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Magnetic Treatment of Irrigation Water: Experimental Results and Application Conditions

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The effects of magnetic treatment on irrigation water have been studied. We showed that the main effects were the increase of the number of crystallization centers and the change of the free gas content. Both effects improve the quality of irrigation water. As an example, changes in natural water due to magnetic treatment in a commercially available apparatus, Magnalawn 2000, have been studied. On the basis of laboratory and field results, the type and the chemical content of natural water for which a magnetic treatment method is the most efficient have been determined. Our analysis shows that the important components for effective magnetic treatment are flow rate through the apparatus and certain chemical parameters of water, namely, carbonate water hardness of more than 50 mg/L and concentration of hydrogenous ions in water at pH > 7.2. Irrigation with magnetically treated water is the most effective for soils with high soda content.

Introduction

Among different physical and chemical methods of natural water treatments, magnetic methods attract a special attention due to their ecological purity, safety, and simplicity. A pioneering contribution to the development of the magnetic water treatment (MWT) was performed by Th. Vermeiren (*1*). The results of field tests vary in different regions and pose a skeptical attitude toward the method on the whole. Indeed, how can any significant changes in medium take place with almost no energy dissipation? Also, how can a magnetic field alter the properties of a natural water that does not contain any ferromagnetic inclusions or a significant amount of paramagnetic substances? In this paper, we present detailed studies of physical and chemical changes occurring in natural water after treatment with a nonuniform magnetic field.

Theoretical Background

Natural water is a multiphase system that contains micro- and macroparticles of organic and inorganic nature, including different ions, zoo- and phytoplankton, and microbubbles. The presence of microparticles and the free gas phase mainly determines physical properties of natural water in contrast to ideal water, which is regarded as a uniform media. Microparticles, microbubbles, and ions carry electrical charges and are surrounded by hydrate and diffuse layers. In a flow, which is a necessary condition for MWT, electrical currents are present even in the absence of a magnetic field. Since charges in the liquid are associated with either microparticles, microbubbles, or ions, electrical currents are accompanied by mass transfer. The interaction of magnetic fields with convection and induced currents forces liquid to spin (*2*), which results in a number of effects such as changes in gas content and in the amount of salt crystallization centers.

Centers of phase formation can be ions, molecules, or microparticles with disturbed hydrate shells. Previous experimental and theoretical works show that the critical stress for hydrate layers is $\tau_0 = 10-15$ N/m^2 (*3*). We calculated that the magnetohydrodynamic pressure in hydrate layers can reach significant values of $p_{\mathrm{MHD}} > 15$ N/m^2 for 1−2 m/s flow rates and 0.1−0.2 T magnetic fields. Such a high value of $p_{\mathrm{MHD}} \geq \tau_0$ results in the total or partial destruction of hydrate layers, an increase in the amount of active crystallization centers, and the enhancement of the probability of coagulation (*4*). A rapid change of the magnetic field in a magnetic apparatus of appropriate design loosens and distracts hydrate layers and films in a moving liquid, thus facilitating coagulation and coalescence. An increase in the number of crystallization centers in the liquid under magnetic treatment shifts the carbonic acid balance

$$\mathrm{Ca(HCO_3)_2} \Leftrightarrow \mathrm{H_2O} = \mathrm{CaCO_3} + \mathrm{CO_2} \qquad (1)$$

toward the formation of insoluble $CaCO_3$, H^+ ions, and free CO_2, i.e., acidification of alkaline hydrocarbonate water takes place. Hence, the number of crystals and pH of the liquid can be used as indicators of the treatment efficiency.

Local dehydration of surface microbubble films and a decrease of pressure in the center of vortices result in an increase of free gas bubbles because of their coalescence and transition from molecular dissolved gases to bubble form. After the liquid reaches an open surface, free gas escapes the liquid easier than molecular dissolved gas. In our experiments, we observed 25−30% enhancement of degassing (*4*).

It should be noted that effects in magnetically treated water are not limited to the ones discussed above. In particular, products of high-energy reactions such as free radicals, atomic oxygen, peracids, and nitrogen-containing compounds can be found in the water. These reactions occur during microbubble collapses due to a decrease of the critical threshold of cavitation in the vortices.

