Clarification of the Recent Scientific Approaches in Magnetic Water Treatment

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Abstract. The paper focused on study of influence magnetic water treatment (MWT) mechanism on physico-chemical properties of aqueous solutions taking into account nature of changes in kinetics of chemical reactions. The theoretical analysis of the magnetic field geometry in the hardware equipment of water purification technologies was used. A review of current data on physicochemical processes was carried out for the processes of the influence of magnetic treatment on the properties and structure of aqueous solutions. The determination of the basic mechanisms of MWT was done taking into account the influence of a non-uniform magnetic field on the librational fluctuations of water molecules, followed by their destruction and disruption of the ortho-para ratio towards more chemically active water molecules. The resulting formalized model makes it possible to explain the nature of the complex effects reorganized after exposure of a non-uniform magnetic field to aqueous solutions. Subsequently, this model can be used to optimize the parameters of the mode of the process of water preparation and water purification.

Keywords: mechanisms of influence, magnetic field, chemical activity, librational fluctuations of water molecules, aqueous solution, formalized model.

1 Introduction

According to the UN, about 500 million people live in areas where water consumption exceeds twice locally renewable water resources. The discharge of wastewater causes significant damage to flora and fauna of water bodies and human health. Direct impact includes degradation of aquatic ecosystems and diseases transmitted through water from contaminated freshwater sources, has long-term consequences for the well-being of social and human resources [1]. The research of nonlinear kinetics models of ecosystem processes under the influence of pollutants and distribution organic impurities in the environment also determines need for expansion scientific and theoretical foundations for implementation of water purification methods [2].

Implementation of reverse water supply systems requires improvement quality of purified water and reduction of demand for additional resources (electricity, reagents, etc.). According urgent task is finding ways to intensify existing cleaning methods to improve the efficiency of such systems.

2 Literature Review

The most common methods of treatment intensification areas are using of technologically justified treating schemes, modernization of existing and development new designs of devices, and use physical processing of aqueous solutions (treatment of external fields, ultra-sound, ultraviolet, etc.). The latter becomes of increasing importance in the direction of intensifying purification methods of contaminated water, which is primarily due to their versatility, economy and lack of need for additional reagents.

The magnetic water treatment (MWT) is the one of the perspective physical methods before filing for purification, which based on change in physical and chemical properties of aqueous solutions. Such method characterized by simplicity of implementation, low capital and operating costs [3]. The only disadvantage is lack of knowledge about MWT mechanism [4–6], which limits its widespread implementation. However, positive experience and numerous studies [4–16], proving presence of changes in kinetics of deposition suspended particles in the volume of solution, nature and volume of deposits on heat exchange surfaces, efficiency of ion-exchange processes, kinetics passage of chemical reactions, etc., al-

lows us to confirm promise of its use in processes of environmental protection, which confirms relevance of our research.

The main problem on the path of widespread introduction of MWT is the lack of an integrated approach to studying the mechanism of manifestation of MWT effects, in particular, the effect on the kinetics of chemical reactions in aqueous solutions, which was partially studied in [7–16].

The aim of the paper is theoretical study of influence mechanism MWT on physicochemical properties of aqueous solutions taking into account nature of changes in kinetics of chemical reactions.

The following tasks set and solved in the article:

– to analyze previous studies of MWT mechanisms of impact on structure and properties of aqueous solutions;

– to form a complex model for description the mechanism of influence non-uniform magnetic field on aqueous solutions properties and change kinetics of chemical reactions.

3 Research Methodology

Since all effects of MWT related to change in physical and chemical water properties caused by influence of magnetic field on water solution, it is important to take into account the basic design and mode parameters of MWT devices, which differ in a number of features [17]. One of the main structural parameters is geometry of magnetic field and heterogeneity of distribution magnetic induction B along the pipe for passage of aqueous solution (Figure 1).
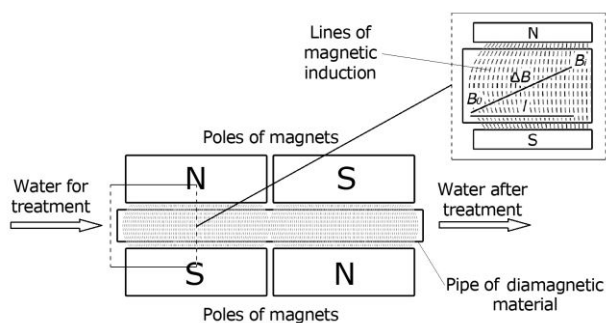

