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Case Study

Physical Effect By The Use Of Peristaltic Pump: The Case Of Tap Water.

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Abstract

In this work, authors proposed an iterative procedure to modify the chemical-physical properties of aqueous solutions with high ionic strength. According to the experiments performed, perturbation was induced by the use of a peristaltic pump. The effects of chemical-physical operating parameters studied were the water electrical conductivity (χ), the hardness and the pH. A very significant decrease in χ and a significant increase in pH were observed. In addition, the formation of abundant white precipitates of carbonates was observed, with the consequent reduction of the water hardness. In this system, the reduction of water hardness was demonstrated to depend on the normal mechanism of chemical precipitation of the carbonates at pH larger than 8 related to the use of pumping procedure. This iterative procedure stabilized electrical conductivity at about 300 μS/cm, indicating a dynamic equilibrium. Results suggest peristaltic pump perturbation promotes the formation of structured water aggregates, affecting ion mobility and solution properties

Keywords: water stable structures, peristaltic pump, electrical conductivity, hardness of water.

INTRODUCTION

Water is the most studied substance in the world, but it is still able to amaze us, yet its anomalous properties and complex molecular interactions continue to challenge scientific understanding and reveal unexpected behaviors [1]. Despite being one of the most extensively studied substances, water continues to play a central role in science to understand its complex properties. Researchers have been intrigued by water's unique behaviors, such as its density anomaly and complex hydrogen-bonding network, which remain subjects of active investigation. Studies have shown that water's anomalous properties, including its behavior under supercooled conditions, present challenges to existing theoretical models, highlighting the need for further research to fully comprehend its nature [2].

In the last ten years, our research team has been interested in the aspects of changes in the chemical-physical properties of pure water subjected to some iterative physical and low-energy perturbations [3-8]. The initial and notable results were achieved using filtration procedures with sintered glass or cellulose (Millipore, Burlington, MA, USA) filters [3], involving the filtration of the recovered pure water. After a relatively small number of iterations on samples of low volume (1-10 mL), the electrical conductivity χ becomes high, enough to be confidently detected (10-200 μS cm-1). Of course, measured parameters are not limited to electrical conductivity but include measurements of pH, density, mixing heat with acids and bases, conductometric, pH-metric and calorimetric titrations, and various microscopic techniques [3-8]. A significant advancement in this research led us to propose that iterative hydration and dehydration cycles of a hydrophilic, inert polymer in Milli-Q water result in the formation of Exclusion Zone (EZ) water within the liquid. EZ water, as described by the literature, is a structured phase that forms adjacent to hydrophilic surfaces and exhibits unique properties distinct from bulk water [9-13].

In order to demonstrate these phenomena, the iterative procedure of subsequent immersions of a hydrophilic (and inert) polymer in milliQ water (hydration) and subsequent drying the polymer at room temperature (dehydration) has been applied [14]. Then dried polymers have been immersed in the liquid obtained previously (rehydration), as already performed in previous works [15-19]. The used hydrophilic and insoluble polymers studied were Nafion, Cellulose (Hydrophilic Cotton and Paper Filters), Cellophane, Crabyon,

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Hemp, Wool, Bamboo and Silk [24].

For all the perturbed waters treated with the iterative method described, IPW (Iteratively Perturbed Water), of the value of χ increased from 3 to 4 orders of magnitude. Nafion as a perturbing polymer produces acid liquids (pH = 3). The other polymers produced alkaline liquids with a pH value up to 9. The chemical nature of the organic insoluble polymers used produced many similarities and some peculiarities in the variations of the chemical-physical parameters detected [20]. It could be difficult to explain these variations by the old paradigms: the iteration cannot determine an increase in the concentration of any electrolytes except at the level of increase of negligible impurities. This statement highlights the limitations of traditional models, such as the Debye–Hückel theory, in explaining variations in electrolyte concentrations, especially at higher concentrations. The Debye–Hückel theory accurately predicts ion activity coefficients in dilute solutions but becomes less reliable as ionic strength increases. This is because, at higher concentrations, ions are closer together, leading to interactions that the theory does not fully consider. As a result, any increase in electrolyte concentration predicted by these models may only reflect the presence of negligible impurities rather than significant changes [21-23].

Therefore, the increase in χ is not dependent on an accidental increase in the concentration of electrolytes. The amount of these variations does not fall within a trivial contamination phenomenon. This statement – apart the many very carefully performed various chemical analyses - finds decisive support in the observation that all the used polymers (natural or synthetic) give the same qualitative and quantitatively different results. We obtained the reproduction of the results, using the same polymer bits, for several years. It is now evident that it is not a trivial chemical phenomenology [3, 7, 8]. UV Fluorescence, optical, atomic force and electronic microscopy techniques highlighted the presence of polymers, as also confirmed by the literature [26-28]. The demonstration of polymer presence would lead to an increase in H+ and OH- mobility due to the increase in the length of the jump proposed by Grotthus (1806) [28, 29]. To our knowledge, this is the first time that the idea of an increase in ions mobility explains an increase in the electrical conductivity of the liquid water. Through measurements of pH, mixing heat, density and the various microscopy techniques, this working hypothesis was widely validated [30].

