

$$L = 0.1l \sqrt{\frac{\varepsilon\sigma}{\lambda_c} \cdot \frac{P}{S} \left(\frac{T_c}{100}\right)^3}; q_c = \lambda_c \frac{T_l - T_0}{l} S,$$

heat influx over the cable without taking account of heat exchange with its side surface for  $\lambda = \lambda_c = \text{const}$ , W;  $q$ , heat influx over the cable, W.

#### LITERATURE CITED

1. E. Kamke, Handbook on Ordinary Differential Equations, Akad. Verl.-Ges. Geest und Por-tig, Leipzig (1959).
2. P. L. Powell, H. M. Poder, and W. M. Rogers, J. Appl. Phys., 28, No. 11 (1957).
3. V. V. Senin, Inzh.-Fiz. Zh., 29, No. 6 (1975).

#### THEORY OF MAGNETIC WATER TREATMENT

V. A. Boichenko and L. G. Sapogin

UDC 663.631:538.24

A mechanism is proposed for magnetic water treatment which makes it possible to explain the known experimental facts. The polyextremal dependence of the treatment effects on the magnetic field strength and the flow velocity as well as the increases in viscosity, thermal conductivity, and the velocity of ultrasound are explained on its basis; specific changes in the IR spectrum of treated water are predicted.

Much time has passed since the discovery of the effect of magnetic water treatment by Vermeiren [1]. Having begun with a decrease in the formation of scale in steam boilers, the magnetic treatment of water and aqueous systems has found wide application in recent years in the most varied fields of practical human activity, since the overwhelming majority of energetic and industrial processes are connected with water. Magnetic treatment is presently used in combating precipitation, in the production of concrete, and in the enrichment of useful minerals, as well as for the intensification of water filtration and purification processes, etc. [2-5].

The numerous studies under laboratory and industrial conditions in recent decades have reliably demonstrated the alteration in the physicochemical processes taking place in water following magnetic treatment: acceleration of coagulation-flocculation of solid particles suspended in the water; the formation of salt crystals during evaporation not on the walls but in the volume; a change in the wetting of solid surfaces, acceleration and intensification of adsorption, etc. [1, 3, 6]. The characteristic features of magnetic treatment should be specially emphasized: a) the necessity of movement of the liquid in the magnetic field; b) the polyextremal dependence of the effects on the water velocity  $\vec{v}$  and the magnetic field strength  $\vec{H}$ ; c) the effects obtained are preserved for from several hours to a day.

The main difficulties in understanding the physical bases of magnetic treatment arise because of the smallness of the energy imparted to the water and the enigmatic nature of the mechanism of the "memory" of the water. The energy expended on the treatment is really very small: It is the energy for overcoming the additional resistance in the gap containing the magnetic field. Therefore, the energy states of the water before and after magnetic treatment are quite close but separated by a high energy barrier, the value of which, on the basis of the relaxation time of tens of hours, must be no less than 50 kT.

A possible mechanism for magnetic treatment which permits an explanation of the majority of the known experimental data is discussed below. We consider pure water passing through a transverse magnetic field  $\vec{H}$  with a velocity  $\vec{v}$ . The trajectory of motion of the hydroxyl ( $\text{OH}^-$ )

---

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 33, No. 2, pp. 350-355, August, 1977. Original article submitted August 13, 1976.

*This material is protected by copyright registered in the name of Plenum Publishing Corporation, 227 West 17th Street, New York, N. Y. 10011. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, microfilming, recording or otherwise, without written permission of the publisher. A copy of this article is available from the publisher for \$7.50.*

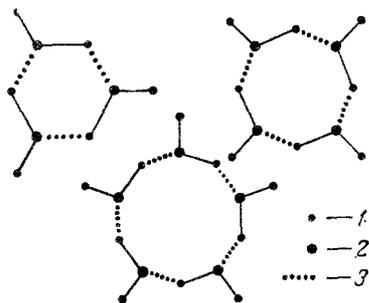


Fig. 1. Scheme of formation of the simplest associations: 1) hydrogen; 2) oxygen; 3) hydrogen bond.