Figure 1 – Typical scheme of elementary plot device MWT:
ΔB – value of magnetic induction changes in a non-uniform magnetic field; l – length of MWT device section, where magnetic induction varies from B_0 to B_i; B_0, B_i – minimum and maximum value of magnetic induction, respectively

The geometry of magnetic field in MWT devices depends on several factors, which based on properties of magnets and how to accommodate them. The effect of magnetic field on water occurs on MWT device areas, where magnetic induction varies from B_0 to B_i, its lines necessarily directed perpendicular to the solution motion, and induction difference $\Delta B \neq 0$ T, otherwise MWT effect not observed.

Among regime parameters MWT [4, 6, 18], it is mandatory that the water flows in magnetic field is mandato-

ry, and water velocity is one of the parameters that determines effectiveness of MWT.

The aqueous solution velocity and value of magnetic induction between them are closely interconnected, and their connection must be taken into account when designing MWT devices and selecting optimal operating modes. In view of current developments MWT devices, one of the main drawbacks is incomplete incorporation of MWT parameters, or their inclusion separately from each other, without analyzing their interconnection. The simultaneous consideration of such MWT parameters as the aqueous solution speed and magnetic induction requires further study.

4 Results and Discussion

4.1 Theoretical formalization of the MWT mechanism

The large amount of data associated with MWT have led to determination of various aspects regarding MWT mechanism, which can be conventionally grouped into three approaches: colloidal, ionic and water [4–7, 9, 18, 19–21]. In the table 1 presents groups of MWT mechanism influence according our analysis.

Modern ideas about kinetics of chemical reactions based on the fact that any reaction occurring in aqueous solution includes the step of rearranging solvent molecules to form "cavities" in which located reacting particles, activated complex and reaction products [22]. The rate of water molecule rearrangement for expected activated complex greatly effects on kinetics of chemical reactions and depends on physical and chemical properties of aqueous solutions that are due to presence of hydrogen bonds [23] and their nature, peculiarity of water molecule isomers structure [24] and features of molecules oscillations [25, 26].

Table 1 – Groups of the MWT mechanisms

Impact object	Mechanisms
Colloidal group of approaches	
Colloidal (ferromagnetic) particles	The surface properties of such particles changes and they act as crystallization centers under the magnetic field influence. This group explains the anti-scale effect.
Ionic group of approaches	
Ions that are present in water	Under the influence of a magnetic field, polarization and deformation of ions occur, which are accompanied by their hydration decrease, which affects the course of physicochemical processes in aqueous systems.
Water group of approaches	
Water molecules	This group combines ideas about the possible influence of a magnetic field on the water structure. This influence, on the one hand, can cause changes in the aggregation of water molecules, and on the other hand, changes in the orientation of the nuclear spins of hydrogen in water molecules, etc.

Changing kinetics of reactions in aqueous solutions is possible due to the weakening of interaction water molecules between themselves and with dissolved substances, breaking of hydrogen bonds, or reducing their energy, which facilitates water molecules restructuring for the expected activated complex [23]. The last becomes possible even with MWT, which is confirmed by many studies [3–6, 18, 19], in which appearance of changes in structure and physical and chemical properties of aqueous solutions due to hydrogen bond (density, viscosity, surface tension), changes in hydration of dissolved substances and changes in rate of reaction. However, nature of such impact requires further research.

Given the value of magnetic induction at MWT, external energy entering aqueous solution is not sufficient for direct breaking or weakening of hydrogen bonds [4, 5]. The results obtained in [6] indicate that defining parameter MWT, which more than induction value determines efficiency of MWT, is the heterogeneity of magnetic field. The changes caused by influence of non-uniform magnetic field on the structure of water, may related not so much to discontinuities of hydrogen bonds, but with decrease in their energy, increase in length and change in angle [5, 27]. In this case, structure of water molecules, presence of quantum differences water molecules and nature of their interaction with each other and with dissolved substances has important role [24, 25].