Further extraordinary phenomenology agrees with the hypotheses of the presence of polymeric molecules of water. It was possible to obtain a solid by dry freezing the perturbed liquids (Iteratively Perturbed Water, IPW). The obtained solid is strictly reproducible and has been named “Xerosydryle”, derived from ancient Greek words meaning material consisting of dry water. Xerosydryle exhibits exceptional resistance to high temperatures, with a fraction of it remaining stable up to 970°C. Thermogravimetric Analysis (TGA) and differential thermal analysis (DTA) have highlighted these properties, with TGA curves clearly distinguishing the different chemical nature of the hydrophilic polymer used to perturb water from that of the corresponding Xerosydryle, which is significantly more stable at high temperatures [25]. From this long introduction, it is evident that we have encountered an unknown and fascinating topic involving the most studied liquid in the world.

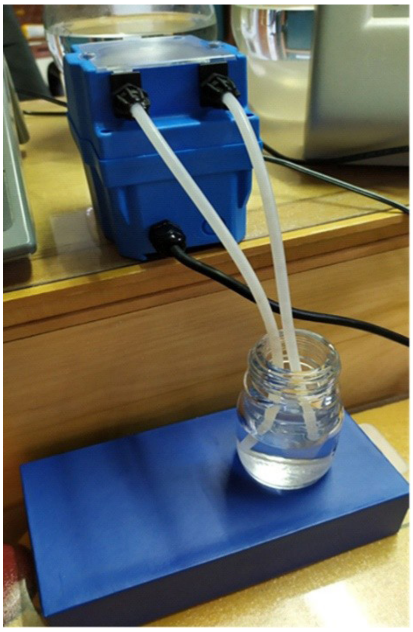
From this long introduction, it is clear that we came across in an unknown and fascinated topic that involves the most studied liquid in the world. Therefore, this study aims to investigate the physical-chemical modifications induced in tap water by an iterative perturbation process using a peristaltic pump. Specifically, it seeks to examine variations in electrical conductivity (χ), pH, and water hardness under controlled recirculation conditions. The research intends to validate the hypothesis that the iterative movement of water, facilitated by the peristaltic pump, leads to the formation of polymeric water structures, which influence proton mobility and ionic equilibria. Additionally, the study explores the role of pH in carbonate precipitation and its subsequent impact on water hardness reduction. Through systematic experimentation, this work aspires to provide new insights into the interplay between mechanical perturbation and water structuring phenomena, potentially unveiling alternative methods for water treatment and conditioning.

EXPERIMENTAL PROCEDURE

Iteratively Perturbed Water System (IPW-MW) Using a Peristaltic Pump

Figure 1 shows a laboratory-scale setup designed to implement the Iteratively Perturbed Water–Moving Water (IPW-MW) procedure, a novel experimental method developed to investigate the physicochemical changes in ultra-pure water subjected to low-energy mechanical perturbation. The central component of the apparatus is a compact, dual-channel peristaltic pump, housed in a blue casing, which continuously circulates milliQ or bidistilled water through a closed-loop system.

Fig 1. A photo of the Peristaltic Pump used for the (IPW-MW).



Two flexible polyethylene or silicone tubes connect the pump to a small glass vial containing a defined volume (typically 15–100 mL) of pure water. The pump draws water from the vial via one tube and reintroduces it into the same container via the other, generating a continuous internal flow without exposure to external environments or reservoirs. This looping movement of the liquid does not aim at transporting or filtering the fluid but rather introduces a repetitive, gentle mechanical stress through flow and deformation, effectively serving as an iterative physical perturbation.

Despite its simplicity, this configuration induces significant and reproducible changes in water's measurable properties over time, particularly an increase in electrical conductivity (χ), often from initial values around 1–2 μS/cm up to plateau values as high as 130 μS/cm, and a shift in pH, typically rising from slightly acidic (≈5.6) to mildly alkaline values (≈8.2).

These variations occur after several hours of operation and are attributed not to contamination or ion release from the pump or tubing (as confirmed via ICP-MS analysis), but to the hypothesized formation of supramolecular aggregates or "water polymers." These aggregates appear to modulate the mobility of dissociated ions, possibly via extended proton-hopping (Grotthuss mechanism), which enhances ionic conductivity and alters acid-base equilibria.

In this setup, the peristaltic action is essential, as it introduces pulsatile mechanical energy at low frequencies, differentiating it from static or turbulent mixing methods. This system has proven particularly sensitive to volume effects—smaller sample volumes yield faster and more pronounced physicochemical responses—indicating a surface-to-volume dependent phenomenon. This experimental system, minimalistic in its design yet profound in its implications, serves as a robust model for studying the emergent properties of water under non-chemical, low-energy perturbations.

pH measurements

pH measurements were carried out with a pH-meter (Crison GLP 21-22), with a resolution of ± 0.01 pH units, equipped with a pH electrode for micro samples model 52 09. The electrode specifications is: asymmetry potential < ±15 mV, pH sensitivity 4...7 (at 25° C) > 98 %.

Electrical conductivity measurements

Specific electrical conductivity, χ (μS cm-1), measurements were performed with an YSI 3200 Conductivity Meter, model 3200. The cell was periodically calibrated by determining the cell constant K (cm-1). We obtain the specific conductivity obtained as the product of the cell constant and the solution conductivity. For a given conductivity-measuring cell, the cell constant was determined by measuring the conductivity of a KCl solution with a specific conductivity known with great accuracy, at several concentrations and temperatures. All conductivities were temperature-corrected to 25°C using a pre-stored temperature compensation for pure water.