Such physical−chemical changes in natural water are caused by the energy of hydrodynamic flow, the presence of ions, charged microparticles, and volume charges at interphase boundaries in a liquid and not by the contribution from magnetic field energy, the absorption of which by a low conducting medium with no ferromagnetic properties is negligible. A magnetic field causes redistribution of flow energy due to the momentum change of charged particles.

Materials and Methods

To investigate the MWT, we used the following methods: pH, optical, and crystallographic.

pH Method. The measurement of pH is the simplest and quickest method of magnetic treatment indication. In general, both the change of gas content and the shift of carbonic acid balance lead to a change of pH. However, several other factors, such as the slow desolution of magnets' material, may result in comparable pH changes between inlet and outlet water samples. We improved the method, making

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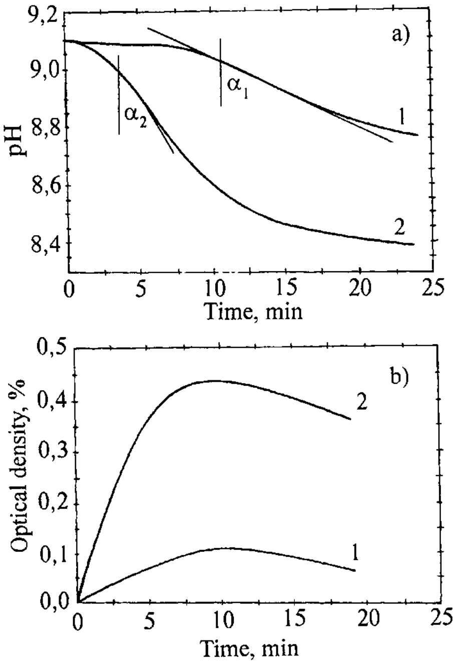

FIGURE 1. Change in concentration of hydrogenous ions (a) and optical density (b) in the bicarbonate solution as a result of alkalinization. 1, control solution (without magnetic treatment); 2, solution after magnetic treatment in Magnalawn 2000 with flow rate of 0.2 L/s.

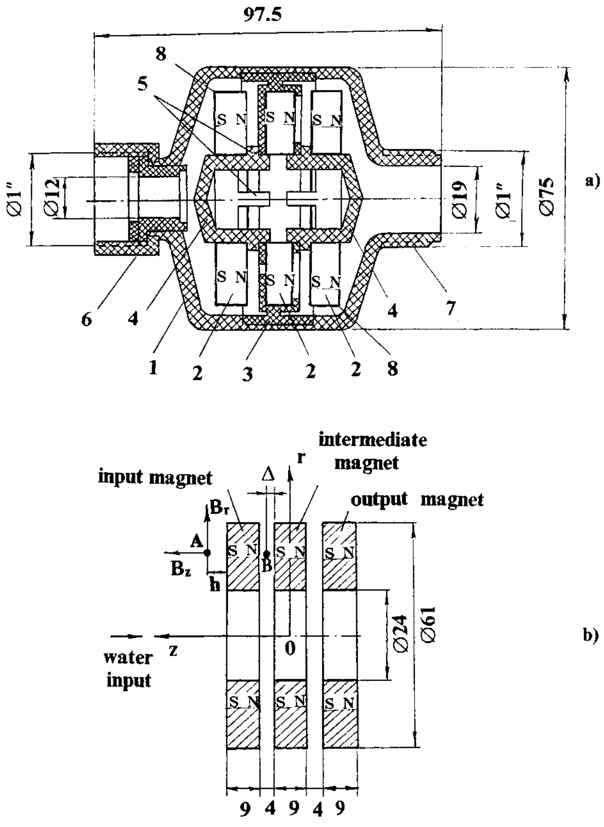

FIGURE 2. (a) Schematic of Magnalawn 2000: 1, cylindrical body; 2, ring magnets; 3 and 5, fastening details; 4, plugs; 6, inlet; 7, outlet pipe; 8, areas of the maximum field gradient. In panel b, we introduce distance notations for magnetic field measurements.