The appearance of quantum differences between water molecules can be explained by states presence librational undamped oscillations in water molecules [25]. Such oscillations cause appearance of hydrogen proton rotation on hydrogen bond line in the directions perpendicular to hydrogen bond line.

The rotation of hydrogen proton around hydrogen bond line has an elliptical trajectory (EPT) whose radius also rotates, as shown in Figure 2.
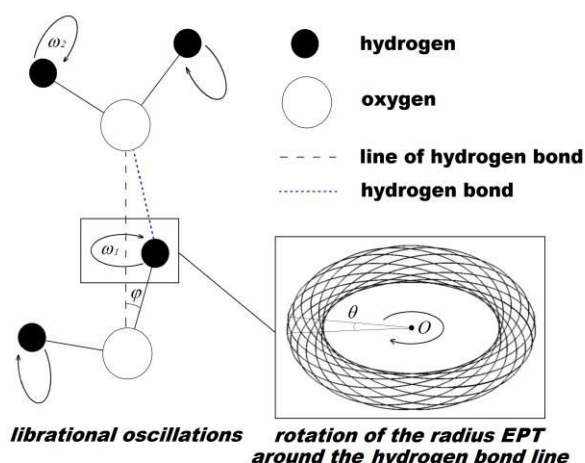

Figure 2 – Rotate proton and electron orbitals of neighboring water molecules connected by hydrogen bonds: ω_i – frequency molecules libration vibrations; φ – angle of proton deviation from hydrogen bond line; θ – phase rotation radius EPT; O –hydrogen bond line

Movement of positively charged hydrogen proton by EPT causes appearance of magnetic and mechanical moment. Magnetic fields formed by rotation of hydrogen protons of one molecule can both coincide in the direction and be opposite directed along molecule axis. In the case of uniform direction of protons rotation, magnetic fields formed and form magnetic field of entire molecule and conversely. Consequently, presence of librational oscillations water molecules is the reason for appearance of quantum differences in water molecules isomers, which mentioned in work [24].

Synchronization of libration oscillations for para-isomers in supramolecular formations is carried out by four hydrogen bonds, and their cooperative nature provides a redistribution of energy received from outside, from collisions with thermal motion [25], which makes possible existence of ice-like structures in aqueous solutions, emergence heterogeneity of water density [26] and the violation of equilibrium ortho/pair ratio in the direction of pair-isomers, more than 2 times [24]. Thus, aqueous solution is a nonequilibrium system that is sensitive to external influences.

The prerequisite for establishing an equilibrium ortho/pair ratio is violation of synchrony librational oscillations in ice structures, where, first of all, weakest hydrogen bonds destroyed, and energy received from outside goes to destruction of ice-like structures. Their destruction leads to "release" of pair-isomers, which, when further collisions with other water molecules, become ortho-isomers [24].

For explain mechanism of appearance pair-ortho conversion under influence of non-uniform magnetic field on aqueous solution, let's consider loss synchronism of libration oscillations under magnetic field influence on hydrogen proton, rotating on EPT. The effect of non-uniform magnetic field on the proton EPT results in precession of EPT radius around hydrogen bonds. Due to structural stiffness of water molecule, appearance precession of one hydrogen proton leads to appearance a similar precession of second proton. EPT precession is not the same as that occurring with electrons orbits, because for EPT precession required rotation the entire water molecule, which is impossible due to presence other hydrogen bonds. EPT precession becomes possible only for those protons, in which plane of EPT is perpendicular to lines of magnetic induction. Since, in case of oscillations, radius proton EPT rotate around hydrogen bond line, appearance of an additional precision with radius EPT changes rotation phase θ of radius EPT, which will be different for two pair-isomers bound by one hydrogen bond due to difference in angle slope plane EPT protons of neighbouring molecules to lines of magnetic induction.