Procedures and results

As described in the literature, the use of peristaltic pumps has been adopted to implement the number of iterative processes. The peristaltic pump withdraws the liquid from the container, Tap Water, bi-distilled water and their solutions in HCl and returns it to the same container. In this way, it was possible to obtain the iteration of the movement of the perturbed liquid, IPW (Iterative Perturbed Water). The latest experimental results confirm the preceding working hypotheses and wide research fields. The techniques we use are extremely simple and within the reach of any experimenter [31]. A very simple and effective parameter for highlighting phenomenology is once again the measurement of electrical conductivity. Following the study applied to the bi-distilled water, χ = 1-2 µS cm -1. The first experiments concern the use of Tap Water (χ between 800 and 600 µS cm-1). The phenomenology is faster to obtain if the volume of the liquid is small (30-50 mL). Higher volumes (for example 500 mL) also lead to changes in electrical conductivity but require much larger perturbation times. Time necessary to obtain measurable results were estimated in a few hours.

With bi-distilled water, it was possible to reach a plateau around 130/150 µScm-1 and a pH >8 [12, 17]. The increase of χ corresponds to the possibility of isolating a white and soft solid by freezing drying. Anyway, the short time needed to obtain the very large variation of the studied parameters, and the simplicity of the adopted procedure cannot attribute the measured variation to occasional contamination nor to biological phenomenology. In this case it is difficult to suppose that the chemical composition of the soft white solid obtained after the lyophilization has a chemical composition different from the one of water. This is in accordance with the iterative filtering procedure [3-6]. In the case of Tap Water, for the first time we obtain a plateau in the decrease of χ as time flows. The electrical conductivity reduced from the initial values that were close to 800-600 µS cm-1. In fact, the electrical conductivity of the reached plateau is around 300 µScm-1 (Fig. 1 A, B, C and Fig. 2). The same Fig. 1A and Fig. 1B show the pH values at the beginning and to the end of the iterative procedure. It shows a significant increase of over one unit of pH. The working hypothesis uses an idea not in contrast to the formation of water polymeric molecules. In the case of bi-distilled water, the contribution of the proton jump mechanism increased, because the increased of the concentration and/or the size of the water polymers (Grotthuss mechanism, increase of H+ and OH- mobility). At the same time, protons are complexed by the water polymers. The decrease of concentration of free protons determines an increase of pH. This is another example of the increase of pH due to the complex formation between the polymeric water molecules and the protons, without adding alkaline solutes. At sufficiently alkaline - pH > 8 - the free proton concentration tends to be very low and the complexation with the polymers reduces. In these conditions, the system reaches a plateau. The possible formation of new polymeric substances has not sufficient protons to complex or to jump. It must be underlined that any kind of perturbation produces an IPW with many similitudes to the other procedures and some peculiarities. This observation is consistent with previous studies on polymeric nanoparticle synthesis and behavior in aqueous environments [34]. Concerning IPW-MW, the use of peristaltic pumps results in too low concentration of protons is the controlling step for the formation of water polymeric substances. Plateaus appear in the two cases studied, namely bi-distilled water and TAP water. For IPW-HC (Hydrophilic Cotton, using the hydration and dehydration procedures, for example) we have no plateau phenomenology. Probably, the physical-chemical nature of the new polymeric substances is very different. Therefore, it was noticed that similitudes and peculiarities. Measuring the water hardness with colorimetric procedure (EDTA - Ethylene Diamine Tetra Acetic Acid) after the peristaltic pump procedure, we obtained a significant reduction of the hardness.

RESULTS

Analyzing the effect of pH, it was possible to demonstrate that the protons have complexed by the produced new substances. This hypothesis supports the strong increase in pH of over one unit (see **Fig. 1A and 1B**). The reached plateau at about 300 µScm-1 would indicate that the phenomena of proton complexation (alkaline pH), reduces the hardness of water and formation of new polymeric molecules stopped. The hardness is stable also at pH about 8.5. There are possible different complexes by water. There would be no protons of sufficient concentration to notice its increase in jumps nor to increase the pH. In this case, we obtained a stasis on the value of χ. The presence of water hardness leads to substantial differences. In this context, a new phenomenon must be considered, which is influenced by water hardness and the associated equilibrium variations as a function of pH. Experimentally at pH values higher than 8, the precipitation phenomenon of a white solid appears. At these high pH values, the bicarbonate/carbonate equilibria move towards the formation of precipitates of carbonate. Therefore, they subtract from the contribution at the electrical conductivity. In fact, there is a sharp decrease in the χ with a noticeable formation of strong opalescence and subsequent formation of a white precipitate. Consequently, the χ decrease as polymers molecules form. We prepared different samples of Tap Water diluted with bidistilled water, that is, with different conductivity due to the variation of their ionic strength. They highlight an extraordinary phenomenon: decrease, stasis and increase in the value of χ as the ionic strength of the samples processed reduces. Seven different solutions have produced with conductivity ranging between 122 and 820 µS cm- 1 with volumes of 50 ml.

In **Fig. 2**, we report the trends of the variation of electrical conductivity of eight samples of different volumes. All that shows the similitudes from the same behavior obtained with bidistilled water [31-33], namely the very clear dependence on the processed volume of the samples: the smaller the volume the smallest the time needed to obtain a plateau.

Figure 1. Electric conductivity (and some pH measurements) of Tap Water as a function of the pumping time.

