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Articles

Education of Students on Physics and Chemistry with Effects of Water Filtration. Modeling of Water Clusters and Hexagonal Structures

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Abstract

In the modern world, water filtration is performed to improve its quality. The most commonly used minerals are zeolite and shungite, as well as filters with nano-sized pores. Due to processes in boundary environments, the resulting waters before and after filtration possess specific properties. Studies after filtration show the structuring of clusters of water molecules. The most stable clusters comprise of two, four, and six water molecules. Hexagonal structures with six water molecules form the basis for the symmetry in the formation of snowflakes. Oleg Mosin (1966–2016) at Moscow State University of Applied Biotechnology conducted research on the modeling of water clusters before and after filtration. Since 2020, the author's team has been studying structuring water clusters using patented Swiss systems called EVOdrop. A program for training students by Mario Iliev is being developed. The students participate in experiments involving the research of Non-equilibrium energy spectrum (NES), Differential non-equilibrium energy spectrum (DNES), pH, oxidation-reduction potential (ORP), and Nuclear Magnetic Resonance (NMR). The knowledge acquired after training is applicable in medical biophysics and nanotechnologies. The effects of water restructuring and changes in its physicochemical parameters are analyzed in applied medicine.

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The parameters of samples of EVOdrop water from the patented device were tested compared to control tap water samples. The device includes an ultra-nano membrane and rotation jet nozzle for water vortexing. The incoming water passes through a rotating turbine, driven by pressure, and rotates through the device. Specific outcomes of such treatment are based on magnetohydrodynamic forces. Investigations were conducted using Non-equilibrium Energy Spectrum (NES) and Differential Non-equilibrium Energy Spectrum (DNES) analysis of hydrogen bonds energy distribution, mathematical models of water molecules clustering, ^{1}H NMR, hardness, and pH. Alterations of hydrogen bonds, energy distribution and chemical shifts were measured. They were subsequently interpreted as restructuring of water molecule clusters leading to beneficial health effects. In addition, reduced hardness and unchanged pH levels of treated tap water were also observed.

Keywords: filtration, water clusters, EVOdrop device, NES, DNES, ^{1}H NMR.

1. Introduction

The authors have developed methods for mathematically modeling water molecules in clusters, which are applicable in the teaching methodology for physics and chemistry students. The foundation of these methods lies in spectral analyses, which are also considered applicable in medical education. Peaks in the spectra of water and solutions of medicinal herbs and plants correlate with those of drugs. Comparative analyses can be conducted with inorganic and organic compounds.

Numerous studies have explored the structuring of water molecules and the alterations in hydrogen bonds under the influence of magnetic fields (Cai et al., 2009; Ignatov, Mosin, 2013a; Esmaeilnezhad et al., 2017; Puzowski, Skoczko, 2020). Furthermore, investigations have detailed the effects of nanomembranes (Thamaraiselvan et al., 2018) on water molecules and clusters (Chen, Ruckenstein, 2014). These clusters can be categorized into positively and negatively charged ionic clusters, represented as $[H^+(H_2O)_n]^+$ and $[OH^-(H_2O)_n]^-$, as well as neutral clusters with the general formula $(H_2O)_n$ (Ignatov, Mosin, 2013a). Theoretical models have been devised to describe the structuring of water clusters with the formula $(H_2O)_n$, emphasizing the importance of hydrogen bonds (Neela et al., 2010). These models have been developed for various cluster sizes, such as n = 6-20, incorporating five key parameters of water molecules: hydrogen bonding, charge-charge interactions, polarization, intramolecular relaxation, and repulsive forces (Massela, Flament, 1997). Additionally, alternative theoretical models have been established, including tetrameter (n = 4) and pentameter (n = 5) ring structures, and cuboid-shaped clusters for n=8, 12, 16, and 20. Pentameric structures with n = 10 and 15 have also been identified (Mahashwary et al., 2001). Density Functional Theory (DFT) has been applied to model water clusters from n = 2 to n = 20. Hexagonal water clusters have been structurally characterized using DFT (Kelkkanen et al., 2009). A Gaussian distribution model has been proposed to explain the occurrence of a maximum number of clusters with n=12 and 13 at 937 cm^{-1} (Mehandjiev et al., 2022).

Smith, Keutsch, and Saykally et al. have conducted extensive studies on water clusters, exploring the range from n=3 to n=50 (Smith et al., 2005). Infrared spectroscopy studies have successfully identified clusters such as $H^+(H_2O)_{22}$ and $(H_2O)_n$ for n=6-22 (Choi, Jordan, 2010). Investigations have also focused on the binary structure of water clusters from Haberlea rhodopensis Friv. in a dry state, with n=2 (Kuroki et al., 2019). Moreover, research has been carried out to examine the structuring of water clusters as a function of the number of water molecules, revealing local maxima at n=15 at 897 cm^{-1} (Ignatov et al., 2022). The nonadditive potential has been employed to optimize the geometry of clusters comprising n=3, 4, and 6 water molecules, with these clusters exhibiting dipole moments consistent with those of isolated molecules (Belford, Cambel, 2013). The Quantum Theory of Atoms in Molecules (QTAIM) and functional analysis have been applied to non-covalent bonding clusters with the formula $(H_2O)_n$, considering n=2-7 (Seijas et al., 2023).