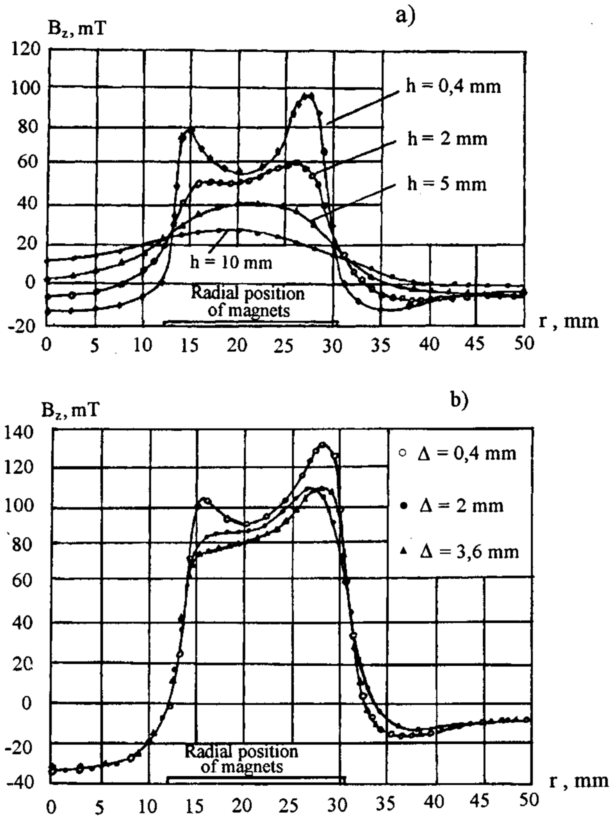

FIGURE 3. Axial component of magnetic field B_z measured as a function of the distance to the magnet points A (a) and B (b) of Figure 1b.

it particularly sensitive to the presence of bicarbonates, by adding $Ca(OH)_2$ to the outlet water samples and recording the change of pH with time, pH(*t*). The pH(*t*) change reflects the process of $CaCO_3$ crystallization. The optimal dosage was found to be 0.2–0.5 mg·equiv of alkali/1 mg·equiv of HCO_3 ions in water; if water hardness is >2 mg·equiv/L, any alkali can be used instead of $Ca(OH)_2$, for example, NaOH. In Figure 1a, the kinetic curve (1) of pH change in a bicarbonate solution is obtained by adding NaOH into the water sample with total alkalinity of 10 mg·equiv/L. The horizontal part of the kinetic curve corresponds to the formation of centers of calcium carbonate crystallization (the latent period of crystallization). The decreasing part of the pH(*t*) curve characterizes the growth of crystals with the rate of $CaCO_3$ crystallization proportional to dpH(*t*)/d*t* (α in Figure 1a). The value of α is an indicator of magnetic treatment efficiency. Advantages of the method are high speed and the possibility to obtain quantitative comparison. The main disadvantage is that the amount of alkali has to be experimentally adjusted for each type of solution.

Optical Method. A change of H^+ concentration changes the transparency of the solution that can be detected by a photocolorimeter or even by the naked eye. By adjusting the amount of alkali (0.2–0.5 mg·equiv of alkali/1 mg·equiv of HCO_3), it is possible to achieve conditions where the control solution remains transparent and the treated solution becomes turbid (sediments of $CaCO_3$ crystals) (see Figure 1b). This method is simple and can be easily used in field conditions. The drawback of the method is that it cannot be used with nontransparent waters.

Crystallographic Method. Since $CaCO_3$ is always present in groundwater, its properties have to be taken into account when preparing water for technical and household needs. $CaCO_3$ has three crystal modifications: calcite, aragonite, and vaterite. From natural water, $CaCO_3$ is usually crystallized as calcite, the most stable form. Thermal conditions are crucial for the reproducibility of crystallization—samples were obtained by drying 0.2 mL of solution in a thermostat at 50 °C. Chemical compositions of the various solutions