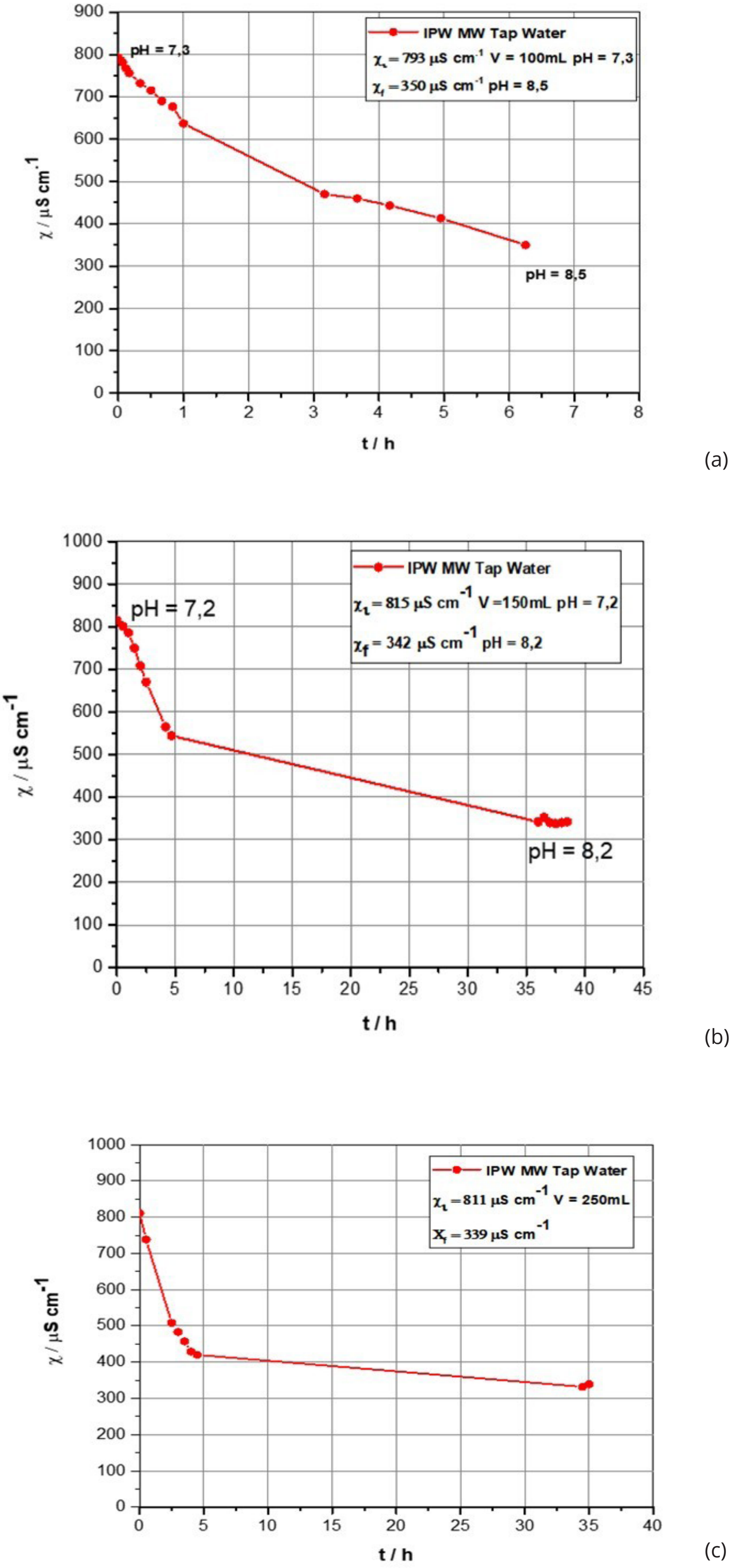


Figure 2. Electric conductivity of different volumes of Tap Water as a function of the pumping time.