In 2022, a theoretical model employing Gaussian distribution was introduced, aligning with results obtained from water filtered using EVOfilter technology beginning (Ignatov et al., 2020). Water filtration is one of the methods that demonstrate changes in physicochemical parameters before and after filtration. Changes in the structuring of water molecules in clusters are also analyzed. After obtaining results with various filters from 2013 to 2020, the authors employed EVOdrop devices from 2020 to 2023. This yields filtered water that undergoes restructuring due to vortex and magneto hydrodynamicforces. The current studies on water treated with EVOdrop technology aim to assess alterations in molecular clustering due to changes in hydrogen bonding, employing the Non-equilibrium Energy Spectrum and ^{1}H NMR. Additionally, observations of changes in hardness and pH are being conducted. The applications for the education of students were shown with goal for the applications of cluster structures for analyses in chemistry, physics and medicine.

The authors educate the laboratory results and analyses in Bulgarian and English with methodology development (Ramankulov et al., 2019). Q-methodology, a reliable method that takes individuals' unique perspectives, was employed to determine students' opinions and perceptions (Servet, 2016). One of the co-authors, Ignatov, performed training with students in secondary schools in Teteven municipality, Bulgaria, with practices for the research of mountain water and digital methods (Soboleva, Karavaev, 2020). In the modern world, the improvement of the methods for online education is necessary. The online learning environment, by changing the students' behavior, improves the quality of the education process (Delen, Liew, 2016). Water processes in the environment are an object of education. University students' education was applied to mobile phones (Valeeva et al., 2019). The basic aim is to make connections for practical applications of the knowledge from physics and chemistry for the processes in the environment for clean water, global warming, and processes of the interfaces between solid-liquid-gaseous media. Especially the students have qualifications for non-equilibrium processes with application in ecology.

2. Materials and methods

2.1. Educational practices and specializations

During the training, network modeling is also applied. Interdisciplinary dependencies are established between results and analyses in the natural sciences (Ignatov, 1989; Traxler, 2022). Iliev takes part in educational project BG051PO001-3.3.07-0001 "SCHOOL PRACTICE with the financial support of the Operational Program "Development of Human Resources," financed by the European Social Fund of the European Union, a project of the Ministry of Education and Science – Bulgaria. Huether developed the systems for the filtration of water from African countries with water salinity of around 4200 ppm. The application is in agriculture and in university studies (Huether et al., 2023).

The municipality of Teteven, Bulgaria, and Ignat Ignatov are co-organizers of the event with training "Days of Mountain Water". The event has been organized since 2010, each year on June 11th (Athanasiadis et al., 2023).

Gluhchev makes studies of the analyses of images (Atanasov et al., 2020) and structuring of water clusters (Mehandjiev et al., 2022) with practical application in education. Gramatikov is the author of the textbook for students, Theoretical Biophysics (Basic Problems and Teaching Methodology) (Gramatikov, 1998). Gramatikov participates in the project: Joint supervision of Ph.D. students in Physics. Supervisor: Kanapia M. Arangazin (Kazakh State University, Kazakhstan) and Plamen Gramatikov (Neofit Rilski South-West University – Blagoevgrad). Funding organization: Karaganda State University "E.A. Buketov" (KSU), Kazakhstan. Period: 2014–2019.

2.2. Evodrop turbine water purifier

The investigated device is the EVOfilter with an ultra-nano membrane and a rotating jet nozzle for vortex water. The ultra-nano membrane is a competing device for the reverse osmosis membrane. The rotation jet nozzle for vortex water has three injection nozzles designed with a golden ratio-based algorithm. The proprietary operating principle and the developed geometry of the EVOdrop turbine (Figures 1, 2) allow for highly efficient treatment. Incoming water passes through a rotating turbine, driven by its pressure, and rotated through the device. Specific outcomes of such treatment are based on magneto hydrodynamic forces.

Figure 1 illustrates the EVOdrop device. The details of the numbers of the compounds of the EVOdrop device are shown in (Ignatov et al., 2022).

Figure 2 shows EVOdrop turbine operation principle. The details of the numbers of the compounds of the EVOdrop device are shown in (Huether, 2019).