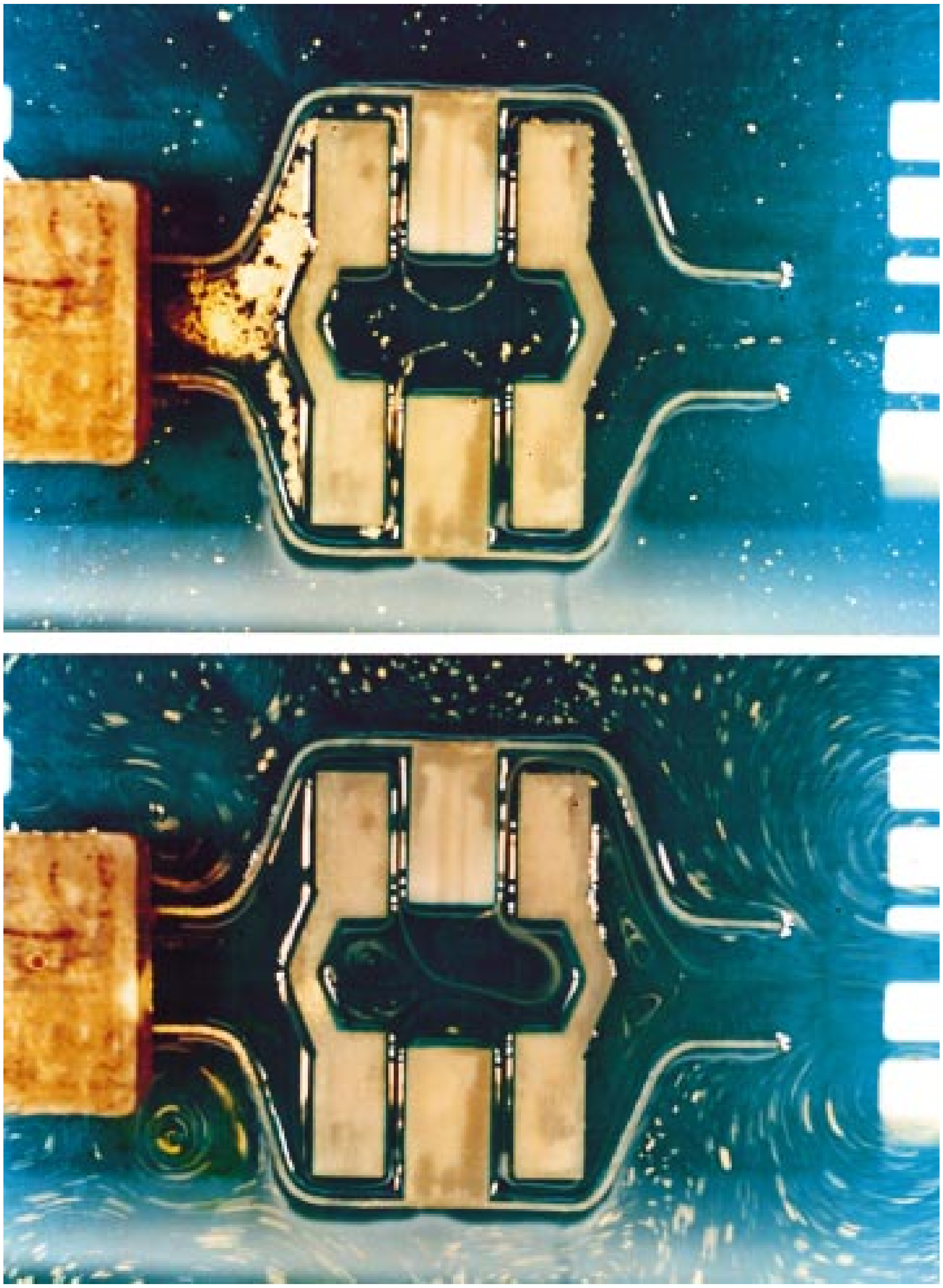

FIGURE 4. Flow structure in the two-dimensional model of the magnetic apparatus at various values of current *I* in the inlet: (a, top) $I = 0.1$ A (laminar regime); (b, bottom) $I = 1$A (turbulent regime)

were 10 mg·equiv/L $NaHCO_3$ + 10 mg·equiv/L $CaCl_2$ for studying the crystallization of $CaCO_3$ in calcite form, 10 mg·equiv/L NH_4HCO_3 + 10 mg·equiv/L $CaCl_2$ for studying crystallization of $CaCO_3$ in aragonite form and ocean water with a 35 g/L concentration. Sediments were studied under a microscope with 400 magnification in polarized light.