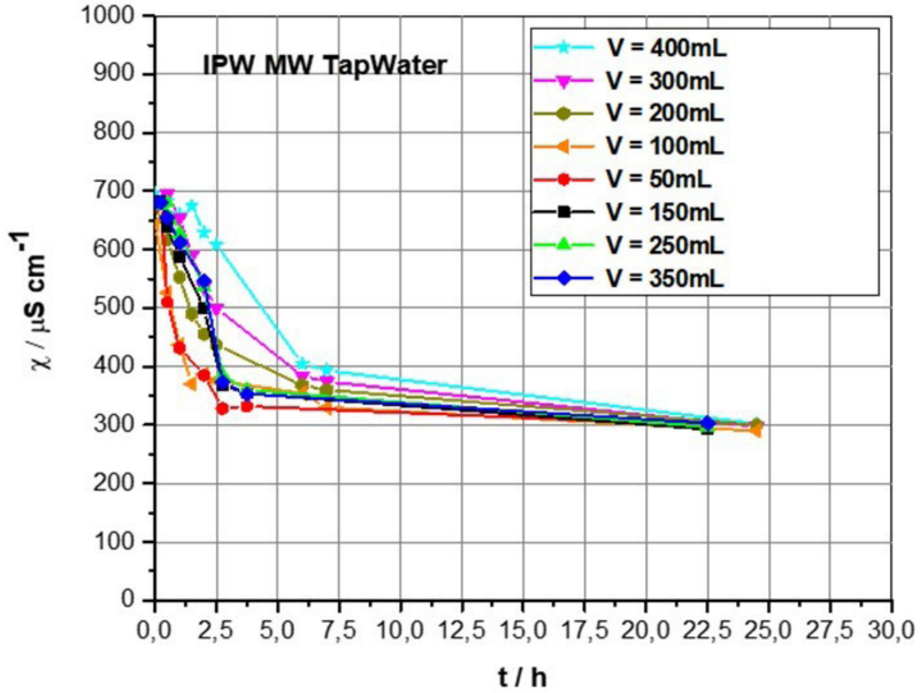
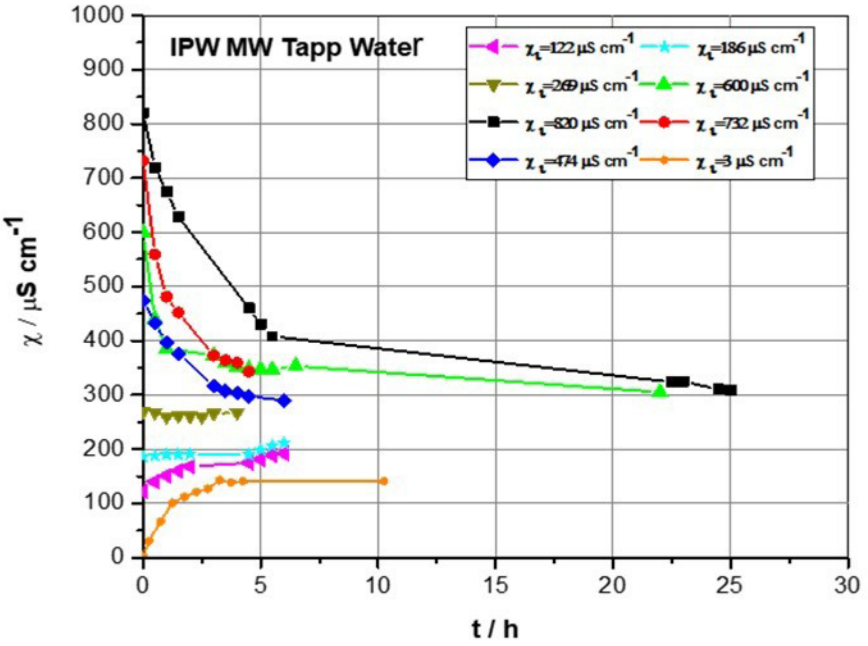


Figure 3. Electric conductivity of different starting conductivity of Tap Water as a function of the pumping time, showing the inversion of the behaviour.

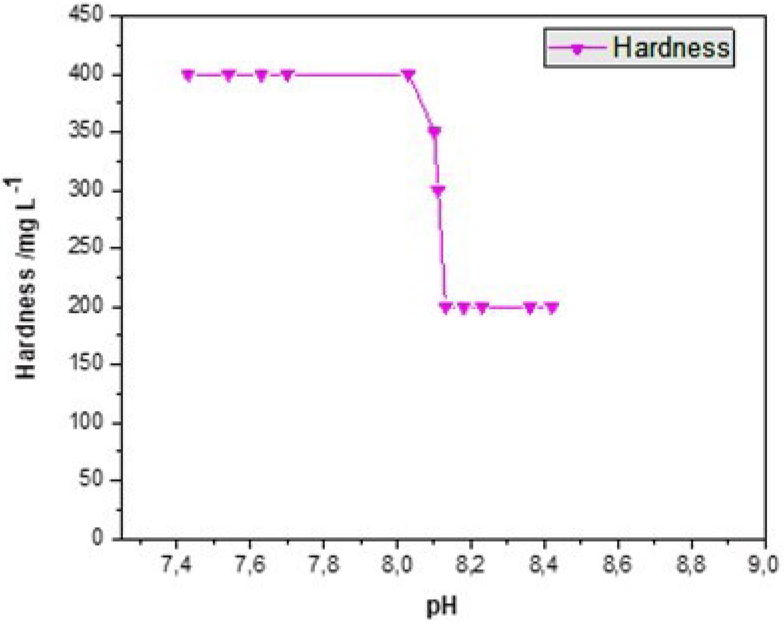


From **Fig. 3**, we can see the behaviors in which the χ decreases, reaches stasis or increases. Therefore, it is possible to identify the electrical conductivity at which the inversion occurs. The inversion is probably due to the prevalence of the phenomena that determine the behavior in this kind of perturbed water: the increase in mobility of H+ and of OH-, the complexation of the proton and the precipitation of carbonates. Increase in mobility depends by the jump mechanism. Increase of pH by complexing of the protons, while indirectly this increase promotes the precipitation of carbonates. The contrasting effects determine the complexity of the phenomenology obtained. This fact agrees with the increase of the pH and the decrease of the hardness. As a comparison, experimental data of bi-distilled water were proposed. In this case, the conductivity of the initial liquid is close to the origin of the axes. Interpreting this highly complex phenomenology is challenging, but the experimental results are undoubtedly reliable (see **Fig. 8**). Here we report the linear correlation between the volume of Tap Water treated and the time needed to obtain the plateau. We suppose that the work hypothesis is substantially the same in the two phenomenologies discovered in the treatment of bi-distilled water that works also in the case of Tap Water.

The use of the peristaltic pump is fully compatible with the formation of polymeric water molecules capable of binding proton ions. The resulting decrease in proton concentration leads to a rise in pH, which subsequently triggers the precipitation of carbonates, ultimately reducing water hardness (see **Fig. 4**). This effect is reminiscent of selective ion-exchange behaviors observed in hypercrosslinked polymer microspheres with pH-dependent properties [36].