The result of the influence of a non-uniform magnetic field on an aqueous solution is the shift of the phase of rotation of the radius of the EPT of hydrogen protons for neighbouring isomers of water molecules by $\pm \Delta\theta$. Such a phase shift occurs non-uniformly with a certain angular acceleration ε in the direction of the Lorentz force, where the magnitude of the acceleration was found from the second law of Newton:

$$ma = F_L,\qquad(1)$$

where m is proton weight, kg; a is acceleration of rotation of the proton EPT radius around the hydrogen bond line, m/s^2; F_L is Lorentz force, N.

$$ma = e\upsilon_m \Delta B \sin\alpha,\qquad(2)$$

where e is proton charge, C; υ_m is the speed of "movement" of the magnetic induction lines relative to something (a circuit of EPT), m/s; ΔB is the magnitude by which the magnetic induction changes, T; $\sin\alpha$ is the angle between the velocity υ_m and the magnetic induction vector B.

The additional motion of the radius of EPT around the hydrogen bond line in a non-uniform magnetic field is rotational motion with angular acceleration, which, by means of standard transformations of expression (2), is represented as

$$\varepsilon = \frac{e\upsilon_m \Delta B}{mr}.\qquad(3)$$

For find the velocity υ_m, an expression was taken from [28] and, having carried out the necessary transformations, we obtain

$$\upsilon_m = \frac{\Delta \Phi}{\Delta B \cdot L \cdot \Delta t},\qquad(4)$$

where $\Delta \Phi$ is magnetic flux, Wb; ΔB is change in magnetic induction, T; L is the length of EPT, m; Δt is the time during which the magnetic induction lines intersect the contour of EPT, s.

The magnetic flux $\Delta \Phi$ can be expressed in terms of the change in the magnetic induction ΔB and the area of the EPT square S, which it intersects:

$$\upsilon_m = \frac{\Delta B \cdot S}{\Delta B \cdot L \cdot \Delta t}.\qquad(5)$$

The radius of EPT was taken equal to r for simplicity of writing the formula (5) as:

$$\upsilon_m = \frac{r}{2 \cdot \Delta t}.\qquad(6)$$

Thus, the rate of "movement" of magnetic induction lines relative to a proton depends only on the radius of EPT and the time during which the magnetic induction B changes and does not depend on how much the magnetic induction changes. In turn, an increase or decrease in induction affects only the direction of the effect of the F_L force. Having made the necessary transformations of expressions (3) and (6):

$$\varepsilon = \frac{e}{2m}\frac{\Delta B}{\Delta t}.\qquad(7)$$

The change θ-phase of radius EPT in a non-uniform magnetic field is due to influence Lorentz force on proton

(Figure 3 a). It has two components, where the first component F_{L1} arises from proton motion in a magnetic field at velocity υ, which is due by librations oscillations. The component F_{L1}, for each proton position on EPT, is oriented perpendicularly to proton movement, and as can we see from Figure 3 a (position 1 and 2), compensates for itself and does not cause shift of turn phase θ. In addition, hydrogen bond formed by electrostatic forces much larger than F_{L1}, so radius EPT remains "rigid" and angular velocity of proton rotation remains unchanged.
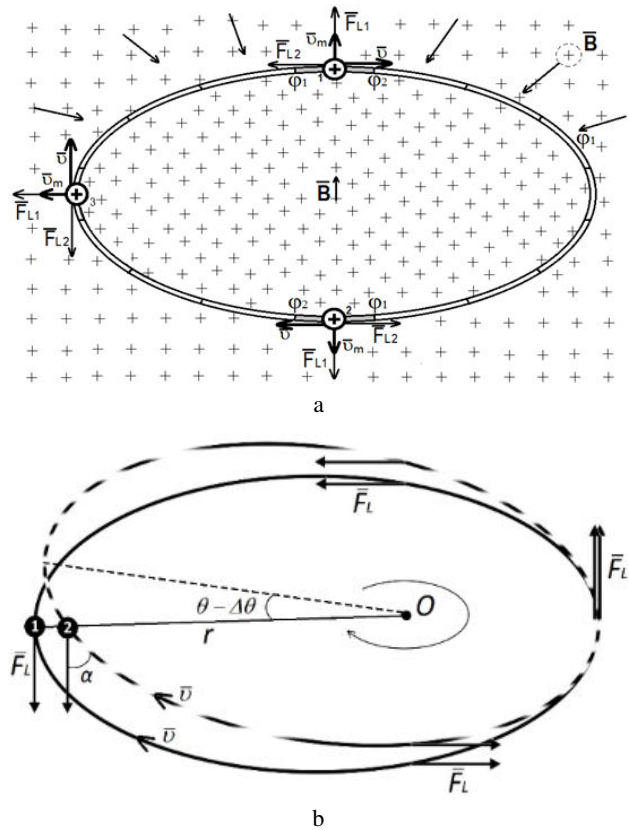

