Environmental Engineering and Management Journal September 2019, Vol. 18, No. 9, 1987-1994
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

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EXTREMELY LOW FREQUENCY (50Hz) MAGNETIC FIELD INFLUENCES PHYSICO-CHEMICAL PROPERTIES OF WATER

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Abstract

The influence of 50 Hz sinusoidal magnetic field on physico-chemical properties of water was studied. Tanks with distilled water (120 mL) were individually exposed to action of homogenous 50 Hz magnetic fields, using a Helmholtz coils system. For magnetically exposure have been used different values of magnetic flux density (between 1 and 5 mT) and different durations of exposure (between 5 and 240 minutes). By means of this experimental study the physico-chemical properties of exposed water samples compared with the control ones have explored. Density, viscosity, surface tension, pH, oxygen concentration and electrical conductivity were recorded. Some physico-chemical parameters analyzed in this experimental study were found changed. The electrical conductivity, viscosity, surface tension and dissolved oxygen rate have been increased when the water samples were under the 50 Hz magnetic field influences. After exposure, the density results no statistically significant changes revealed. The intensity of absorbance peaks had slight increases with enhancing of magnetic flux density.

Key words: distilled water, extremely low frequency magnetic field, properties, electrical conductivity, viscosity

Received: March, 2018; Revised final: June, 2018; Accepted: September, 2018; Published in final edited form: September, 2019

1. Introduction

Being the most common material present in nature, water is used in different activities of life; all living organisms need water for growth and development. Water is indispensable to solubilize and change the properties of complex structures involved in functioning of living organisms like as nucleic acids, proteins and carbohydrates, by achieving of hydrogen bonds with their polar functional groups (Jerman et al., 1996).

Water is a diamagnetic material and its physical features can be affected by magnetic field action (Rai et al., 1994). Thus, the magnetic moment of water molecule keeps only while it's applied an external magnetic field. The magnetic moment is induced by change of the orbital motion of electrons under the external magnetic field action and is in a opposite direction to the applied field.

Many of studies on this research field focused on the static magnetic field effect on the pure water properties gave contradictory research results. In their study, Cai et al. (2009) have highlighted that exposure to 500 mT magnetic field can lead to water surface tension decreasing while the viscosity was enhanced. On the other hand, Toledo et al. (2008) have obtained increasing of the surface tension of water under magnetic field influence (between 45 mT and 65 mT for 3 h). The results of Amiri and Dadkhah (2006) research have showed that surface tension of water magnetically exposed is very responsive to experimental particularity. Also, reduction of surface tension of water magnetically exposed has been reported by Cho and Lee (2005). Ghauri and Ansari (2006) have notified an enhancement of viscosity of magnetically exposed water, explaining this phenomenon based on stronger hydrogen bonds. In their study Holysz et al. (2007) have concluded that

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magnetic field presence could lead to enhanced electrical conductivity of exposed water and decreased surface tension. Nakagawa et al. (1999) have reported significant enhance of pure water evaporation at magnetic field exposure supposing that the enhanced evaporation could be caused by magnetization force convection. Sugiyama et al. (2000) have observed an enhanced rate of dissolving of oxygen in water, induced by the magnetic field. Other researchers have established that the magnetically exposed of water affects the water structure and the water cluster size (Lee et al., 2003). The electrical conductivity of water has decreased under a constant magnetic field exposure (2.5 mT, frequency of 1-100 Hz) (Akopian and Airapetian, 2005). In contrast, the water exposure at low frequency magnetic field (between 1–12 Hz) with low magnetic flux density (0.35 –1.77 mT) has led to increasing of the electrical conductivity (Ageev et al., 2007).

Relatively lower magnetic field (200 mT) has led to increase the number of monomer water molecule, in simulation (Zhou et al., 2000). In recent study, Wang et al. (2018) have showed that 300 mT magnetic field modified the specific heat, evaporation amount and boiling point of water. The optical properties of water exposed to static magnetic field have been investigated by Han et al. (2016) and they observed changes under infrared absorption properties.