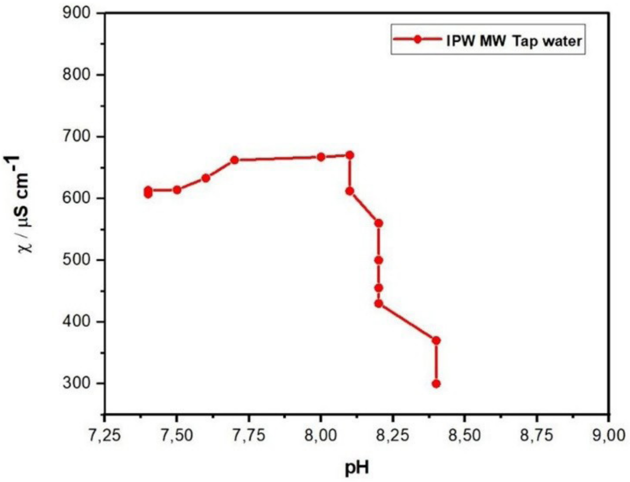
The hardness before and after the treatment of the peristaltic pump has been measured, finding that the hardness of Tap Water (before the pump treatment) is about twice the one after the treatment. This fact is in part compatible with the formation of insoluble carbonates via the increase of the pH and to the experimental visible formation of white precipitate. This white substance is soluble in HCl with the formation of gas bubbles, in accordance with the formation of insoluble carbonates. "Normal movement of equilibria via normal pH variation". The hardness remains consistent in the liquid phase, suggesting that the presence of polymeric water induces the formation of a new type of complex that remains stable at higher pH levels. The simple addition of sodium hydroxide after the initial precipitation event triggers a second precipitation, which could be attributed to the presence of two distinct types of polymeric substances. Additionally, solid deposits form inside the inlet and outlet tubes.

Figure 4. The very sharp effect of the variation of hardness as a function of the pH.



As we can see from **Fig. 4** and **Fig. 5**, at pH larger than 8 the hardness of the sample rapidly reduces at one half of the initial one and their correlated effect. This fact is simply connected with the formation of opalescence visible by naked eyes, and finally with the precipitation of a white solid. Similar mechanisms have been observed in studies on polymer-induced liquid precursors for calcium carbonate formation [35]. The increase of pH induced the transformation of the equilibrium bicarbonate-carbonate to the one of carbonate an insoluble material in alcaline solution.

Figure 5. The very sharp effect of the decrease of electrical conductivity as a function of pH.



The phenomenolgy is also clearly visible in **Fig. 5** were we reported the correlated effect of the decrease of electrical conductivity as a function of pH. The reduction of the electrical conducticity χ depends on the formation of insoluble carbonates that normally reduces the χ.

Figure 6. pH and electric conductivity as a function of pumping time.

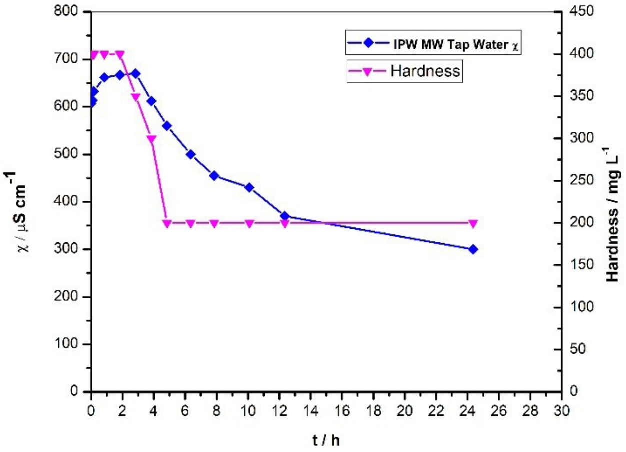


Figure 7. pH and hardness as a function of pumping time.

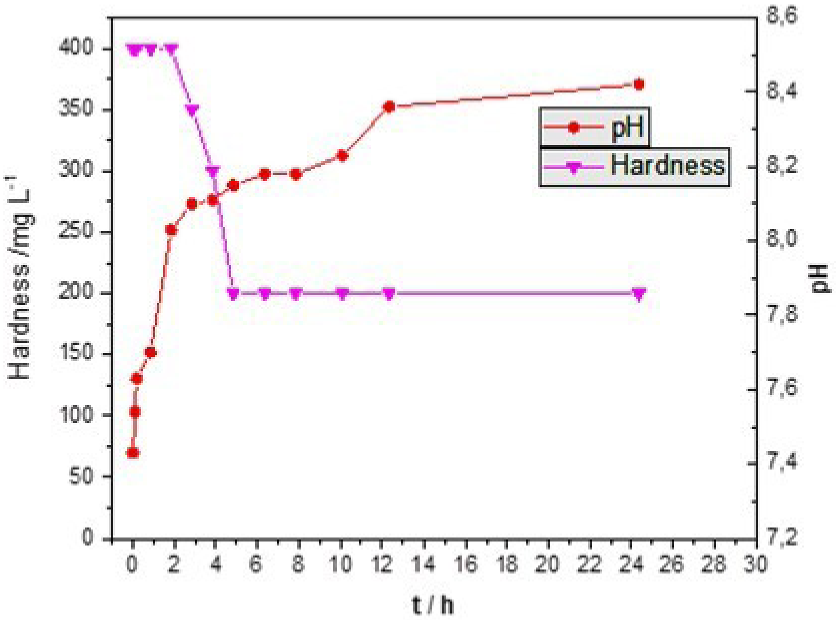
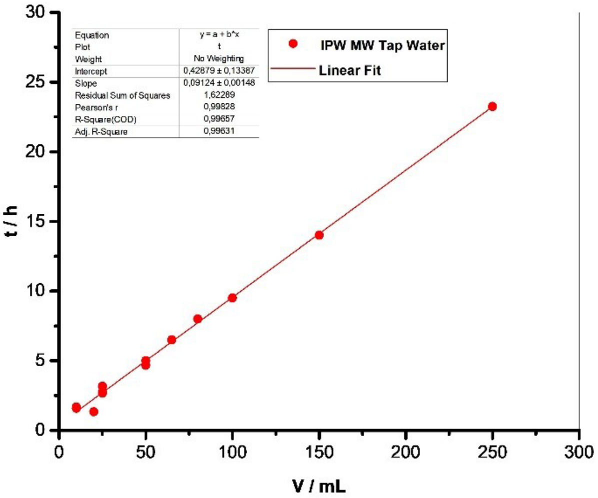