and hydronium ( $H_3O^+$ ) ions which are always present in water consists of a cycloid. This can be resolved into translational motion and rotational motion with a radius proportional to  $mv/eH$ . Ions with the same  $mv/e$  have the same radii and direction of rotation. Since water molecules have a large dipole moment, the  $OH^-$  and  $H_3O^+$  ions, moving from the same point at which they were formed by the dissociation of a dimer and rotating in the same plane but in opposite directions, will orient the nearest water molecules as if "threading them along the arc of a cycloid." As a result, the molecules lying along the "hydroxyl" and "hydronium" arcs are combined into plane annular associations through collective hydrogen bonds. An oxygen atom has four hybrid electron orbitals, two of which are isolated. Each collective hydrogen bond includes one isolated and one valence orbital; thus, a water molecule can participate in two such bonds of an annular association [7]. The simplest such associations are shown in Fig. 1. For their appearance the condition of cyclization or the optimum treatment conditions must be satisfied:  $n$  units of water molecules must be arranged along the arc length of the cycloid. The arc length of the cycloid is proportional to  $v/H$ , so that the treatment effects have a polyextremal type of dependence on the magnetic field strength and the flow velocity.

Let us make a rough estimate of the concentration of annular associations which form in a single treatment.

The process of formation of hydroxyl and hydronium ions is dynamic; i.e., ionization and recombination processes take place simultaneously, so that their average concentration equals about  $10^{-7}$  [9]. According to the data of [14], the formation of  $H_3O^+$  and  $OH^-$  takes place mainly from dimers. The time of formation of one annular association is on the order of  $r/v$  while  $L/r \sim 10^7$  acts of cyclization occur in the time of passage through the pole pieces of length  $L$ . Since the area of the cross section in which the formation of annular associations takes place is about 10-20 times less than the pipe cross section, we obtain a value on the order of several percent for the concentration of annular associations.

The effects of magnetic water treatment display stability for several hours, a fact which is remarkable and not explainable from the standpoint of quasicrystalline models of water. In fact, with the variation in the arrangement of the molecules, the period of recovery of the properties should be on the same order as the lifetime of a molecule in a structural unit. On the basis of Samoilov's two-structure model of water [8], according to which some of the molecules are in a framework analogous to the crystal lattice of ice and some fill the cavities of the framework, this time equals  $10^{-9}$  sec, which is far less than the experimentally established time of recovery of the properties. The energy of the hydrogen bond, to which the annular association owes its existence, equals 4.5 kcal/mole. It would seem that the strength of a ring would also equal 4.5 kcal/mole and it would easily break up. But from the point of view of quantum mechanics this is not so for such an annular structure. We have a similar situation with benzene, whose ring is bound far more strongly than would be assumed for an ordinary system of "unsaturated double bonds." An annular association can exist in states  $|1\rangle$  and  $|2\rangle$  (Fig. 2). The probability amplitudes of these states are equal to  $1/\sqrt{2}$  and the energies are the same; therefore an association must be considered as a system with two states, and by analogy with the case of benzene the energy of a chemical bond of the ring will approximately equal the half-sum of the energy of an O-H bond and of an O...H hydrogen bond, i.e., 58 kcal/mole [9]. Analogous O...H bonds, for which the ordinary criteria of hydrogen bonds are no longer applicable, were predicted by the author of [10].

All the ions which are in solution are surrounded by shells of water molecules. Samoilov [8] introduced the concept of the positive and negative hydration of ions: In the first case the ions are stably bound with the closest water molecules, while in the second case with negative hydration the water molecules near the ions become more mobile than in pure

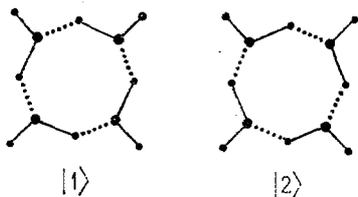


Fig. 2. States of an annular association.

water. The hydration of the ions determines their behavior in solution to a large extent: It affects the velocity of migration of the ions and the conditions of their mutual approach and adsorption at phase interfaces. The larger and more stable such a hydrate "fur coat" is, the lower is the mobility of the ions and the harder it is for them to approach each other, be adsorbed, and react. Magnetic treatment alters the hydration of the ions [2, 11]. Let us consider the coagulation process, since this is the clearest effect of treatment. With the formation of annular associations from water-molecule dipoles the total amount of free water decreases, which decreases the hydration of the surfaces of particles and their electrokinetic potentials and leads to the coagulation of hydrophilic particles. The coagulation process proceeds differently for hydrophobic particles. In water there is always a small amount of coagulating ions, which do not cause coagulation since the polar water molecules form a "fur coat" around an ion owing to the orientation interaction and prevent it from approaching the micelle. After treatment the conditions of formation of the "fur coat" deteriorate and the coagulating ions approach the micelle and participate in ion-exchange sorption with its outer double-layer coating, causing coagulation.