These contradictory results could be possible connected with the experimental design (like flowing water versus static one), magnetic field distribution (perpendicular or tangential field on the water-air interface) and its variability in time (static magnetic field or low frequency magnetic field), duration of exposure, type of water used for exposure (distilled, double distilled, ultra-pure or tap water). Therefore, many exposure studies are difficult to be reproduced.

Therefore, the study of the effects of magnetically treatment of water on its properties and the mechanism of those effects is very important in science with significant value in practical applications. According with Maffei (2014) the magnetic fields can affect the plant growth and development. In future, the magnetized water could be an environmentally friendly ways of magnetic field use for agricultural production increasing. Water exposed to the magnetic field has been also used for improvement of physico-chemical properties of the materials used in construction industry. Lin and Yotvat (1990) said that magnetically treatment of drinking water influence its quality, that contributes to enhancement of farms efficiency in quantity and quality. A significant influence of magnetic treatment on irrigation water quality was also observed by Bogatin (1999) leading to increase of the crop yield by 10-15%. Nan Su et al. (2000) showed improved properties of mortar samples mixed with magnetic treated water (for magnetic induction of 0.8 - 1.35 T the constraint strength of mortar increased by 9-19 %). In the last years, many applications of the magnetized water order to improve freezing of foods or living cells and chemical and pharmaceutical products have been developed (Otero et al., 2016).

The studies about magnetization of water are considered to be a rather delicate problem, so thorough investigations of water properties using new methods and techniques are needed. The water properties variations under the action of low frequency magnetic field (ELF-MF) influence are still a high research topic, the mechanism of water magnetization and its properties changes are not clear yet, even if some theoretical ideas have been proposed. Few research studies have been focused by now on extremely low frequency magnetic field (ELF-MF) impact on water properties (Ageev et al., 2007; Akopian and Airapetian, 2005; Morshed et al., 2010; Semikhina and Kiselev, 1988; Vallée et al., 2005). ELF-MFs are generated by both natural and artificial sources; the artificial sources being the predominant ones and they are correlated with the electrical network processes at the frequency of 50 or 60 Hz. Biological effects of ELF-MFs draw more and more attention of researchers (Buzdugan and Balan, 2011; Gurney and van Wijngaarden, 1999; Singh et al., 2004).

Studies of the water exposure in electromagnetic fields are important because water has a significant role in the living and industrial worlds, and electromagnetic field is one of important environmental influences factors.

This paper is focused on evaluation of the impact of extremely low frequency (50 Hz) sinusoidal magnetic field on physico-chemical properties of distilled water. For magnetic exposure of water samples was used homogenous 50 Hz sinusoidal magnetic field with different magnetic flux densities for different exposure durations. The density, viscosity, surface tension, electrical conductivity, pH, dissolved oxygen concentrations, and visible absorbance spectra compared with the control one have been experimentally analyzed.

2. Material and methods

For magnetic exposure, a laboratory Helmholtz coil system, formed by two coils, was used (Răcuciu et al., 2015). It was generated a uniform vertical magnetic field in the central zone of the coils system. The magnetic field uniformity in the center of the exposure system (within 10 cm diameter area) was established by measurements using a NARDA device (Răcuciu et al., 2015). No temperature variations revealed in the central zone of the exposure system without sample, in the case of all values of magnetic induction used in this experimental study for the duration of 15,000 s. The same occurred in water samples when Helmholtz coil system was not electrically supplied (absence of magnetic field exposure). A Luxtron One device with fiber optic and using a thermal fluoroptic probe having 1.5 mm diameter, was used to accomplish temperature recording.

The magnetic exposure of water samples was accomplished putting each water tank (cylinder with 6 cm diameter), containing 120 mL distilled water, in the center of the coils system. Each water sample was exposed in the central zone of exposure system for different exposure durations between 5 and 240 minutes, to presence of homogenous magnetic field with magnetic induction ranges between 1 and 5 mT. Three water tanks were used for each experimental group (magnetic flux density/exposure time). The vertical magnetic field background was measured using a C.A.40 Gaussmeter and it was obtained 0.13±0.01 μT value. For evaporation of water limitation, each water recipient was closed during the magnetic exposure. The distilled water used in this experimental study was obtained using a DEST3 - BOECO (Germany) water still.