Fig. 1. EVOdrop device

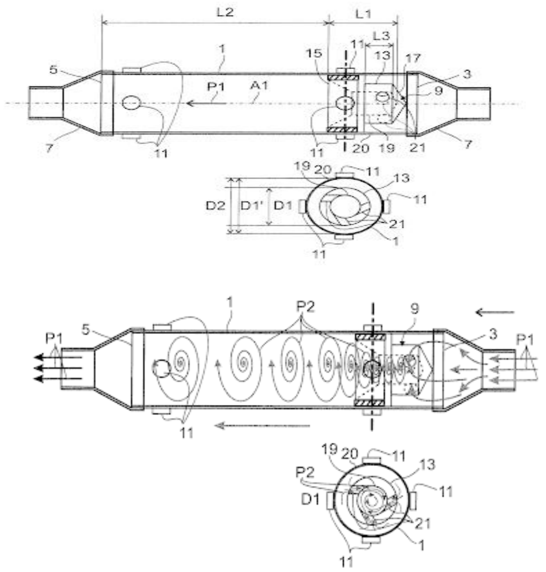

Fig. 2. EVOdrop turbine operation principle

2.3. Spectral methods Non-equilibrium energy spectrum (NES) and Differential non-equilibrium energy spectrum (DNES)

Luck considers that water consists of hydrogen bonds between one water molecule's hydrogen atom and another's oxygen (Luck, 1980). Most of them are bound by the energy of the connection (-E), and the remaining are free (E=0). It is accepted that E has a negative value. This is known as the Luck two-state model (Kontogeorgis et al., 2022; Vega, Lovell, 2016). Each water molecule has two hydroxyl groups. The number of hydrogen bonds between the hydrogen atom of one water molecule and the oxygen of another in a specific volume of water The water molecules linked by van der Waals forces and electromagnetic hydrogen bonds considered water an associated liquid. The wetting angle θ was measured with a specially designed instrument described in detail in (Antonov et al., 1989). Deionized water drops were evaporated in a sealed chamber with a stable 22°C. The device is working in the range(-E) = 0.08 - 0.1387 eV or λ=8.9-13.8 μm.

During the process, the wetting angle changes in discrete steps and characterizes the average energy of hydrogen bonds as follows:

$\theta = \arccos(-1+bE)$, where $b = I(1+\cos\theta_0)/C\gamma o$,

where θ is the wetting angle, E is the average energy of hydrogen bonds, and b is a temperature-dependent parameter (Gramatikov et al., 1992). The development of the method is the Non-equilibrium energy spectrum (NES) and Differential non-equilibrium spectrum (DNES) (Todorov et al., 2008; Todorov et al., 2010). They are used to research natural waters. The water droplet distribution on the sandstone surface under different salinities was studied with molecular dynamics simulation. The system equilibrium configuration was used to study the interaction of its components. The number of hydrogen bonds was calculated (Gao et al., 2021).

The parameter for measuring the energy (E) of hydrogen bonds is electron volts (eV). The energy distribution spectrum is the function f(E). A non-equilibrium evaporation process of water droplets characterizes the energy spectrum of water. This non-equilibrium energy spectrum (NES) is measured in eV^{-1}. DNES is defined as the difference*:*

Δf(E) = f (water samples) – f (control water sample), DNES is measured in $eV^{-1}$where *f (*)* denotes the evaluated energy (Todorova, Antonov, 2000; Mehandjiev et al., 2023)

2.4. Bruker Avance II+ 600 NMR spectrometer

The nuclear magnetic resonance (NMR) spectra were measured on Bruker Avance II+ 600 NMR spectrometer using 5 mm direct detection dual broadband probe. The experiments were performed at a temperature of 293 K. ^{1}H NMR spectra were acquired with 128K time domain points, spectrum width of 9600 Hz, 16 scans, and a relaxation delay of 60 s. The chemical shifts were referenced to the residual dmso-d6 resonance userd as an external reference (2.5 ppm). The dmso-d6 was placed in a coaxial capillary in the sample tube and also used as a locj signal.

3. Discussion

The presented research provides a comprehensive overview of water filtration techniques and their effects on the structural properties of water clusters. Utilizing minerals such as zeolite, shungite, and filters with nano-sized pores for water filtration is a common practice to improve water quality. This study highlights the significance of understanding the specific properties of waters before and after filtration, shedding light on structuring water molecules in clusters. From 2020 to 2023 the filtration and structuring of water was made with EVOdrop patented device. The research conducted by Oleg Mosin at Moscow State University of Applied Biotechnology and the subsequent work of the author's team with the patented Swiss EVOdrop system, demonstrates a dedication to advancing the understanding of water clusters. The involvement of students in experiments involving Non-equilibrium energy spectrum (NES), Differential non-equilibrium energy spectrum (DNES), pH, oxidation-reduction potential (ORP), and Nuclear Magnetic Resonance (NMR) reflects a commitment to hands-on, practical learning in the fields of physics and chemistry. The comparison of samples from the EVOdrop device with control tap water samples using spectral analyses provides valuable insights. The observed differences in NES and DNES between EVO drop-treated water and control tap water emphasize the impact of the filtration process. The statistical analysis, supported by the Student's t-test, further strengthens the validity of the results. The mathematical modeling of water clusters, particularly concerning hydrogen bonding and hexagonal structures, enriches the educational experience for students. Visualizing these complex phenomena makes theoretical concepts more tangible, enhancing comprehension and retention. The preference for figures over tables among the students indicates the effectiveness of visual aids in the learning process.