Ions with outer hydrate shells become mass crystallization centers, which leads not only to significant acceleration of volumetric precipitation in the form of a slurry but also to a change in the size and shape of the particles [12]. Volumetric precipitation reduces the precipitation on the walls, the competing process of dissolution begins to predominate, and old deposits are dissolved.

Let us determine the radius of the generating circle of the cycloid for the case of laminar flow in a round pipe of radius  $R$ . For this we consider the steady motion of a liquid dielectric with a constant velocity  $\vec{v}$  over the cross section in a uniform magnetic field  $\vec{H}$ .

A constant electric field  $\vec{E}$  with a potential  $\varphi$  develops in the surrounding space and within the dielectric. Since there are no free charges, the potential of the field outside the dielectric satisfies the Laplace equation

$$\Delta\varphi_e = 0. \quad (1)$$

Since the magnetic susceptibility of water is equal to unity, the magnetic field in the dielectric is also equal to  $\vec{H}$ . The induction  $\vec{D}$  and the electric field strength  $\vec{E}$  in a moving dielectric are connected by the equation [13]

$$\vec{D} = \epsilon\vec{E} + \frac{\epsilon - 1}{c} [\vec{v}\vec{H}]. \quad (2)$$

But  $\text{div } \vec{D} = 0$ , and consequently for the potential  $\varphi_i$  we obtain from Eq. (2)

$$\Delta\varphi_i = \frac{\epsilon - 1}{\epsilon c} \text{div } [\vec{v}\vec{H}]. \quad (3)$$

From Eqs. (1) and (3) for the potentials and the boundary conditions we find that the electric field in the pipe is uniform and equal to

$$\vec{E} = -\frac{\epsilon - 1}{\epsilon + 1} \frac{1}{c} [\vec{v}\vec{H}].$$

An ion with a mass  $m$  and a charge  $e$  in such crossed fields  $\vec{H}$  and  $\vec{E}$  (Fig. 3) moves relative to the dielectric along a cycloid with a radius of the generating circle  $r = [2/(\epsilon + 1)] \cdot (v/\omega)$ :

$$x = r(\omega t - \sin \omega t), \quad y = r(1 - \cos \omega t).$$

In this case the formation of annular associations is possible in the entire volume. For the usual laboratory values of  $v = 10$  cm/sec and  $H = 1000$  Oe the radius is  $r \sim 10 \text{ \AA}$ . If in solving the problem one allows for a parabolic velocity distribution over the pipe cross section then the electric field in the dielectric will be nonuniform, which leads to a decrease in the radius by two to four times and to a contraction of the volume in which the

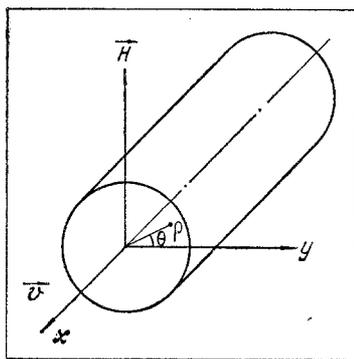


Fig. 3. Motion of an ion in crossed magnetic and electric fields.

formation of associations is possible, since the cyclicity condition is satisfied only in an elliptical layer of  $\rho^2 = R^2/(3 - 2\cos^2\theta)$ . This is just what explains the weak effect of magnetic treatment of pure water even under the optimum conditions. The addition of dissolved salts increases the conductivity of the solution, which leads to equalization of the velocity profile (the Hartmann effect [13]) and to strengthening of the treatment effects. Similar results are obtained for laminar flow through elliptical and rectangular pipes.

Magnetic treatment of pure water should increase the velocity of ultrasound and the thermal conductivity. The pattern of propagation can be represented as follows: The velocity of transmission of acoustical or thermal energy by a molecule is very high, since the molecular vibrations perform the "instant transmission" of any imparted energy to all parts of the molecule. As for the space between molecules, it forms a barrier to the transmission of energy. Since the number of such barriers decreases after magnetic treatment, the velocity of ultrasound and the thermal conductivity increase.

The annular associations which form are extremely passive, since they are nonpolar, neutral, and of low mobility because of the large size and mass. Therefore, the viscosity of the treated water increases and the dielectric permittivity and chemical activity decreases. In addition, the appearance of annular associations facilitates the reorganization of the water into an ordered ice structure (treated water freezes considerably faster) [6].