The magnetic treatment of water was used to examine the effects on the density, viscosity, surface tension, electrical conductivity, pH, dissolved oxygen and visible absorbance spectra in comparison with the controls (non-exposed samples). All measurements have been performed immediately after magnetic field exposure of water samples.

The water density measurements were performed by pycnometric method using an electronic laboratory analytical balance (RADWAG AS 220 R2 - Poland) with accuracy of 0.0001 g and a pycnometer. Water samples viscosity values were measured using capillary method with an Ubbelohde type capillary viscosimeter and surface tension by stalagmometric method.

pH, dissolved oxygen contents and electrical conductivity of water samples have been measured by means of digital WTW Multi 3430 -F meter (Germany). The visible absorbance spectra of water samples were recorded using a UV-VIS spectrophotometer (JASCO V530 device) provided with quartz cells having 1cm width. Magnetically exposure and all measurements were performed at the same temperature (295 Kelvin degree). All distilled water samples have been magnetically exposed in the same experimental conditions.

Experimental data were processed using *Microsoft Excel* soft package and *Statistica v.7.0*, to evaluate reliability of the 50 Hz sinusoidal magnetic field induced changes on the distilled water properties. The analyzed parameter values are presented like mean of experimental data obtained for three samples per each experimental group and standard deviation. Regression analyses have been done using the *Statistica v7.0* software.

3. Results and discussion

The results show that the electrical conductivity increased for distilled water under the 50 Hz magnetic field influence. The significance of the variations observed to the properties of water after magnetic exposure depends on the magnetic induction and the exposure time. In Fig. 1, the electrical conductivity changes of distilled water exposed to magnetic field (between 1 and 5 mT) for different durations (between 5 and 240 minutes) are presented.

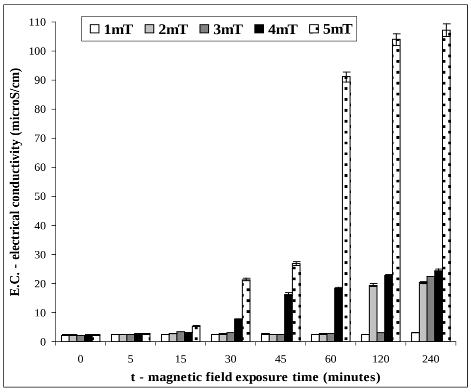

Fig. 1. Electrical conductivity (E.C.) changes of water samples magnetically exposed

For magnetic exposure of water samples at lower values of magnetic flux densities and exposure times, no significant changes of electrical conductivity were revealed. Electrical conductivity of water has had statistically significant and increased for higher magnetic flux densities and enhanced exposure times. The highest value of electrical conductivity of exposed water was observed for 5 mT and 240 minutes' magnetic field exposure (increased by 46 times than control sample). Regression analysis using *Statistica* soft revealed a quadratic dependence between the electrical conductivity (E.C.) and exposure times (t) ($\mathbf{EC}=-7.5718+1.41465*\mathbf{t}-0.0039*\mathbf{t}^2$) with determination coefficient $R^2=0.95$ for 5 mT magnetic field exposure (Fig. 2).

Holysz et al. (2007) have been also reported enhanced values of electrical conductivity of water exposed for 5 minutes under static magnetic field (15mT) influence. Gaafar et al. (2015) have observed increasing electrical conductivity of distilled water with the magnetic field intensity (0.3-0.5T) at lower exposure time than 10 minutes.