Moreover, exploring different types of water and their respective energy distributions provides a valuable comparative perspective. The variation in local maximums for (-E) across different water sources underscores the diverse structural properties of water clusters influenced by geophysical and environmental factors.

In conclusion, this research contributes to the scientific understanding of water filtration. The cluster structuring is a robust foundation for educational practices in physics and chemistry. The hands-on experiments, mathematical modeling, and visualization techniques offer students a holistic learning experience. Additionally, the implications of this research extend beyond academia, potentially impacting areas such as applied medicine and nanotechnologies. The consistent pursuit of knowledge and innovation in water research exemplified by this study is commendable.

In progress is a preparation of the program for students in medicine for analyses of spectral peaks and structuring of water clusters for biochemical, biological, and medical effects.

4. Results

Analyses of the education of education with non-equilibrium process of water were performed with analyses of solid-liquid-gaseous media (Ignatov et al., 2023).

4.1. Visualization of the Gaussian distribution and mathematical modeling of hydrogen bonds between water molecules and structuring of clusters

The authors create with spectral methods NES and DNES mathematical models of clusters of water molecules (Ignatov, Mosin, 2013b; Ignatov et al., 2021). Also, the cluster calculation was performed with the model of the Gaussian distribution of water molecules (Mehandjiev et al., 2022). The visualization of the structuring of water molecules makes education more attractive and visible for the students.

For the period 2013–2023, 73 students were tested (Table 1). The main questions were:

1. Estimate the mathematical models of water molecules with tables
2. Estimate the mathematical models with figures (Table 1).

The results are similar to the results of the visualization method (Fuchova, Korenova, 2019) for the parts of the human brain. The results with visualization are more extensive than 90 %.

Table 1. Results with estimation of water molecules with tables and tables

Which model is more understated for you?		
With tables	5	6.8 %
With figures	68	93.2 %

The education with visualization is for the processes that are not directly visible with the human visual analyzer.

4.2. Training program for measurement of non-equilibrium spectrum and physicochemical parameters of water. Mathematical modeling of water clusters and hexagonal structures

Our measurements and the studies of the students involve samples with filtered water and control samples of tap water with spectral methods NES and DNES (Todorov et al., 2008; Ignatov et al., 2021; Ignatov, Huether et al., 2022). Both students and doctoral candidates carry out the analyses in the following manner.

Using the NES method, we conduct analyses on various types of water, including tap water, mountain spring water, glacier water, mineral water, and seawater. We also study the parameters after filtration with zeolite (Popova et al., 2022) and shungite (Ignatov et al., 2022). The training showcases the sizes of non-organic chemical particles, with the size of a water molecule measured at 0.27 nm. Analyses are based on the physicochemical composition of peaks in the NES spectra. Calculations are made using ORP (Oxidation-Reduction Potential) and pH formulas to determine the presence of free electrons, positive ions, H^+ ions, and hydroxyl groups (OH-). A comprehensive analysis of the properties of the examined waters is conducted. When examining with filtering systems, analyses are conducted using the DNES method on control samples both before and after filtration. DNES is obtained by comparing the NES of samples and control samples. Statistical analysis is employed to demonstrate the reliability of the results. The analysis also delves into the energy distribution between hydrogen bonds in water molecules, involving research conducted using Nuclear Magnetic Resonance (NMR). According to Luck's research, hydrogen bonds exist between the hydrogen atom of one water molecule and another (Luck, 1980). Most of them are bound by the energy of the connection (-E), while the remaining are considered free (E = 0), with E typically having a negative value. This is known as Luck's two-state model. A model involving the Gaussian distribution of water molecules in clusters was described, aligningji with the results obtained from NES and DNES spectrums (Mehandjiev et al., 2022). The students are tasked with conducting Gaussian distribution analyses to study the behavior of water molecules and estimate the size of water clusters. For instance, a dodecahedral cluster with 21 water molecules has a size of 0.822 nm (Ignatov et al., 2021).

4.3. Results with spectral analyses of water with spectral methods NES and DNES

The NES and DNES spectral methods measurements show a significant difference between the EVOdrop water and the control sample with tap water. The result for EVOdrop water in the NES spectrum is E=-0.1254 eV, while for the control sample water with tap water, it is E=-0.1132 eV. The value of ΔE for EVOdrop water measured by the DNES method is (-0.0112 eV).