In the case when dissociating salts are present in the water the situation is complicated, since both the processes of formation of annular associations and of destruction of hydrate shells of ions proceed in parallel. Therefore, the change in the properties of the solution after treatment should depend on the concentration of the salts, their hydration, and the temperature of the solution, and it must be determined in each concrete case.

For a direct test of the proposed model one must take the spectrum of treated water or its vapor in the far-IR region ([2] p. 18). The following changes in the IR spectrum should be observed: in the region of stretching vibrations a shift into the high-frequency region and an increase in absorption; absorption bands appear corresponding to stretching, deformation, and stretching-deformation vibrations of a ring ( $1200-1600\text{ cm}^{-1}$ ); a vibrational spectrum of the rings develops at frequencies of 106, 183, 237, 280, and  $318\text{ cm}^{-1}$  (vibrations at the second and third frequencies can be suppressed owing to redistribution of the energy); absorption in the region of  $5-20\text{ cm}^{-1}$ , the rotational spectrum of a ring, grows sharply. The authors will present a detailed calculation of the IR spectra in another report.

For the successful practical application of magnetic treatment one needs reliable methods of indicating the changes in properties after treatment in addition to clear knowledge of its physical bases. Besides the natural requirement of high sensitivity and accuracy, the indication process must be operative. The existing control methods (determination of the magnetic susceptibility, the rate of clarification, or the precipitation of salts and various methods of crystal chemistry) are very laborious, not very accurate, and, chiefly, not operative, which eliminates the possibility of the rapid tuning of the magnetizing device to the optimum operating conditions. The formation of annular associations makes possible the solution of this problem.

In annular associations the hydrogen atoms not making up the ring can lie on either one side or the other relative to the plane of the ring. The possibility of flipping the hydrogen atoms from one position to the other (upon which the electric dipole moment reverses direction) leads to splitting of the energy levels into two closely spaced levels and to the resonance absorption of the alternating electric field having a frequency equal to the energy

difference of these levels. The intensity of the absorption will be proportional to the number of annular associations formed. An estimate shows that the resonance frequency lies in the microwave range. The creation of an instrument for monitoring the efficiency of magnetic treatment on this principle is possible.

#### NOTATION

$\vec{v}$ , flow velocity;  $\vec{H}$ , magnetic field strength;  $\varphi$ ,  $\vec{E}$ ,  $\vec{D}$ , potential, strength, and induction of electric field, respectively;  $\epsilon$ , permittivity;  $R$ , pipe radius;  $r$ , radius of generating circle;  $k$ , Boltzmann's constant;  $t$ , time;  $\rho$ ,  $\theta$ , polar coordinates;  $c$ , velocity of light;  $m$ , ion mass;  $e$ , ion charge;  $\omega = eH/mc$ .

#### LITERATURE CITED

1. T. Vermeiren, *Corros. Technol.*, 5, 215 (1958).
2. In: *Problems of the Theory and Practice of Magnetic Treatment of Water and Aqueous Systems* [in Russian], Novochoerkassk (1975).
3. V. I. Klassen, *Water and a Magnet* [in Russian], Nauka, Moscow (1973).
4. In: *Materials of Third All-Union Symposium "Effect of magnetic fields on biological objects"* [in Russian], Kaliningrad (1975).
5. G. R. Solov'eva, *Med. Tekh.*, No. 3 (1970).
6. V. I. Klassen (editor), in: *Problems of the Theory and Practice of Magnetic Treatment of Water and Aqueous Systems* [in Russian], Moscow (1971).
7. M. Ageno, *Proc. Nat. Acad. Sci. USA*, 57, 567 (1967).
8. O. Ya. Samoïlov, *Structure of Aqueous Solutions of Electrolytes and the Hydration of Ions* [in Russian], *Izd. Akad. Nauk SSSR*, Moscow (1957).
9. A. N. Kharin, N. A. Kataeva, and L. T. Kharina, *A Course in Chemistry* [in Russian], Taganrog (1971).
10. E. R. Lippincott, *Science*, 164, 1482 (1969).
11. V. S. Dukhanin, *Author's Abstract of Candidate's Dissertation*, Moscow (1973).
12. N. I. Eliseev, N. V. Kirbitova, and V. I. Klassen, *Dokl. Akad. Nauk SSSR*, 209, 415 (1973).
13. L. D. Landau and E. M. Lifshits, *Electrodynamics of Continuous Media*, Addison-Wesley (1960).
14. F. Franks (editor), *Water. A Comprehensive Treatise*, Vols. 1-3, Plenum, New York-London (1972-1974).