Magnetic exposed water densities results revealed statistically insignificant changes. The experimental results show an increased viscosity for the water samples exposed to 50 Hz magnetic field (Fig. 3). According to Fig. 3, for the (5 mT and 120 minutes) magnetic exposure, viscosity of exposed water increased up to 10 % than control. Ghauri and Ansari (2006) have also reported increasing water viscosity under the magnetic field influence. In addition, using *Statistica* soft revealed a quadratic dependence between the viscosity (n) and exposure times (t) ($\mathbf{n}=1018.21+0.899025*\mathbf{t}-0.00259*\mathbf{t}^2$) with determination coefficient $R^2=0.864$ for 1 mT magnetic field exposure (Fig. 4).

For surface tension the same tendency of variation with time of exposure was observed (Fig. 5). Surface tension of magnetized water increased up to 18% than control, for the 3 mT magnetic field exposure for 120 minutes.

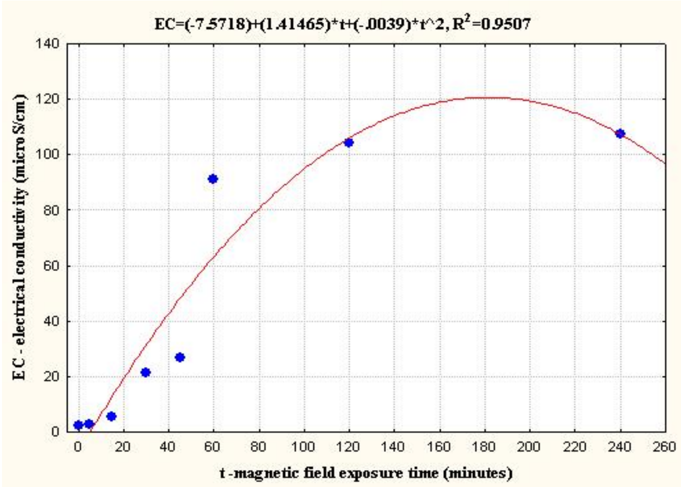

Fig. 2. Dependence between the electrical conductivity (E.C.) (μS/cm) and the exposure time (minutes) for 5 mT magnetic flux density

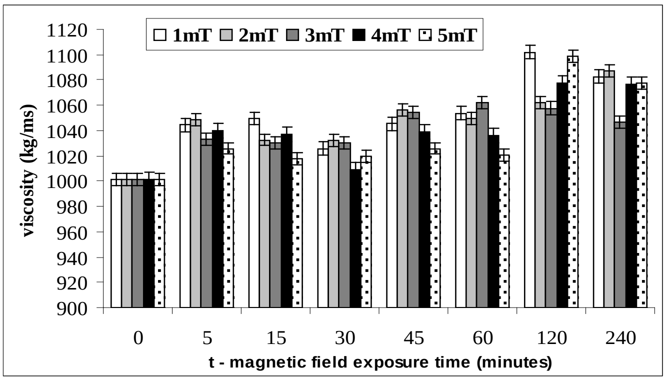

Fig. 3. Viscosity changes of water samples magnetically exposed

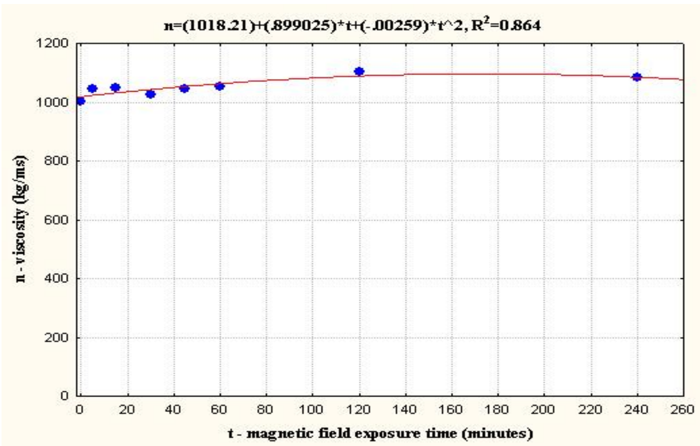

Fig. 4. Dependence between the viscosity (kg/ms) and the exposure time (minutes) for 1mT magnetic flux density