Fig.6 and **Fig.7** report the experimental measurementes of the three paramenters: Hardness, pH and χ.

In the last part of this work, the repeatability of these new methodologies was demonstrated through the following experiments. Tap water samples of different volumes (10–100 mL) have been used, at fixed flow rates of the peristaltic pump. The experiments were stopped once the conductivity parameter reached a plateau of χ ≈ 300 μS/cm. The graph of the time required to reach the plateau as a function of volume shows a highly reproducible linear trend. This emphasizes both the repeatability and, in some cases, the reproducibility of the experiments, based on physical-chemical parameters (see **Fig.8**).

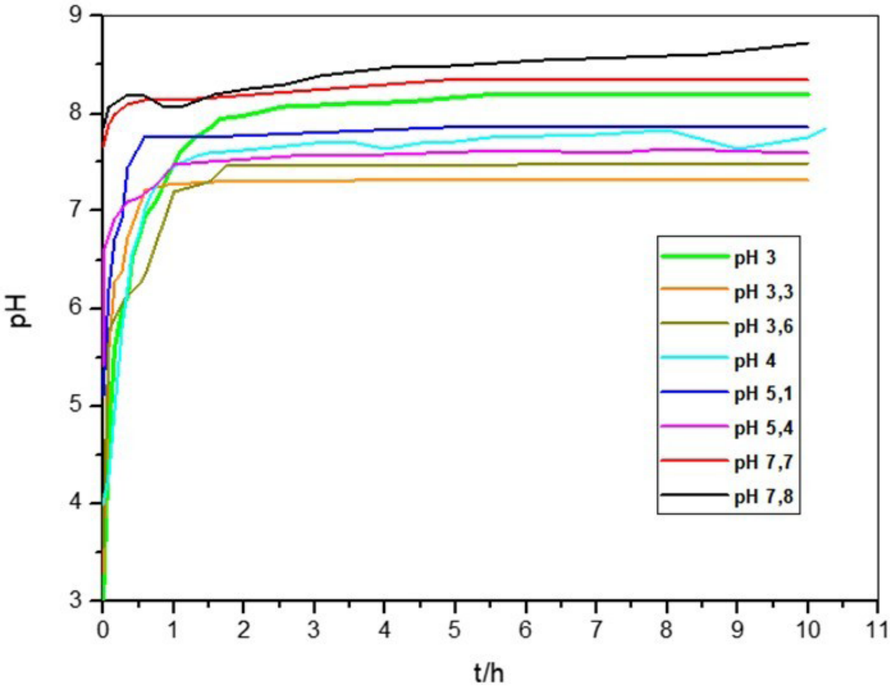
Figure 8. The most significative variations of the measured parameters are reported as a function ot the time duration of the experiments.



In **Fig. 8** all the most significative variations of the measured parameters are reported as a function ot the time duration of the experiments. To verify the working hypotheses of the very complex and new phenomenology, more experiments were performed tap water with a pH modified by the addition of HCl. Consequently, the precipitation phenomenology did not occur. If the movement of the peristaltic pump induces the formation of "polymeric water molecules", this determines, according to the Grotthuss jump mechanism, an increase of mobility of both the ions deriving from water dissociation, and then the increment of the conductivity χ. At the same time [8-11] the binding constant of the two ions, H+ and OH- to the water polymers determines the formation of the complexes.

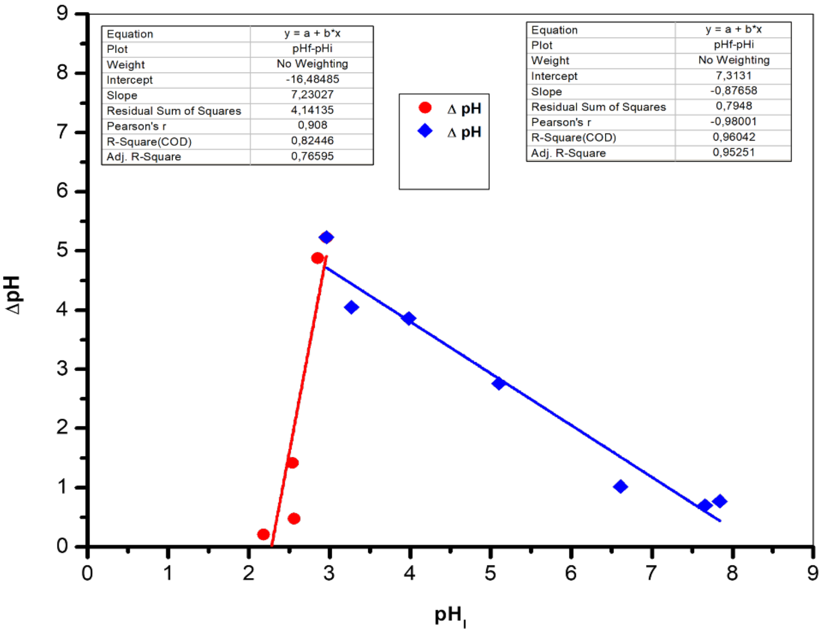
To check some confirmation of the work hypotheses and have information on the determining role of the presence of H+ we measured the effect of the use of the peristaltic pump on solution of HCl in Tap Water. The procedure and the results are identical to the ones obtained using milliQ water. At the beginning of the procedure in pure water, there are a very rapid and noticeable increase of both parameters (χ and pH), registering for both an increase consistent with the work hypotheses (see **Fig. 9**).

