MAGNETIC TREATMENT OF WATER — A THEORETICAL QUANTUM MODEL

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Abstract It is claimed that magnetic treatment of water can prevent formation of hard calcite scale on the walls of hot–water containers, and devices based on this phenomenon are already commercially for industrial use. The present paper puts forward and examines a theoretical model with a view to explain why the low–energy magnetic field of a permanent magnet is effective at all and why the phenomenon persists for some time after the treatment (memory effect).

INTRODUCTION

It has been repeatedly observed that when tap water passes through a magnetic field generated by an array of up to ten permanent magnets arranged in an alternating sequence of poles (i.e. S–N, N–S, S–N...) at the centre of the steel pipes conveying the water, hard scale deposition (calcium carbonate in the form of calcite or aragonite) on the walls of boilers, heat exchangers, cooling towers, irrigation piping systems etc. is reduced and may even be completely prevented [1]. Moreover, accumulated old scale dissolves when the magnetically treated water is used.

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Under ordinary circumstances, the scale forms through heterogeneous nucleation of CaCO_3 on the substrate surface. By contrast, when magnetically treated is used, nucleation takes place homogeneously in the body of the water, and small disc-shaped crystallites (about 50 μm in diameter and 1 μm thick) are formed. Initially suspended, these crystallites gradually settle as a sediment at the bottom of the container.

An unusual aspect was the controversy that ensued between industrial and scientific circles as a consequence of the fact that, while the advantages of the phenomenon were demonstrated at plant level (in about 70% of reported cases [1, 2]), attempts to reproduce it on laboratory scale inexplicably used to fail [4, 5], until recently. Now this drawback has also been remedied [3, 6, 7], and the way is open for experiments that would help explain both the phenomenon itself and its attendant memory effect (see *Experimental Basis*, point 6).

Several approaches were suggested [8 to 14], mostly based on physico-chemical background. While the phenomenon is definitely too complex for detailed analysis, the proposed model could be helpful in devising experiments and predicting destructive perturbations that may have been responsible for the 30% failures mentioned above.

EXPERIMENTAL BASIS OF THE MODEL

Below a brief summary of the basic facts regarding the magnetically treated water (MTW), serving as a framework for working hypothesis, is given.

1. MTW prevents formation of hard scale, and descales equipment downstream of the magnetic units
2. Distilled water (or melt water) does not exhibit the phenomenon in question [15]
3. The flow is an essential prerequisite; in fact, the phenomenon was proved [3, 8] to depend both on flow velocity and on the field intensity

4. An alternating arrangement of the poles improves the efficiency of the treatment [3]
5. An optimum transit time between two poles was found [3, 15]
6. A remarkable feature of the phenomenon is its tendency to persist ("memory effect") up to six hours in the field [2], and up to two days in laboratory, even in motionless water, let alone under a dynamic regime [3]
7. The energy involved is very low [2, 3]
8. MTW at 60 – 80° C has a higher nucleation efficiency than at room temperature; still higher temperatures are detrimental [2, 8].

ANALYSIS

1. The phenomenon originates with the dissolved ions of the treated water, which form complexes* (the so-called "clathrates") sufficiently stable to compete with the deposited scale.
2. The magnet generates a force ($\mathbf{F} = q\mathbf{v} \times \mathbf{B}$) which jolts the water molecules surrounding the ion and permits the formation of the clathrate, which serves as a seed for homogeneous nucleation.
3. We assume that a quantum eigenstate of the clathrate which remains "frozen" after the magnetic treatment is over, in analogy to the well-known ortho–para conversion in hydrogen [16]. This can explain why low energies suffice, and accounts for the memory effect as well.