Applying the highest magnetic flux density (5 mT) slight decreases of surface tension were registered, but statistically insignificant. Increasing of viscosity and surface tension of water could be in relation with the enhancing of the molecular interactions. These results agree with of Toledo et al. (2008) that have reported increasing of the surface tension and the viscosity of water after magnetic field exposure, between 45 and 65 mT for 3h. Increasing of surface tension has also obtained by Fujimura and Iino (2009) after exposure of water at 10 T magnetic field. Increased dissolved oxygen rates of the exposed water samples (up to 11%) for enhanced exposure durations have obtained. The increased magnetic flux density led to the dissolved oxygen rate decreasing, as shown in Fig. 6. Hassan and Rahman (2016) have been obtained that the dissolved oxygen rate increased up to 17% for water exposed to 0.1 T magnetic field.

No systematic tendency for the pH variation has been observed in this experimental study (Fig. 7). The highest value of pH (up to 11%) for 4 mT and 30 minutes' magnetic exposure of distilled water was revealed. The pH measurements of water at magnetic field (0.3 - 0.5T) and variable exposing time have been shown increased values with increasing exposure time and magnetic field intensity (Gaafar et al., 2015).

No correlations between electrical conductivity, viscosity, pH and surface tension changes for exposed water samples have been observed. In the visible light absorption spectra measurements case, the distinctive absorption peaks of water haven't been influenced by magnetic field exposure. Only the intensity of absorbance had slight increase with enhancing of magnetic flux density (Fig. 8). Pang and Deng (2008) have also studied the UV-VIS absorption spectrum of water exposed to 0.44 T static magnetic fields for 20 minutes. They concluded that magnetic field presence led to magnification of the UV-VIS absorption characteristics of water.

External electromagnetic field presence induces Lorentz force action on the water molecule. The Lorentz force action on the water molecule induces eddy currents in orthogonal plan to the direction of the magnetic field.

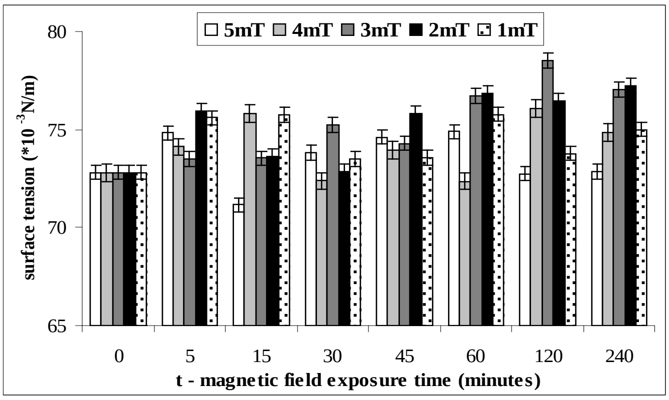

Fig. 5. Surface tension changes of water samples magnetically exposed

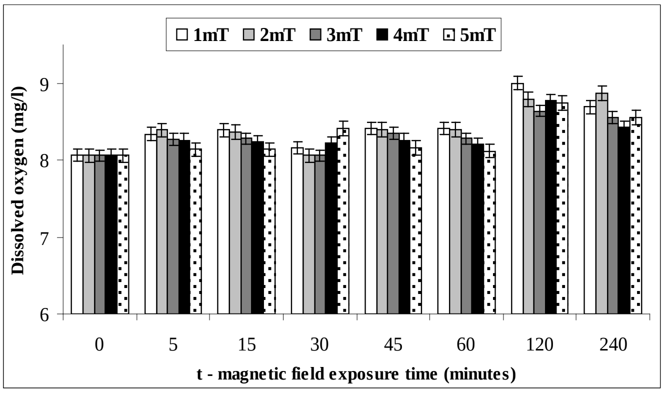

Fig. 6. Changes in dissolved oxygen (mg/L) of distilled water caused by 50Hz magnetic field exposure versus time exposure

