19)
40	0.4 (0.12)	0.1 (0.08)	0.0 (0.24)	−0.2 (0.04)
80	0.7 (0.03)	0.1 (0.06)	0.2 (0.02)	−0.1 (0.09)
120	0.3 (0.6)	0.1 (0.13)	0.1 (0.1)	−0.1 (0.05)
160	0.3 (0.05)	0.1 (0.13)	0.2 (0.07)	0.0 (0.05)

TABLE 2. Differences in the change in the water quality coefficient between the tested filters

	p-value				
AFW (L)	0	40	80	120	160
ΔWQC I and II	0.03	0.03	0.03	0.03	0.06
ΔWQC I and III	0.03	0.03	0.03	0.06	0.03
ΔWQC I and IV	0.03	0.03	0.03	0.03	0.03
ΔWQC II and III	0.11	0.88	0.03	0.88	0.19
ΔWQC II and IV	0.19	0.03	0.03	0.11	0.31
ΔWQC III and IV	0.11	0.3	0.03	0.03	0.03

$p < 0.05$ was considered statistically significant; AFW – amount of filtered water

TABLE 3. Correlations between the change in water quality coefficient, the amount of filtered water, and the change in calcium ions levels before and after filtering for the tested filters

Correlation between	p-value (correlation coefficient R)			
	I	II	III	IV
ΔWQC and AFW	<0.01 (−0.7)	0.5 (0.2)	0.1 (0.4)	0.02 (0.5)
ΔWQC and ΔCa	<0.01 (0.8)	0.7 (−0.09)	0.04 (−0.5)	0.01 (−0.6)
AFW and ΔCa	<0.01 (−1.0)	<0.01 (−0.7)	<0.01 (−0.9)	<0.01 (−0.9)

$p < 0.05$ was considered statistically significant

TABLE 4. Differences in physico-chemical parameters before and after filtering for the tested filters, depending on the amount of filtered water

Mean	Filter	AFW (L)				
		0	40	80	120	160
Difference in the level of calcium ions ΔCa (mg/L)	I	90	75	75	25	0
	II	50	50	75	25	0
	III	50	50	25	25	0
	IV	50	50	25	25	0
Difference in the level of iron ions ΔFe (mg/L)	I	0.02	0	0.02	0.02	0.02
	II	0.02	0.02	0.02	0	0
	III	0.02	0.04	0.04	0.02	0.02
	IV	0.02	0.02	0.05	0.02	0
Difference in the level of copper ions ΔCu (mg/L)	I	0.25	0.35	0.15	0.11	0.2
	II	0.32	0.17	0.14	0.42	0.12
	III	0.35	0.22	0.22	0.42	0.45
	IV	0.18	0.2	0.4	0.15	0.3
Difference in pH ΔpH	I	1	1.4	1.7	2	1.2
	II	1.1	1.2	1.4	1.6	0.8
	III	0.9	1.4	0.8	0.8	1.2
	IV	1.1	1.5	1.2	1.2	0.7
Difference in conductivity Δσ (μS/cm)	I	81	150	139	90	25
	II	41	134	126	85	69
	III	90	139	169	77	65
	IV	117	178	144	153	113

sensitive to changes in temperature and ultraviolet radiation [33]. The rate of ascorbic acid degradation in aqueous solutions is accelerated by the presence of contaminants, such as heavy metals (e.g. iron, copper, manganese, mercury, nickel) [34, 35]. In terms of the newly-defined WQC, a low value suggests that the tested water contains contaminants that have accelerated the degradation of ascorbic acid, while high WQC values would indicate a low content of such substances. These properties of ascorbic acid have formed the basis of a novel method for determining water quality that can be used to analyze the filtration effectiveness of water filter jugs and to compare the various cartridges.

Filter I showed statistically significant differences in terms of the ΔWQC to almost all other filters tested, until filtering 120 L of water. On the basis of the WQC results, filters II and III were indistinguishable throughout the entire period of use (i.e., up to 160 L).

Only filter I showed a strong statistically significant correlation (high values of |R|) between ΔWQC and AFW. This suggests the degree of wear of the filter cartridge did not change the ΔWQC significantly for filters II, III, and IV. Therefore, filter I seems to remove water contaminants that accelerate the degradation of ascorbic acid that are not removed by other cartridges. The analysis shows that these were not iron or copper ions, nor chlorides or sulphates, as no correlation between the ΔWQC and the above components was demonstrated. Similarly, there was no statistically significant correlation between the ΔWQC and the pH or conductivity. Moreover, the ΔWQC does not appear to depend on the amount of calcium in the analyzed water, because the negative correlation only occurred for filter I, whereas the efficiency of calcium ion filtration decreased for all tested filters. As there was no single analyzed parameter that significantly affected the degradation of ascorbic acid, the component that had the greatest impact on the WQC should be further investigated. Most likely, the WQC is sensitive to certain contaminants that have little or no effect on the conductivity or pH of the solution. Determining these specific contaminants, which may be present in trace amounts, will require further research. In addition, the value of ΔWQC for filter I is definitely higher than for the other analyzed filters, particularly during the 1st 120 L of filtration. This suggests a higher efficiency of filtration of the sought compound at the beginning of the cartridge application. Overall, these results confirm that the WQC could be a useful parameter for effective assessment and comparison of the filtration effectiveness of individual cartridges. Moreover, as the WQC has previously been shown to decrease with the degree of water pollution [28], it can be concluded that filter I has the highest filtration efficiency.

Analysis also showed a very strong correlation between the ΔCa and the AFW for all filters. This suggests a continuous decrease in the efficiency of the filtration of calcium ions as the amount of water that is filtered increases. Filter I showed the highest efficiency in this regard, while all cartridges had ceased to fulfill this function after filtering 160 L of water. These results contradict the manufacturers' information, which states the filters do not change their efficiency over time (i.e., contaminants should not get into the water). While it is recommended the filter cartridge is replaced after 30 days, only the filtration speed, not its efficiency, should decrease over time. In addition, there was no change in the level of chlorides or sulphates in the filtered water compared to tap water for all 4 of the filters, which is also not concordant with the product specification. Finally, there were no significant differences in ΔFe, ΔCu, ΔpH, nor Δσ for the 4 individual cartridges, suggesting that all the filters have a similar filtration efficiency.

It is worth noting that ascorbic acid is a relatively inexpensive and, importantly, non-toxic reagent; therefore, compared to other methods of determining water quality, the one proposed here is relatively inexpensive, eco-friendly, simple and quick. This method also has the potential not only to be used to assess the efficiency of household water filtration devices but also wherever it is important to determine water quality. Indeed, this technique may be used as an additional tool for determining the effectiveness of water purification in appropriate laboratories, and, after further simplification, has the potential to be used by consumers at home.

It should be remembered that the way of using the filter cartridge (time of contact of the cartridge with water, the length of breaks in use, and so on) may have a major impact on filtration efficiency, and the research presented was related to the domestic use of the cartridge. Thus, water quality assessment using this method should be investigated more broadly in terms of the physico-chemical indicators and analytical methods, and the correlation between the WQC and other standard measurements should also be determined.

The results of the presented study can be useful for laboratories testing the efficiency of water filtration, in particular for filter manufacturers.

CONCLUSIONS

1. The WQC allows for effective analysis of the filtration efficiency of individual household filter jugs but requires further research.
2. A decreasing efficiency of calcium ion removal from the water was observed with ongoing use of the household filter cartridges.
3. The proposed method of determining water quality based on the measurement of absorbance changes of ascorbic acid is relatively inexpensive, sensitive, simple, fast and eco-friendly.

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