* Clathrates represent $(\text{H}_2\text{O})_n$ groups with $20 < n < 200$, preferably centered on dissolved foreign ions such as Ca^{2+} . Under ordinary circumstances, clathrate molecules undergo continual exchange with the "free" water molecules (designated $\text{H}'_2\text{O}$) of the aqueous solution:

4. The higher the temperature, the more high-energy molecules are available for decomposition of the frozen clathrate, but once the embryo has reached a critical size, it can withstand their collisions. Thus a higher temperature (with attendant higher diffusion rate) can improve the efficiency. In these circumstances we expect the efficiency of the process to be a function of temperature, of the dynamic regime (which accelerates the crystalline growth) and of the ion concentration.
5. The natural candidate for formation of a "frozen" quantum state are the nuclear spins of the hydrogen atoms.
6. Thus, the main object of the model is correlation of the vibration, rotation and magnetic levels of the clathrate so as to prevent its decomposition. The underlying principle is that of Woodward and Hoffman [17] (whereby the symmetry must be preserved throughout the reaction) combined with the idea of Atkins and Lambert [18] who applied this principle in explaining how the presence of an external magnetic field influences the direction of the reaction.

QUANTUM-MECHANICAL MODEL

The relevant model consisting of two stages is as follows:

1st Stage

In an ordinary clathrate, the $n\text{H}_2\text{O}$ molecules attached to the Ca^{2+} ion are unrelated to each other. Accordingly, a generalized nuclear wave function can be established:

$$\Phi_N(n\text{H}_2\text{O}) = \prod_{i=1}^n \phi_{vib}^{v_i}(\alpha_i) \cdot \phi_{rot}^{J_i}(\beta_i) \cdot \phi_{spin}^{S_i}(\gamma_i) \equiv \prod_{i=1}^n \phi_N(i) \quad (2)$$

where ϕ_{vib} , ϕ_{rot} , ϕ_{spin} are, respectively, the vibrational, rotational and total nuclear spin wave functions of the H_2O molecule, v_i – the vibration level, J_i – the

rotation level, s_i — the total molecular nuclear spin, and $\alpha_i, \beta_i, \gamma_i$ are the respective phase differences of i in the three functions, relative to a reference phase (see below). $\phi_N(i)$ is the eigen nuclear wave function of the hydrogens in $\text{Ca}^{2+} \cdot \text{H}_2\text{O}(i)$. We need to assume only the hydrogens' degrees of freedom in $\phi_N(i)$, since the oxygen of $\text{H}_2\text{O}(i)$ is bound to the Ca^{2+} (see below). $\phi_N(i)$ is antisymmetric relative to the paired hydrogens' exchange (which are fermions); by contrast Φ_N is not an eigenfunction, hence not antisymmetric for the hydrogens' exchange in the overall clathrate. It is believed, however, that a stationary state for the latter is the key to the magnetohydrodynamic (MHD) effect.

Formation of such a stationary state requires correlated changes in the vibrational, rotational and spin wave functions. First let us assume the following equilibrium:

where the designation $\text{Ca}^{2+}(\text{H}_2\text{O})_n$ implies that a normal mode has been created for the vibrations of the overall clathrate (see Fig. 1).

Fig. 1. The formation of a normal mode

At this stage, the $3N-3$ vibrational and rotational degrees of freedom of the individual molecules (where N is the total number of atoms) are transformed into

$3N-6$ vibrational and 3 rotational degrees of freedom of the overall clathrate. In practice, this number is considerably reduced, as it should be recalled prior to the formation of $(\text{H}_2\text{O})_n$ each water molecule had in practice only one rotational degree of freedom left, its oxygen being bound to Ca^{2+} (see Fig. 2). Actually, the rotational behaviour of the H_2O molecule closely resembles that of H_2 (because it has the same complex ions).

Fig. 2. Rotation of $\text{H}_2\text{O} \cdot \text{Ca}^{2+}$ behaving as H_2

We assume in Eq. 3 that $\Delta E \cong 0$. However, there is a sharp decrease in entropy, $\Delta S < 0$. Accordingly, the resulting K can generally be expected to be very small ($K \ll 1$), so that under ordinary circumstances the contribution of the process represented by this equation is negligible. However, even when K is not small, the stability of the clathrate is ruled out by quantum considerations, as $(\text{H}_2\text{O})_n$ is not in the steady state. (Creation of a spin eigenstate is highly unlikely; the probability of the spins of all hydrogens being co-directional and in-phase is practically zero).