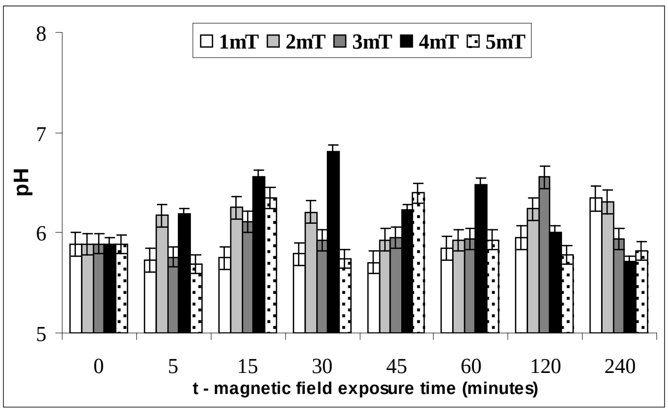

Fig. 7. Changes in pH of distilled water caused by 50Hz magnetic field exposure versus time exposure

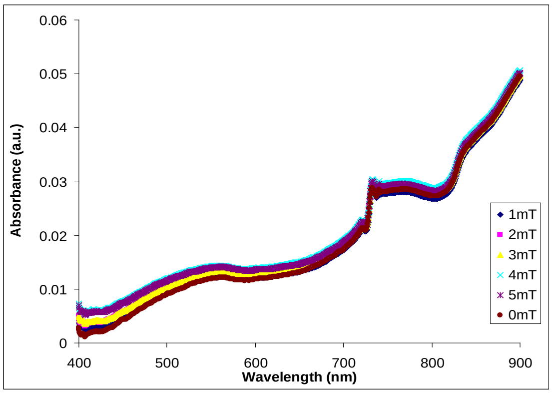

Fig. 8. Visible light absorption spectra of the analyzed water samples

If *r* is the water tank radius, *f* is the frequency, σ is the electrical conductivity and *B* is the magnetic induction (expressed in Tesla), then the induced current *J* has the density given by following formula (Eq. 1):

$$J = \sigma \cdot \pi \cdot f \cdot B \cdot r \quad (1)$$

Applying this equation, the induced current (*J*) is null in the center of water tank (*r* = 0) and increases with approaching of proximity of outer edge (Eq. 1). The internal currents then produce a self-induced magnetic field contrary to the applied magnetic field. This opposite magnetic field will induce a repulsion force. Thus, water molecules under such repulsion force action are stretching and leading to break of the hydrogen bond and covalent one. The electric field (*E*) induced in water sample exposed to magnetic field (*B*) has been evaluated (Eq. 2):

$$E = \frac{J}{\sigma} = \pi \cdot f \cdot B \cdot r \quad (2)$$

Thereby, the power dissipation density delivered to the water unit volume have been evaluated (Eq. 3):

$$w = \sigma \cdot E^2 \quad (3)$$

Since the exposed water tank samples has 120mL in volume, one can takes an radius value about r = 3 cm for estimation of the induced electric field (E) corresponding to the highest value of the magnetic induction (5mT). Consequently, the highest electric field induced by 5 mT magnetic field is of about 0.0236V/m. Thereby, for 4 hours exposure time (the highest exposure time) the delivered energy to the water sample of about 120 cm^3 was about $2.204 \cdot 10^{-4}$ J. The conductivity of non-exposed distilled water has 2.3±0.04 μS/cm value by measurements. Hence, the delivered energy by 50 Hz magnetic field to one mole of water was of $0.333 \cdot 10^{-4}$ J. This value of energy is too small to break a hydrogen bond from water molecule or formation of this one. The hydrogen-bond energy in water had been estimated at $6.3 \cdot 10^3$ J per mole (Smith et al., 2004). However, we have obtained variations of the measured parameters under the influence of the weak 50Hz magnetic field. Increasing of the diamagnetic energy affects internal energy and entropy of water, leading to increase of the Helmholtz's free energy. Increasing of the Helmholtz's free energy could explain the surface tension rise in the magnetic field presence. Viscosity and surface tension are characteristics that can be associated with the intermolecular forces presence. Increasing of these physico–chemical properties means molecular interactions enhancing. Krems (2004) has established that van der Waals complexes with weak bonds can be dissociated into magnetic field and lower magnetic levels could deliver enough energy for breaking of the van der Waals bonds.