Figure 9. pH Evolution Over Time in HCl Solutions with Tap Water Under Peristaltic Pump Action.



In **Fig.9** the variation of pH with time flow has been reported. From this graph we have information of the initial pH of the experiment of time and the maximum of the reached parameters. In **Fig. 10**, instead, the difference of pH values from the initial one and the reached maximum (Δ pH) and put it as a function of the initial one were determined.

Figure 10. Difference of pH values from the initial one and the reached maximum (ΔpH) as a function of the initial one (pH-metric titration procedure.



Equation	y = a + b*x
Plot	pHf-pHi
Weight	No Weighting
Intercept	-16,48485
Slope	7,23027
Residual Sum of Squares	4,14135
Pearson's r	0,908
R-Square(COD)	0,82446
Adj. R-Square	0,76595

Equation	y = a + b*x
Plot	pHf-pHi
Weight	No Weighting
Intercept	7,3131
Slope	-0,87658
Residual Sum of Squares	0,7948
Pearson's r	-0,98001
R-Square(COD)	0,96042
Adj. R-Square	0,95251

The procedure used to obtain the experimental results reported in Fig. 10 is in accordance with the experimental results reported in literature [15]. The difference between the initial pH value and the maximum pH reached (ΔpH) is calculated and expressed as a function of the initial pH (see **Fig. 10**). As observed in the case of Milli-Q water, a breakpoint can also be identified, providing insight into the concentration of water polymers.

It is shown that there are two very distinct trends (See **Fig.10**). At pH higher than 3.5 the linear trend has a negative slope, while the opposite happens for the lower ones. The two trends determine a break point. By adding HCl (lower pH, higher concentration of free protons), the ΔpH should increase, and the prevision has been respected. Consequently, there is a direct relation between the concentration of protons and the increase of ΔpH. Substantially the polymers of water molecules produce complexes with the protons. Naturally, the maximum concentration of aggregates is expected to be finite. Once the system reaches saturation, the increase stops, as all polymeric structures have formed complexes with the available protons. Any excess protons, beyond the capacity of the aggregates, remain free in the solution, leading to a subsequent decrease in pH.

This result underlined the role of protons in determining the formation and the stability of the water polymers. The break point in **Fig 10** gives us information on the maximum concentration of polymeric substance (solubility). This fact agrees with the observed phenomenology. From **Fig. 10** it is possible to find the pH of the break point at about pH=3.5. It means that at this H+ concentration of the added HCl the system cannot bind more free protons. Depending on the stoichiometry of the binding process, we may have information on the concentration of the polymers. From more acidic solutions, pH lower than 3.5 the concentration of proton is higher than the ones of polymeric substances. Therefore, the reduction of free protons via binding to the polymers stopped and the value of ΔpH reduces. It is interesting to note that at the lowest pH (pH=2) the ΔpH is null. This fact underlines that in the liquid (aqueous solution of HCl) is present a very high number of free protons and the polymeric water can bind only a limited number of them. From more acidic solutions, pH lower than 3.5 the concentration of free proton is higher than the ones of polymeric nature and ΔpH reduces. At pH = 2 the H+ concentration is so high respect to the one of the polymeric substances that the ΔpH is practically negligible.

CONCLUSIONS

This study demonstrated that iterative perturbation via a peristaltic pump significantly altered tap water's chemical-physical properties, affecting conductivity, pH, and hardness. The reduction in hardness, due to carbonate precipitation at alkaline pH, suggests a structural reorganization of water molecules into polymeric-like aggregates influencing ion mobility. These findings support the idea that physical perturbation can induce stable changes in water properties, ruling out contamination. The nature of this phenomenology makes drawing definitive conclusions a challenge, as we are only beginning to discover its full implications. Ongoing research continues to expand our understanding, but the experimental data obtained is remarkably consistent with literature. For the first time, the unknown phenomena of reaching a plateau in the variation of χ as water moves have been obtained and confirmed. In addition, experimental results were obtained showing that χ increases or decreases depending on the ionic strength of the liquid. As a consequence, pH increases, and hardness is reduced. The pH increasing is able to produce a phenomenology very similar to the ones obtainable with the simple addition of a basic solute. The reduction of the hardness should be due to the mechanism of binding of the water polymers with the proton (increase of pH), with the consequent formation of carbonates ions, and decreasing of the hardness of the Tap Water. In conclusion, this represents an effective and very simple, purely physical (mechanical) procedure to reduce the hardness of Tap Water, without adding any chemicals.

Conflict of interest statement

The authors declare that there is no conflict of interest.

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