Apparatus Applied. To study magnetic treatment effects, we used as a magnetic apparatus the Magnalawn 2000 intended for irrigation of lawns, gardens, vegetables, and plants (*5*). A cross-section of the Magnalawn unit is shown in Figure 2a. The magnetic part of the device consists of three barium ferrite flat rings (2) with alternating polarities separated by 4 mm gaps. Plugs (4) in the inlet and outlet force water through the gaps between magnets, so the stream intersects magnetic fields of different polarities four times. A speed vector changes its direction in the areas of the maximum gradient of magnetic field (8). Distribution of the axial component of magnetic field in the gaps is shown in Figure 3; measurements were performed with a standard Hall sensor in positions A and B indicated in Figure 2b. The axial component of the magnetic field above the outside ring decreases rapidly with the distance from the surface, the field values in the gaps being within the range of 60−100 mT. The radial component of the field has the maximum value on the surfaces of the input and the output magnets.

In lab experiments, we used a hydraulic system with 0−0.4 L/s throughput, which corresponds to 0−1.5 m/s inlet flow rates. Samples of liquid were taken from the inlet and the outlet of the apparatus. Control tests were carried out with an apparatus of a similar design with no magnetic field.

Hydrodynamic Model of the Apparatus. To understand the physical phenomena that take place in the apparatus, we performed calculations of velocity distribution and

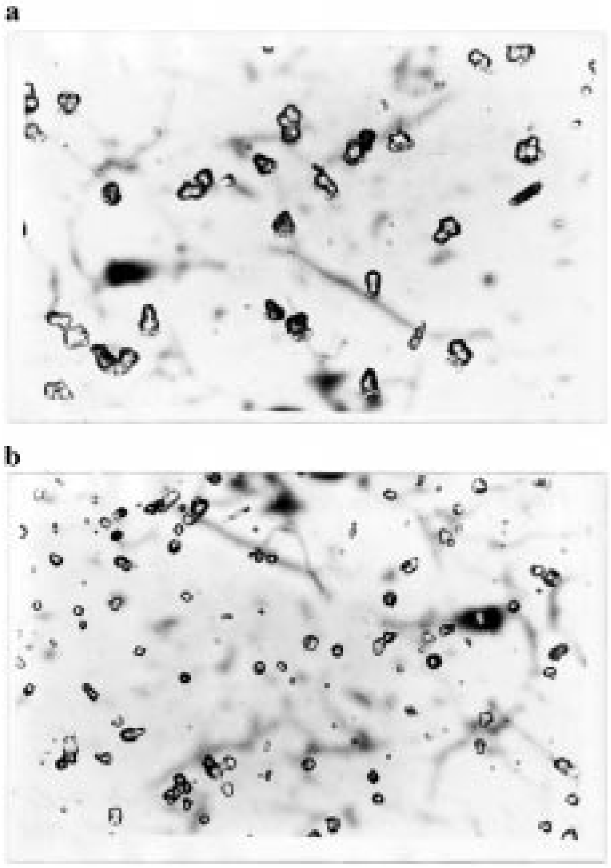

FIGURE 5. Influence of magnetic treatment on crystallization of calcium carbonate in the calcite form. Solution: 10 mg·equiv/L $NaHCO_3$ + 10 mg·equiv/L $CaCl_2$. (a) Control solution; (b) solution after the treatment (flow rate of 0.2 L/s). Magnification is 400×.

Reynold's numbers. We made a two-dimension model of Magnalawn 2000 in scale 2:1 (2D model) from organic glass, which allows visualization of hydraulic flow and the study of laminar flow zones and zones with vortex structures.

The flow was generated magnetohydrodynamically in a flat channel consisting of two high-quality copper conductors by constant current I and magnetic field $B \perp \mathbf{I}$. The magnetic field in the channel is created by strontium ferrite magnets on the top and the bottom of the channel; the field of the channel is 150 mT. The channel is filled with 2 N $CuSO_4$. The advantage of using both copper vitriol solution and copper electrodes is that we avoid passivation of electrodes and achieve high reproducibility of the results. The electric current is varied in the range from 0 to 20 A.