Water exposure to magnetic field aligns the water clusters and the alignment can be increased by increasing of the magnetic flux density. Chang and Weng (2006) established that magnetic field presence can influence the structure of water and increases the number of hydrogen bonds, indicating the formation of larger water molecule clusters. They also assert that existence of electric field could lead to break of the hydrogen bond system, while a magnetic field presence increases the hydrogen bonding ability. Pang and Deng (2008) have been also concluded that due to the exposure of water in the magnetic field the closed chains of hydrogen bonds become circular elements of electric current due to the Lorentz magnetic force action.

The presence of magnetic field lead to polarization of water molecules dipoles directly and influences the structure of water molecules groups, connected to each other via a low energy intermolecular Van der Waals forces, dipole-dipole type interactions or by means of hydrogen bonds. These could induce distortion of hydrogen bonds and their partial break, as well as the movement of free protons H+ and redistribution of water molecules in the provisory clusters groups (Ignatov and Mosin, 2013).

Weaker hydrogen bond can appear in magnetic field presence and is also associated to the Lorentz force, which makes the positive and negative ions spin in oppositely way. The motion of molecules reaches more intense, the thermal motion enhances and hydrogen bonds go weaker. Hence, the weaker hydrogen bonds are obtained with magnetic field exposure time rising (Wang et al., 2013).

The experimental results previously presented contribute towards an improved description of the interaction between water molecules and extremely low frequency magnetic field. These results could be also useful for understanding of extremely low frequency magnetic field influence on living organisms with high content of water. No clear mechanisms of magnetic field effect to living organisms have been reported in the literature, yet. The magnetic field can influence living organisms directly or indirectly through water content. Changes of physico-chemical properties of water induced by magnetic field presence can also affects biological properties of water. As mentioned by Toledo et al. (2008) magnetic field exposure of water leads to the weakening of intra-cluster hydrogen bonds and the formation of smaller clusters with stronger inter-cluster hydrogen bonds. Small water molecules could easily diffuse through cell walls. Thus, biological influences of magnetic field on living tissues could be done by means magnetized water molecules.

4. Conclusions

The experimental results suggest that exposure to extremely low frequency (50Hz) magnetic field has influenced the physico-chemical properties of distilled water. Electrical conductivity of water has significantly increased for higher magnetic flux densities and enhanced exposure times. For lower values of magnetic flux densities and exposure times no significant changes of electrical conductivity were revealed. The highest value of electrical conductivity of exposed water was observed for the 5 mT and 240 minutes' magnetic exposure (46 times higher than control).

Viscosity and surface tension of distilled water have increased under the 50Hz magnetic field influence. For highest magnetic flux density (5 mT) insignificant slight decreases of surface tension were registered. The highest increase of surface tension (up 18% than control) for (3 mT and 120 minutes) magnetic exposure has obtained. For the (5 mT and 120 minutes) magnetic exposure, viscosity of exposed water increased up to 10 % than control. Increasing of viscosity and surface tension of water could be in relation with the enhancing of the molecular interactions.

Magnetic exposed water densities results revealed statistically insignificant changes. Increased dissolved oxygen rates of exposed water samples (up to 11%) for enhancing exposure durations have obtained. The increased magnetic flux density led to the dissolved oxygen rate decreasing. No systematic tendency for the pH variation has been observed in this experimental study. In the visible light absorption spectra measurements case, only the intensity of absorbance had slight increase with enhancing of magnetic flux density. These results contribute towards an improved description of the interaction between water molecules and extremely low frequency magnetic field. These results could be also useful for understanding of extremely low frequency magnetic field influence on living organisms like plants, with high content of water (up to 80%).

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