The results are average between using the device with ten different water samples after treatment with the EVOdrop devices and the 10 control samples with tap water. Ten measurements were performed. Student's t-test was applied. A statistically significant difference was proved between the three groups of results with the samples and control samples according to the

Student's t-test at the $p < 0.001$ level, t statistic is 27, coefficient of correlation $r=-0.916$. There is a strong negative linear relationship.

4.4. Mathematical models of EVOdrop water clusters

There was created A mathematical model of water molecule numbers according to the energy of hydrogen bonds in EVOdrop water (Ignatov, Mosin, 2013a; Ignatov et al., 2022) has been developed (Table 2, Figure 3).

Table 2. Distribution of the number of water (H_2O) molecules in EVOdrop water according to the energy of hydrogen bonds

-E(eV) x-axis	EVOdrop® Water (Samples) Number of water molecules	Tap water (Control Samples) Number of water molecules	-E(eV) x-axis	EVOdrop® Water (Samples) Number of water molecules	Tap water (Control Samples) Number of water molecules
0.0912	0	0	0.1162	1	5
0.0937	2	9	0.1187	1	6
0.0962	4	7	0.1212	**8**[2]	**3**[2]
0.0987	5	14	0.1237	2	6
0.1012	0	3	0.1262	3	3
0.1037	4	9	0.1287	4	2
0.1062	6	5	0.1312	5	3
0.1087	1	5	0.1337	6	2
0.1112	**11**[1]	**3**[1]	0.1362	5	6
0.1137	5	6	0.1387	**27**[3]	**3**[3]

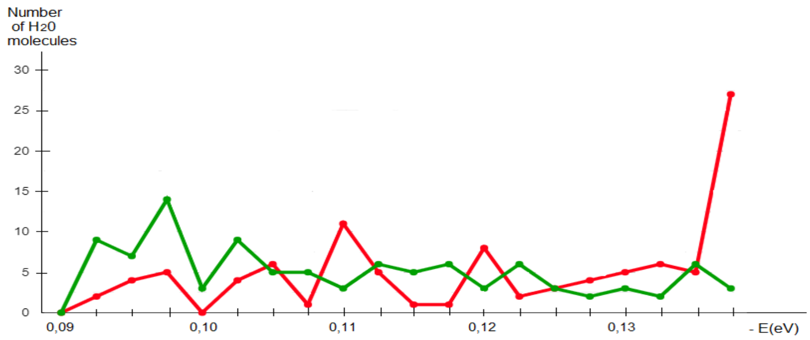

Fig. 3. Distribution of the number of water (H_2O) molecules in EVOdrop (red color) water and tap water (green color)

Water molecules were structured in clusters with a mathematical model.

Notes:

E=-0.1112 eV; λ=11.15 μm; ṽ=897 cm^{-1} is the local extremum for the conductivity of calcium (Ca^{2+}) ions (Soares et al., 2020), (Ignatov, Valcheva, 2023).

E=-0.1212; λ=10.23 μm; ṽ=978 cm^{-1} is the local extremum for anti-inflammatory effect (Ki et al., 2016) (Ignatov et al., 2022).

E= -0.1387 eV; λ=8.95 μm; ṽ=1117 cm^{-1} is the local extremum inhibiting molecular level tumor cell development.

The local extremum at ṽ=1117 cm^{-1} exists in the cancer cell spectrum (Lasalvia et al., 2022) (Neshev et al., 2022).

The t-test of Student had the following results – $p<0.05$, t-statistic (-2.04), coefficient of correlation r=(-0.168) for the results of water clusters with several molecules for group and control group.

Table 3 shows the students' results with a a manual calculation of the t-test of Student.

Table 3. Results of students with manual calculation of the t-test of Student

Results	
Excellent	22
Very good	5
Good	5

The water molecule has a size of 0.27 nm. Hydrogen bond length is 1.5-2.6 Å or 0.15-0.26 nm. The covalent bond length is 0.096 nm. Hydrogen bond strength between two water molecules is 5-6 kcal/mol or 0.22-0.26 eV.

The results for different types of hexagonal water clusters for the wavenumbers $\tilde{\nu}$ are 929, 992, 1117, 3072, and 3171 cm^{-1}. There are wavenumbers of hexagonal water clusters with different combinations of water molecules for n=6 (Table 4) (Heine, 2013).

Table 4. Wavenumbers of hexagonal water clusters with different combinations of water molecules for n = 6

Combinations Hexagonal water clusters	$\tilde{\nu}$ (cm^{-1})	$\tilde{\nu}$ (cm^{-1})	$\tilde{\nu}$ (cm^{-1})	$\tilde{\nu}$ (cm^{-1})	$\tilde{\nu}$ (cm^{-1})
1st combination	929	992	1117	3072	3171
2d combination	929	992	1117	3072	
3rd combination	929	992	1117		
4th combination	929		1117		
5th combination			1117		

The EVOdrop water cluster model comprises 27 water molecules at E= -0.1387 eV; λ=8.95 μm; 1117 cm^{-1}. The cluster is structured from 4 hexagonal groups with 6 water molecules and 3 additional molecules (Figure 4).