Visualization of the flow structure was realized by spraying aluminum powder or leucopodium (small plant seeds) on the surface and recording their tracks with a camera. Changing the speed of photoexposures and measuring the length of particle tracks allow us to determine local flow rates in the 2D model as a function of electric current $V = f(I)$. As an example, two kinds of flow structures in the 2D model are shown in Figure 4: (a) low inlet flow rate ($V = 0.2$ cm/s, $I = 0.1$ A) and (b) moderate rate ($V = 5$ cm/s, $I = 1$ A). The model permits the study of flow distribution in the apparatus, the structure of vortices, and the interactions between them. The strongest effects of magnetic treatment are found in the gaps between magnets and at magnet edges (zones 8 in Figure 2). In these areas there are high values and gradients of magnetic field. Flow rates are also high, on the order of the inlet rate. As shown in Figure 4b, liquid flow changes its direction near magnet edges almost at right angles, which results in flow instability, large pressure gradients, and separation of microvortices. Vortex structure changes when the flow rate increases, and the interaction of vortices starts to be observed in the central chamber. In the low-pressure central region of vortices, the concentration of free and molecular dissolved gases increases.

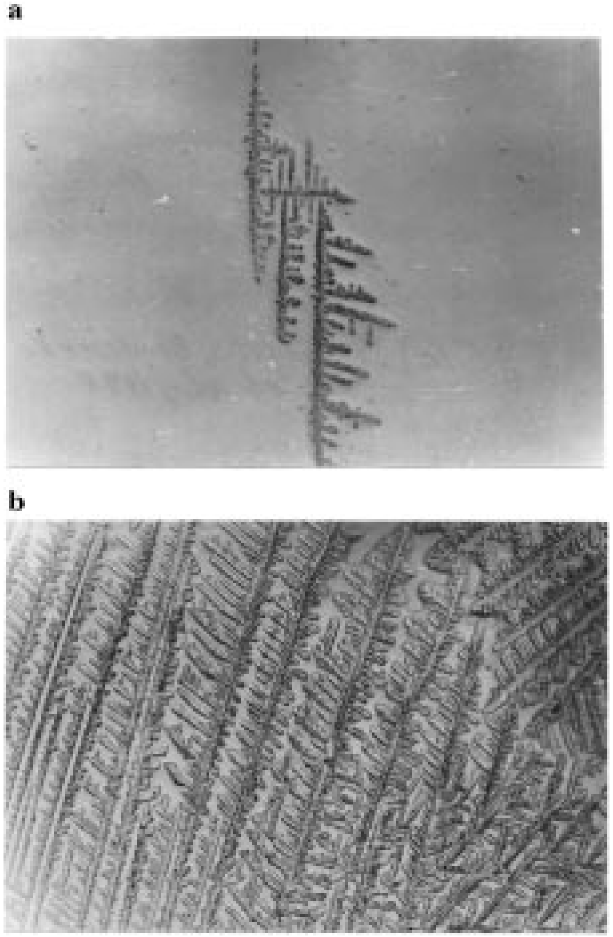

FIGURE 6. Influence of magnetic treatment on crystallization of calcium carbonate in the aragonite form. Solution: 10 mg·equiv/L NH_4HCO_3 + 10 mg·equiv/L $CaCl_2$. (a) control solution; (b) solution after the treatment (flow rate 0.2 of L/s). Magnification is 400×.

Experimental Section

Indication of Magnetic Water Treatment. In Figure 1a, kinetic curves of pH change in treated and nontreated solutions are shown. The rate of $CaCO_3$ crystallization is higher in the presence of a magnetic field. In the given example, $\alpha_1 = 49°$ and $\alpha_2 = 17°$ with and without a magnetic field, respectively, $(\alpha_1)/(\alpha_2) = 3.7 > 1$. A typical change of optical density before and after the treatment is shown in Figure 1b.

Figures 5−7 demonstrate seeds of calcium carbonate obtained after drying a drop of different bicarbonate solutions before (a) and after (b) treatments in the magnetic apparatus. The flow rate was 0.2 L/s.