2nd Stage

When an external magnetic field is imposed on the water, a quantum-mechanical splitting effect of ortho-para hydrogens is precluded by the equilibrium of

dissociation: $\text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^-$. Insofar as the water molecules are exchanged with the solution, no eigenstates of the total spin can be obtained. However, we claim that in the presence of Ca^{2+} ions, a small percentage of the clathrates can form a stable eigenstate which no longer exchanges any water molecules with the solution. We shall develop this approach step by step.

In a single water molecule the total nuclear function must be antisymmetric:

$$\phi_N(i) = \phi_{rot}^{J_i}(i) \cdot \phi_{vib}^{v_i}(i) \cdot \phi_{spin}^{S_i}(i). \quad (4)$$

The spins of the hydrogens may then be either in a singlet or in a triplet state (see Fig. 3). In the first case, the total spin vector is zero throughout, since the spins of the hydrogens are totally opposed to each other; in the other case, there are three possibilities for the total Z component: at $+1$; at zero, with the total spin rotating in the xy plane; and at -1 . In both cases, there must be coordination between the two spins as they move together.

Fig. 3. The total spin states of the two nuclei

Since $\phi_N(i)$ has to be antisymmetric, any change in the spin state is correlated with those in ϕ_{vib} and ϕ_{rot} . In principle, all these changes occur. There are symmetric and antisymmetric vibrations of the water (see Fig 4).

Fig. 4. The vibrational normal modes of H_2O

However, the energy in the symmetrical bending ν_2 is much lower and is assumed to dominate the water molecules. The oxygen side being bound to Ca^{2+} ion, the molecule rotates mainly as H_2 and the symmetry behaves as $(-1)^J$ (where J is the quantum number of the rotation levels)^{*}. Thus, transitions between symmetry and antisymmetry in ϕ_{rot} calls mainly for corresponding transitions between the singlet and triplet states of the spin, which in turn require nonhomogeneous magnetic interaction in the Hamiltonian.

Following Atkins and Lambert [18], we propose the following mechanisms:

Mechanism (a)

The nonhomogeneous field has to ask differently on each spin and break the correlation, so that each spin can rotate or "flip" independently of the other. This is made possible by the presence of strong paramagnetic ions which induce a local magnetic field, or alternatively, if the two hydrogens have different " a " constant, as may happen in two isotopes. Another possibility is that protons are in dissimilar chemical environments, where electron densities about the nuclei differ. In our case, these local differences can result from antisymmetric vibrations. in these

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There are very small energy differences between the J levels, which are readily provided by the kinetic interactions in the solution.

circumstances, a different chemical shift develops, and an external field B can induce the exchange.

The interaction operator H is:

$$H = a_{H_1} \frac{\mu_p}{\hbar} B I_z^1 + a_{H_2} \frac{\mu_p}{\hbar} B I_z^2 \quad (5)$$

where μ_p is the Bohr magneton for proton, and I_z^1 and I_z^2 are the nuclear spin components of hydrogens 1 and 2, along the Z -direction.

H can be resolved into two components: one symmetrical and the other antisymmetrical, of which only the latter promotes the S - T transition (for a detailed analysis, see [18]). This antisymmetrical component is proportional to $(a_{H_1} - a_{H_2})B$ and thus depends linearly on the magnetic field intensity and requires different " a " constants, permanent or transient.

When the external field is applied, the degeneracy of T splits into three levels with only T_0 at the energy level of S , so that only $S \rightarrow T_0$ is possible via different Larmor precession frequencies caused by the different local fields [18]. Thus, individual molecules may be in S or T_0 state. The latter molecules in the T_0 state may in turn populate $T_{\pm 1}$ as well, via "flip-flopping" of the spins [18]. As long as we deal with an individual molecule, regular dissociation of H_2O still takes place, and recombination forms molecules with all possible spin states.

So far, the transition in a single H_2O molecule has been analyzed. A detailed treatment is required in order to apply this mechanism to the S - T transition in the overall clathrate.