Figure 3 – Displacement phase of EPT rotation hydrogen proton in a non-uniform magnetic field (magnetic induction lines directed from us): B – magnetic induction; F_{L1} – first component of Lorentz force; F_{L2} – second component of Lorentz force; υ – proton speed movement by EPT; υ_m – rate intersection of contour EPT by magnetic induction lines; φ_1 and φ_2 – potentials; 1, 2 – position of hydrogen proton on EPT in plane rotation radius EPT, in accordance before and after turning radius EPT; r – radius EPT; α – angle between direction of force F_L and tangent to contour EPT; O – hydrogen bond line; θ – phase of radius EPT rotation; $\Delta\theta$ – shift of turn phase radius EPT

The appearance of second component of Lorentz force F_{L2} becomes possible only in non-uniform magnetic field, which is a prerequisite for MWT. Force F_{L2} directed in one direction at tangent to EPT (Figure 3 a, positions 1, 2, and 3). The process of occurrence electromotive force (EMF) in non-uniform magnetic field isn't considered as the result of appearance vertical electric field, but it's the result of increase in density of magnetic field due to "flow" field lines from surrounding space into magnetic flux through closed circuit. In process of "entering" lines

of induction into the contour, they cross contour, causing EMF induction by "mechanism of intersection" [28].

Supposed that closed circuit in Figure 3 a is the region in which fluctuates radius EPT of the hydrogen proton (Figure 2), on which proton moves and creates elemental current in circuit. Conditionally divide contour into n sections that "isolated" from each other. Each section corresponds to certain position of proton and during its movement there is a potential difference. With increase of magnetic induction, its lines "penetrating" into contour, intersect it with velocity υ_m (expressions (6)) in direction to the center. Otherwise, with decrease magnetic induction, its lines move from center to periphery, and Lorentz force F_{L2} changes its direction.

The effect of Lorentz force F_{L2} (further F_L) is shown in Figure 3 b, which depicts elementary act turning radius EPT taken from Figure 2. Additionally, Figure 3 b clearly shows that when $\upsilon_m = const$, the direction and value of force F_L stored for proton irrespective of its position on EPT, only angle α between vector of force F_L and tangent to EPT changes. Thus, at p.1 angle $\alpha = 0°$, after turning EPT (position 2) angle $\alpha \neq 0°$. That's why, with coincidence of basic direction rotation radius EPT and direction of force F_L, it accelerates, and in opposite case, slows rotation radius EPT around hydrogen bond line, changing rotation phase EPT by value $\pm\Delta\theta$ and with prolonged influence of F_L, with each turn EPT displacement phase of the rotation increases.

4.2 Development of a complex model of the influence of a non-uniform magnetic field on the properties of aqueous solutions

Figure 4 shows the formed model of the non-uniform magnetic field impact on the kinetics of chemical reactions in aqueous solutions, which takes into account complex factors that reasoned by this influence.