This represents approximately a circumscribed sphere where the size of the EVOdrop cluster is: 0.822+0.293=1.115 nm with a basic frequency of hydrogen bonds $\nu=33.56.10^{12}$ Hz= 33.56 THz.

A bigger cluster brings more energy into the water flow of structuring EVOdrop water.

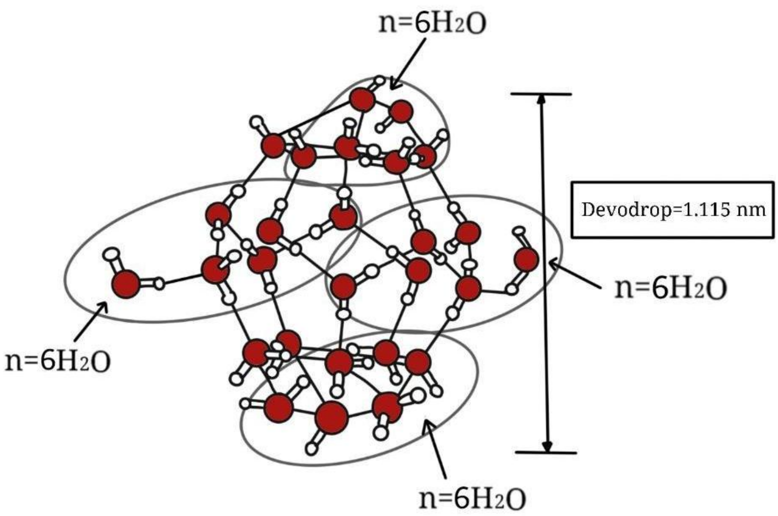

Fig. 4. The function f(E) is the spectrum of distribution based on energies of hydrogen bonds of EVOdrop water and is measured in eV^{-1}

The highest local extremum for EVOdrop water is 128.3 eV^{-1} at (-0.1362 eV; 9.10 μm; 1099 cm^{-1}) – (-0.1387 eV; 8.95 μm; 1117 cm^{-1}). The value is responsible for the antitumor effect. The results from NES for E and DNES for ΔE show that the wetting angle at the EVO drop water is more significant than that of the tap water (control sample). The present investigation highlights the relationship between the number of water molecules and the energy of hydrogen bonds, which may serve as a starting point for future research.

4.5. Problem for Students on Hexagonal Cluster Structure of Water Molecules

The water molecules structure water hexagonal clusters in the liquid phase of water. Six water molecules have stable hexagonal structures in the solid phase of water (Kuo et al., 2001; Ignatov et al., 2013b). Gluhchev, created the following mathematical problem (Ignatov et al., 2022). The regular hexagon is the only regular polygon whose distance from the center to any vertex equals the distance between two adjacent vertices. Let's consider a regular polygon with center point O and points P and Q as two adjacent vertices. We'll denote the side length as R and α as the central angle ORQ, equal to 360°/p. Let point M be the midpoint of side PQ. From the right triangle OMR, we have

$MP/OP = R/(2OP) = \sin(\alpha/2) = \sin(360^o/2n)$

$OP = R/2\sin(360^o/2n)$

For OP = R the result is

$R = R/2\sin(360^o/2n)$

or

$\sin(360^o/2n) = 1/2$ or $360^o/2n = 30^o$ или $n = 6$.

With this, the theorem has been proven.

Corollary: If p < 6, then α > 60°, and OR < R; if p > 6, then α < 60°, and OR > R.

Hypothesis: In a planar ring-like structure of a water cluster with p < 6, having an H atom at the center is impossible due to the limitation of permissible distances between atoms. With p > 6, the distance from the central atom to the atoms at the vertices is greater than the distance between two adjacent atoms of the polygon, resulting in a weaker bond.

Conclusion: A hexagon is the most stable configuration of a planar cluster, representing a regular polygon with an atom at the center.

Table 5 illustrates the results from the mathematical task of 32 students with estimation of hexagonal structures and the connection of the results that the snowflakes have six vertices.

Table 5. Results with a mathematical task for estimation of hexagonal structures

Results/Information about six vertices of the snowflake		
Excellent	18	16
Very good	9	7
Good	5	9

Based on the Mann-Whitney U test, there is no significant difference between the two groups. The base that the snowflakes have six vertices helps with the decision of the mathematic problem, with excellent results from 56 % of the students.

The results of different types of water were studied (Table 6) (Ignatov, Valcheva, 2023).