Mechanism (b)

The clathrate is formed of a few water molecules (around Ca^{2+}), each of which is in the S or T state. Without the external magnetic field, there can be no coordination between the S or the T states of different water molecules, hence they cannot be correlated and induced to form part of the S or the T state of the overall clathrate

(which includes all hydrogens of all then n water molecules). Under such a field, however, the correlation develops immediately between all spins, which are now co-directional with or counter-directional to the field, although the spins of different molecules are not in phase yet.

The Hamiltonian whose nuclear magnetic component includes only interactions between the hydrogens and the field would yield an eigenstate even without re-phasing. When the interaction between the hydrogens themselves is included, only spins in phase can form an eigenstate. The re-phasing requires a perturbation to cause different electron densities, and thus different Larmor precession frequencies in different hydrogens. Since we assumed only very few molecules to be in antisymmetric vibration, we cannot count on these vibrations to "provide" the necessary nonhomogeneity in the electron density. However, the hydromagnetic force (HMF) exerted by the magnet on the moving ions jolts the molecules and causes a temporary inhomogeneity, following which different spins rotate at different velocities ($\Delta\omega$), and re-phasing sets in over the time span of the order of $\frac{\pi}{\Delta\omega}$ [18].

By the above mechanism the clathrates develop an **S** or a **T** eigenstate (**S** signifies that all H_2O molecules of the clathrate are in the S state and in phase with each other; **T** signifies that at least one of the molecules is in the T state). The ratio between the states is governed by statistical considerations, namely by the probability of one molecule out of n being in the T state (see Fig. 5).

The process was described as consisting of two stages, with a normal mode formed first and an eigen spin state afterwards. In practice, proper perturbation can induce these changes simultaneously. This perturbation is caused by the force acting on the ions moving through the magnetic field. The field thus has the following two effects:

- (1) The spins are co-directional
- (2) "Impingements" on the clathrate cause strong vibrations and enhance formation of normal modes, permitting re-phasing according to Mechanism (b).

FIGURE 6 Formation of the T state

Let us assume that clathrates of both **S** and **T** eigenstates were actually formed. Our main hypothesis is that without the field, a clathrate in the **T** state cannot disintegrate unless there are very strong, destructive collisions. If we postulate disintegration with no perturbation after the process has started, we actually require that the symmetry be conserved throughout the process. This kind of concept served as key principle in the classical work of Woodward and Hoffman [17], and recently also Atkins and Lambert [18] in their analysis of reactions under a magnetic field. The conditions for disintegration of a clathrate in the **S** or the **T** state is therefore:

which means that at the end of the process the wave function can be resolved into a set of individual wave-functions of the H_2O molecules. The latter are all bound to the ion, but the vibrations and rotations of their hydrogens are no longer those of the clathrate. At the end of the disintegration each $\phi_N(i)$ must be antisymmetric by itself with respect to the vibrations between the hydrogens, their rotations, and, of course, to the *S* or to the *T* state of nuclear spin functions (see Figs. 3 and 4). What is needed is that the only reactants to disintegrate be those that can continuously lead to the product, subject to the antisymmetric requirements.

At this point, a detailed analysis of possible symmetries is in order. The discussion can be simplified by resorting to the following assumptions:

- a. When the clathrate has been finally converted into an aggregate of bound water molecules, the overall complex continues its movement with the same angular momentum as before, but irrespective of the eigenstate of each water molecule, i.e. there is not transition during the disintegration of the complex, from the overall angular momentum to that of individual molecules.
- b. When the clathrate is in the **S** state, all molecules after disintegration are also in an *S* state. When a clathrate in the **T** state disintegrates, one molecule is also in a *T* state, but all others in an *S* state.