Using the solution $NaHCO_3 + CaCl_2$ in the control sample (Figure 5a), anisotropic transparent crystals of irregular shape (closer to cubic) were observed. These crystals are calcite crystals (refraction index −1.56, birefringence −0.14) with an average size of 0.012−0.015 mm. After the water was treated in the magnetic apparatus, a significant increase in the amount of calcite crystals and a decrease of their size to 0.0006−0.0009 mm (Figure 5b) were observed.

Changing the chemical composition of the solution (in particular, replacement of $NaHCO_3$ by NH_4HCO_3) allowed

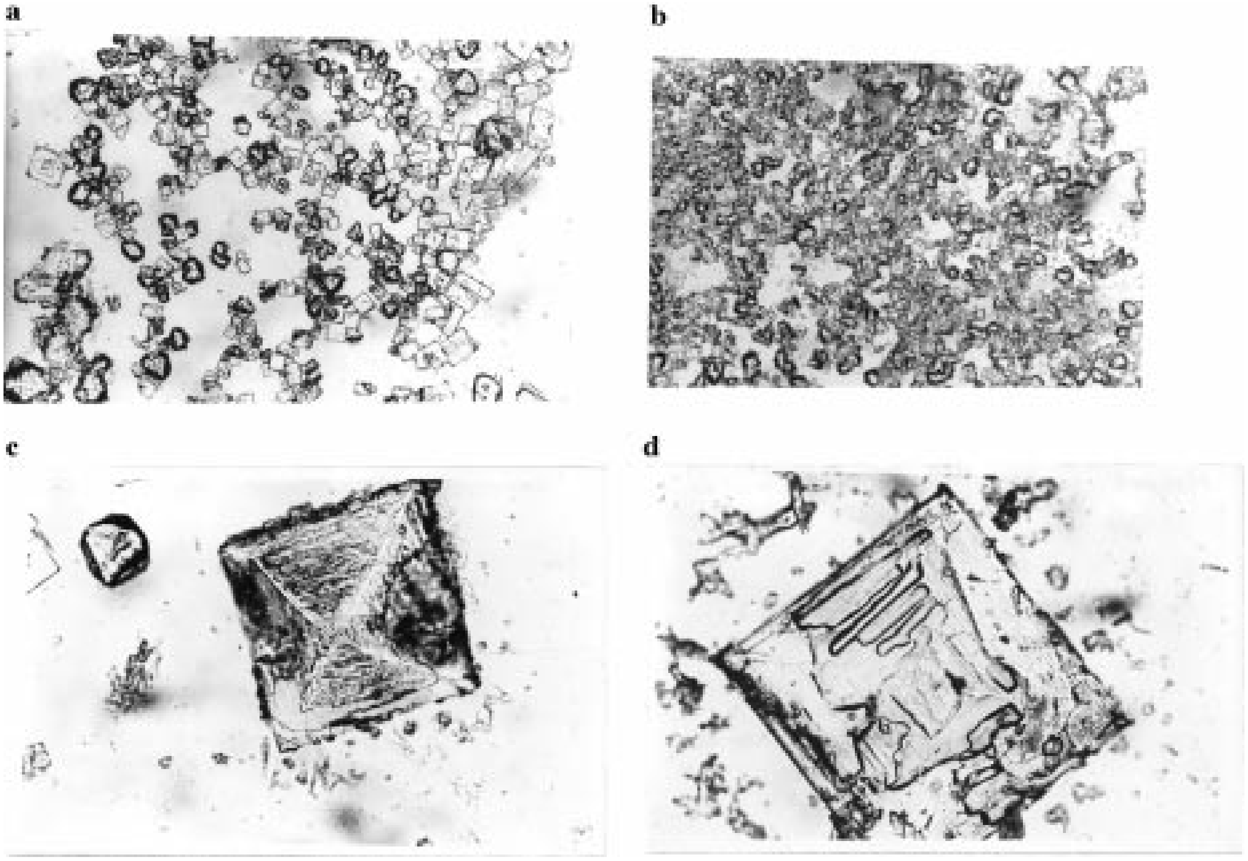

FIGURE 7. Influence of magnetic treatment on the extraction of (a) calcite and (c) halite from an ocean water. (b) Control solution; (d) solution after the treatment (flow rate of 0.2 L/s). Magnification is 400×.

us to obtain aragonite with a typical needle shape. Magnetic treatment changes the number and the size of aragonite crystals: in the control solution there are separate groups of crystals (Figure 6a), and there is uniform distribution of aragonite crystals in the treated solution (Figure 6b).