Table 6. Results of different types of water for the value of local maximums for (-E)

Type of Water	Value eV^{-1} of Local Extremum at (0.1362–0.1387 eV)
Deionized water	18.2±1.2
Mountain water from Vasiliovska mountain, Bulgaria	44.9±2.2
Northern Rhodope	59.3±3.0
Glacier Rosenlaui, Switzerland	70.1±3.5
Glacier Mappa, Chile	81.3±4.1
Tap water from Zurich before the EVODROP device	38.3±1.9
EVODROP drinking water	128.3±6.5

The parameters from table 5 at (-0.1362 eV; 9.10 μm; 1099 cm^{-1}) – (-0.1387 eV; 8.95 μm; 1117 cm^{-1}) for EVOdrop water are a result of water filtration, vortexing, and magnetic effects (Huether, 2019; Ignatov et al., 2022).

4.6. Research of hardness of EVOdrop water

Table 7 illustrates the results with a hardness of water using the EVOdrop device.

Table 7. Results with a hardness of water under the influence of the EVOdrop device

Number of samples*	hardness of water ($mgeqv.L^{-1}$) Tap water	hardness of water ($mgeqv.L^{-1}$) EVOdrop water	hardness of water difference ($mgeqv.L^{-1}$)
6870; 6869	5.29±0.26	2.71±0.14	2.58±0.13
7064; 7063	2.72±0.14	0.49±0.05	2.23±0.11
average result	4.04±0.20 very hard water	1.60±0.08 moderately hard water	2.44±0.12

Table 7 shows the pH results with the influence of the EVOdrop device

Table 8. pH results with the influence of the EVOdrop device

Number of samples*	Water pH Tap Water	Water pH EVOdrop water
6870; 6869	7.83±0.11	7.80±0.11
7064; 7063	7.64±0.11	7.12±0.11
average result	7.74±0.11	7.46±0.11

The data* are from the accredited Laboratory Eurotest Control, Sofia, Bulgaria.

The hardness of EVOdrop water is 7.02±0.35 $mgeqv.L^{-1}$. The difference 7.82-7.02=0.8±0.04 shows the effect of decreasing the hardness of tap water by the EVOdrop water device.

The difference between the pH of tap water and EVOdrop water is 7.74-7.46=0.28

The external magnetic fields structure and increase the energies of hydrogen bonds between the water molecules. Hydrogen ions (H^+) increase (Purnami et al., 2020; Mehandjiev et al., 2023). The amount of hydrogen ions (H^+) in EVOdrop water is 1.91 bigger than in the control sample. The difference is 16477 mM.

Table 9 illustrates the students' results from 32 students with manual calculation of the amount of hydrogen ions (H^+) in water from pH values.

Table 9. Results of students with manual calculation of the amount of hydrogen ions (H^+) in water from pH values**.**

Results	
Excellent	27
Very good	3
Good	2

4.7. Results of EVOdrop water with ^{1}H NMR

Nuclear Magnetic Resonance (NMR) is a physical phenomenon in which a weak, oscillating magnetic field distributes nuclei within a strong, constant magnetic field. In response, they emit an electromagnetic signal with the characteristic of the magnetic field strength at the nuclei.

The ^{1}H NMR spectra were measured on Bruker Avance II+ 600 NMR spectrometer using a 5 mm direct detection dual broadband probe (Stroobants et al., 2014). The experiments were performed at a temperature of 293 K. ^{1}H NMR spectra were acquired with 128K time domain points, spectrum width of 9600 Hz, 16 scans, and a 60 s relaxation delay. The chemical shifts were connected to the DMSO-d6 resonance used as an external reference (2.5 ppm). The DMSO-d6 was placed in a coaxial capillary in the sample tube and used as a lock signal.

The results of EVOdrop water and control samples with ^{1}H NMR are shown in Figure 5.

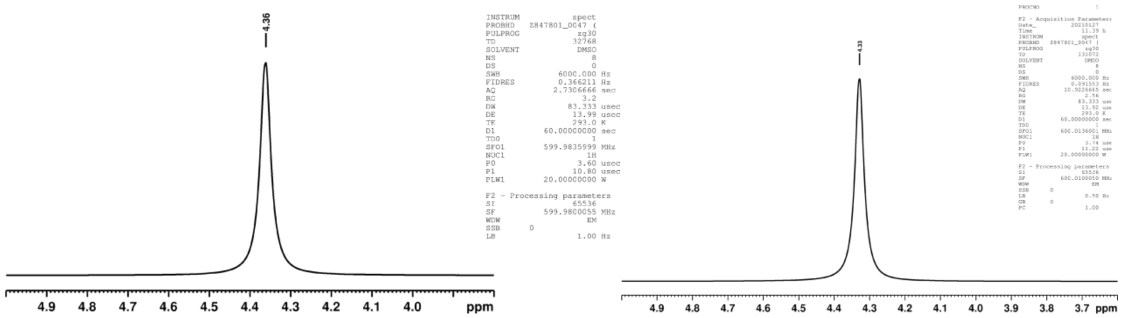

Fig. 5. Results of EVOdrop water and control sample of tap water with ^{1}H NMR

Here we find the following parameters:

EVOdrop water Sample – Chemical shift = 4.36 ppm, line widths $\nu_{1/2}$ = 17.7 Hz

Control sample – Chemical shift= 4.33 ppm, line widths $\nu_{1/2}$ =16.9 Hz

Bigger chemical shifts correspond to bigger clusters (Gruenberg et al., 2004).