Thus, influence of non-uniform magnetic field on kinetics chemical reactions in aqueous solutions does not depend on whether induction of magnetic field increases or decreases, result of effect remains the same, an important value becomes value at which magnetic induction changes and time for which this change occurs. The Lorentz force, caused by change in induction value, directed at proton-tangent to EPT and its direction may coincide with direction of rotation proton radius EPT, and be opposite directed. The effect of this force becomes possible only when moving in non-uniform magnetic field, where it shifts the phase of rotation radius EPT by a value of $\pm\Delta\theta$. In turn, because the water molecules in the volume of solution oriented arbitrarily, phase displacement $\pm\Delta\theta$ is not the same for adjacent water molecules in ice structures, which causes asymmetry of libration oscillations pair-isomers and affects their synchronicity and cooperability.
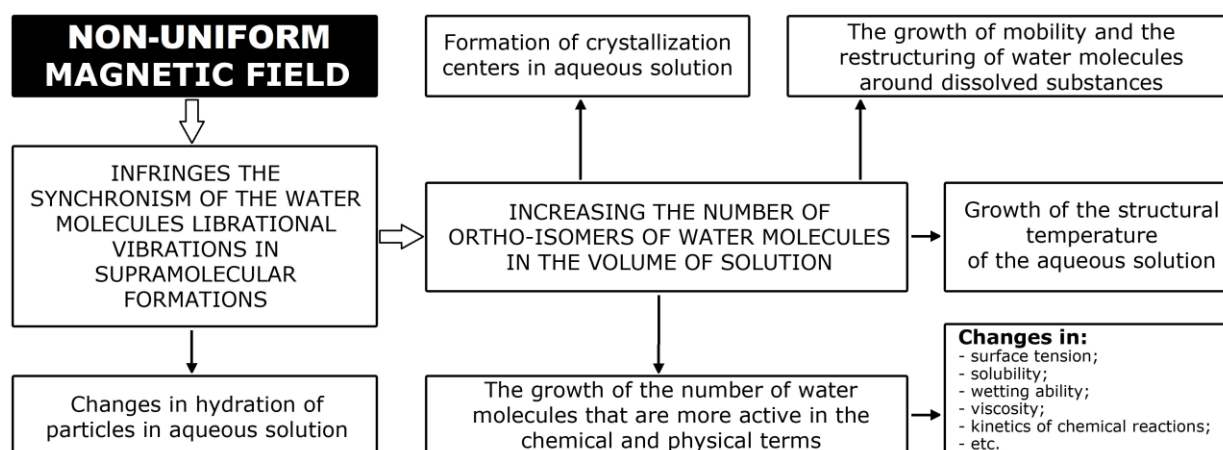

Figure 4 – Complex model of non-uniform magnetic field influence on kinetics chemical reactions in aqueous solutions

Because water is a non-equilibrium system, violation of synchronous oscillations in supramolecular formations, which, due to collisions with other molecules, results in excess energy and collapses, results in conversion of pair-isomers, increase in number of ortho-isomers, causing changes in density, viscosity, in infrared spectrum of water, hydration of dissolved substances, registered after MWT, etc.

5 Conclusions

The analysis of technical realization of MWT allowed establish that one of the main structural parameters is heterogeneity of distribution magnetic induction along the pipe for passage aqueous solution. The groups of MWT mechanisms were formed for interpretations of the physicochemical effects of MWT.

The theoretical model of the complex mechanisms of the influence non-uniform magnetic field was formed for considering quantum differences between two types of water molecule isomers and librational oscillations of water molecules in supramolecular formations. Further research will be directed to use the complex model of magnetic field influence for regime parameters rationalization of water preparation and purification processes.

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Уточнення останніх наукових підходів до магнітної обробки води

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Анотація. Досліджено механізм впливу магнітної обробки на фізико-хімічні властивості водних розчинів з урахуванням характеру змін кінетики хімічних реакцій. Використано теоретичний аналіз геометрії магнітного поля в апаратному обладнанні технологій очищення води. Проведено огляд сучасних даних про фізико-хімічні процеси, обумовлені впливом магнітної обробки на властивості та структуру водних розчинів. Здійснено розширення концептуальних засад теорії механізму магнітної обробки з урахуванням впливу неоднорідного магнітного поля на лібраційні коливання молекул води з подальшим їх руйнуванням і порушенням орто-пара-відношення у бік більш хімічно активних молекул води. Отримана формалізована модель пояснює природу ефектів, що спостерігаються після впливу магнітного поля на водні розчини та може бути використана для оптимізації режимних параметрів процесів підготовки та очищення води.

Ключові слова: механізм впливу, магнітне поле, хімічна активність, лібраційні коливання молекул води, водний розчин, формалізована модель.