Investigating crystallization processes in natural waters, including ocean water, is more complicated; however, an apparent change of both shape and size of crystals can be detected. Figure 7, panels a and b, shows the change of calcite crystallization in ocean water as a result of magnetic treatment. In Figure 7, panels c and d, we show the change in a rhomboidal structure of halite crystals. One of the main advantages of the method is its visualization; however, it requires a long time to obtain information (a few hours) and special equipment.

Reclamation Effect. Laboratory experiments were performed on different saline soil samples as well as on a model bicarbonate solution with 2 mmol/L $CaCl_2$ and 2 mmol/L $NaHCO_3$ at pH 8.2. This solution composition is close to the composition of natural water in arid regions. We used magnetic systems similar to Magnalawn 2000 in laboratory experiments; typical flow rates were 1 m/s. Leaching was carried out in filtration columns with a diameter of 5.5 cm and 11 cm high. Water pressure was kept constant with the help of Mariott's vessels. Each leaching experiment was accompanied by a control experiment without a magnetic field; all experiments were repeated five times, and statistical averages and standard deviations of investigated values were calculated. The strongest leaching effect was found for soil samples with soda salinity and for those with chloride and sulfate salinity with some soda (total salinity 20−50%). Chlorine salt removal in treated water was increased by 30−40%, and filtration rate increased 1.5 times.

Field Experiments. We accumulated a considerable experience in the use of magnetic treatment for intensification of agricultural production. A series of experiments was performed on large areas up to 2 km^2 with magnetic apparatus of different designs and throughput from 36 to 360 m^3/h. Tests were conducted in Turkmenia, Armenia, Azerbaijan, and Uzbeckistan. The results of these tests show an acceleration of saline soil leaching that results in a decrease of water consumption up to 25%. Application of magnetic treatment is found to be the most efficient for soils with a high concentration of soda (*6*−*8*).

Studies of the influence of MWT on growth, development, and productivity of agricultural plants, conducted by Russian researchers (*6, 7, 9*), show an increase of yield by 15% together with simultaneous improvement of production quality. Experiments were conducted for 20 types of grain, fodder, vegetables, and melon-field crops on an area of 100 km^2. According to the data obtained from Russia, Romania, Bulgaria, Slovakia, Spain, and Israel (*6*−*13*), a decrease of the soil alkalinity, an increase in mobile forms of fertilizers, an increase in crop yields, and earlier vegetation periods can be achieved by MWT.

Discussion

Physical−chemical changes in magnetically treated water as well as laboratory and field experiments of the magnetic apparatus lead to the understanding of the reclamation effect:

(i) Degassing of water increases permeability in soil, which results in an appreciable increase of irrigation efficiency.

(ii) Increase in the amount of CO_2 and H^+ in alkaline soils is similar to the addition of fertilizers. In wet soil, CO_2 forms H_2CO_3, which converts insoluble carbonates into soluble bicarbonates. Bicarbonates exchange with Na of the cation exchange complex (CEC). As a result of the exchange reaction, Na is removed from CEC into the soil, which improves properties of alkaline soils and accelerates their leaching.

(iii) Acidification of soil moisture accelerates the transfer of phosphoric fertilizers into a more soluble form and becomes additional nutrition for plants. A direct introduction of CO_2 into irrigating water or nutrition solution (*14*) shows results similar to MWT: a more intensive root formation, an increase of yield by 10−15%, the transfer of phosphorus fertilizers into more soluble form, and a decrease in the risk of a secondary salinification of soil. Thus, the reclamation effect improves conditions of root layers due to (i) better permeability of irrigated water, (ii) leaching of superfluous salts, and (iii) better dissociation of mineral fertilizers.

Our analysis shows that the required parameters for an effective magnetic treatment of water are as follows: (i) concentration of hydrogenous ions in the water at pH >7.2 and (iii) carbonate hardness of the water is more than 50 mg/L. Irrigation with magnetically treated water is most effective for soils with high soda content.

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