The results show that in EVOdrop water, more extensive sets are structured compared to the control tap water samples.

Analyses of the structuring of hydrogen bonds between water molecules are performed on students in order to understand the dynamic processes in water.

The signal area determines the number of nuclei of hydrogen atoms and ions (Oka et al., 2019). A larger line width $\nu_{1/2}$ means faster relaxation of hydrogen nuclei. The increased relaxation rate with NMR is observable in natural water (Elgarbarty, Khaliullin, 2015). Education in physics and chemistry is complementary (Rogach et al., 2018; Gruzina et al., 2020) and has different applications and natural sciences, industry, sport, agriculture, and veterinary medicine. This education develops statistical methods for comparing different scientific results (Sidorov et al., 2018). One of the applications is modeling the water processes with acid rain (Popova et al., 2019).

5. Conclusion

The EVOdrop drinking water treatment technology, in addition to reducing hardness and preserving the pH level of treated tap water, has been shown to significantly rearrange water molecule clustering toward greater similarity to, or even superior to, that of high-quality natural waters.

The authors created a model with 27 water molecules in clusters at E= -0.1387 eV; λ=8.95 μm; 1117 cm^{-1}. This cluster penetrates ion channels with sizes from 5 to 100 nm better than smaller clusters.

The cluster with 27 water molecules is structured from 4 hexagonal groups with 6 and 3 additional molecules.

Therefore, further research could be conducted on scaling up this technology for wastewater treatment. It can be expected that such a development would lead to more effective protection of the environment.

This comprehensive research significantly advances our understanding of water filtration processes and the structural properties of water clusters. The utilization of advanced techniques, including spectral analyses and mathematical modeling, has provided valuable insights into the effects of filtration on water quality and cluster organization. Incorporating students into practical experiments involving Non-equilibrium energy spectrum (NES), Differential non-equilibrium energy spectrum (DNES), pH, oxidation-reduction potential (ORP), and Nuclear Magnetic Resonance (NMR) exemplifies a commitment to hands-on learning and skill development in physics and chemistry. This educational approach not only enriches the students' academic experience but also equips them with valuable skills applicable in medical biophysics and nanotechnologies.

The comparison of samples from the EVOdrop device with control tap water samples, supported by statistical analysis using the Student's t-test, provides robust evidence of the significant impact of the filtration process on water properties. The observed variations in Non-equilibrium Energy Spectrum (NES) and Differential Non-equilibrium Energy Spectrum (DNES) between treated and untreated water samples highlight the effectiveness of the EVOdrop system.

The preference for visual aids, particularly figures, over tables among students underscores the importance of visualization in enhancing comprehension. The mathematical modeling of water clusters, particularly in relation to hydrogen bonding and hexagonal structures, serves as a valuable educational tool, making complex concepts more accessible.

Furthermore, the exploration of different water sources and their energy distributions highlights the diverse nature of water clusters, influenced by environmental and geographical factors. This knowledge is crucial in understanding the variability in water properties and lays the groundwork for further research in this field.

Directions for Student Education:

1. Hands-On Experimentation: Encourage students to actively participate in experiments involving NES, DNES, pH, ORP, and NMR. Providing opportunities for practical application reinforces theoretical knowledge.

2. Visualization Tools: Emphasize the use of visual aids, such as figures and diagrams, to facilitate a deeper understanding of complex concepts related to water clusters and filtration processes.

3. Mathematical Modeling: Foster students' skills in mathematical modeling, particularly in areas concerning hydrogen bonding and cluster structures. This will empower them to approach complex problems with confidence.

4. Environmental Context: Explore the influence of environmental and geographical factors on water clusters. Encourage students to consider the broader implications of their research in real-world contexts.

5. Interdisciplinary Learning: Encourage interdisciplinary thinking by establishing connections between physics, chemistry, and related fields. This approach enhances students' ability to address complex scientific challenges.

6. Research Opportunities: Provide avenues for students to engage in independent research projects, enabling them to explore specific areas of interest within water science.

In essence, this research not only contributes significantly to the scientific understanding of water filtration and cluster structuring but also sets a high standard for educational practices in the fields of physics and chemistry. The hands-on approach, coupled with advanced analytical techniques, equips students with practical skills and fosters a deep appreciation for the complexities of water science. The implications of this research extend beyond academia, potentially influencing applied fields such as medicine and nanotechnology. The dedication and innovation demonstrated in this study are commendable and represent a valuable contribution to the field of water research.

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