- c. When the clathrate is in the normal vibrational mode, there is on independent motion of individual molecules; rather, motions are interrelated so that the centre of mass remains undisplaced. In (a) we assumed that no angular momentum is transferred from the clathrate to the water molecules. Now we add an assumption that after disintegration there are no single exceptional molecules but that, if one molecule undergoes clockwise antisymmetrical rotation, another molecule in appropriate position within the clathrate undergoes a counter-clockwise rotation. Similarly, both molecules could attain symmetrical rotations. Included in this assumption is a model for the first layer of water molecules, showing it to be composed of an even number of water molecules in a symmetrical structure in which for each such molecule there is another of inverse coordinates.
- d. Arguments similar to those used in (a) and (c) lead to a conclusion that the two proper water molecules would have the same vibration symmetry at the end of disintegration. It should be noted that antisymmetrical vibration of a water molecule causes the complex to rotate. The only way to avoid this (since we assumed that no rotation of the complex would be caused by individual vibrations and that rotations at the end of disintegration, i.e. the total inner angular momentum, is zero) is by having a counter water molecule with the same antisymmetrical vibration, like a pair of "twins" shown in Fig. 6. In fact, the symmetry is constrained not only between the "twin" molecules, but also between J and v . for our analysis, the first constraint suffices, and we mention the second only for the sake of completeness of the picture.

The possible states of a clathrate and its ability to disintegrate into products must be analyzed in the light of the above assumptions, and with regard to the requirements of antisymmetry. To this end, we introduce the following notation:

	Vibration		Rotation		Spin	
	Anti-symmetric	Symmetric	Anti-symmetric	Symmetric	Singlet	Triplet
Clathrate	A_v	S_v	A_r	S_r	S	T
Single molecule	a_v	s_v	a_r	s_r	S	T

Fig. 6. A pair of "twin" water molecules.

The ability of a clathrate in a **T** state to disintegrate can be assessed by tracking the quantum states of two similar H_2O molecules, the first (marked 1) attaining *T*-spin (with two hydrogen spins parallel), and the second (marked 2) *S*-spin — both with the same rotation and vibration symmetries following the conditions (c) and (d) above. There are only two possibilities for starting with an antisymmetrical state of a **T** clathrate: (**T**, A_r , S_v) and (**T**, S_r , A_v), which in turn yield the following four alternatives:

$$\left. \begin{array}{l} (\mathbf{T}, A_r, S_v) \\ (\mathbf{T}, S_r, A_v) \end{array} \right\} \Rightarrow \left\{ \begin{array}{l} \text{(I)} \quad (T_1, S_{r_1}, S_{v_1}) \text{ and } (S_2, S_{r_2}, S_{v_2}) \\ \text{(II)} \quad (T_1, a_{r_1}, S_{v_1}) \text{ and } (S_2, a_{r_2}, S_{v_2}) \\ \text{(III)} \quad (T_1, S_{r_1}, a_{v_1}) \text{ and } (S_2, S_{r_2}, a_{v_2}) \\ \text{(IV)} \quad (T_1, a_{r_1}, a_{v_1}) \text{ and } (S_2, a_{r_2}, a_{v_2}). \end{array} \right. \quad (7)$$

Explanation

The same rotation and vibration symmetries in both molecules follow conditions (c) and (d). Only one molecule can attain *T*-spin, while all the others should be in *S*-spin, in accordance with condition (b). It thus becomes clear that the disintegration described above is actually impossible. For example, in cases (I) and (IV) molecule 1 is in a symmetrical state, which is not permitted by the Pauli

principle. The same applies to molecule 2 in cases (II) and (III), namely none of the possibilities is permitted, and the **T** clathrate is actually frozen and incapable of disintegration. By contrast, the **S** clathrate can disintegrate as follows:

We conclude that the Hamiltonian and the dynamics of the system allow formation of Ψ^S and Ψ^T , with only Ψ^S capable of disintegration. At very high temperatures, of course, with the breakdown of the Born–Oppenheimer model, the above partitioning into vibration, rotation etc. is no longer valid, and the transition becomes possible via strong collisions.

In other words, our model assumes that in the presence of the external magnetic field and at moderate temperatures, a single water molecule is readily converted from the *S* state in the *T* state, with the clathrate adopting either the **S** or the **T** state. Outside the range of the magnetic field only the **S**–state clathrate can disintegrate. It is noted that, by contrast, $\text{Ca}^{2+}[\text{H}_2\text{O}]_{n-1}^S \cdot \text{H}_2\text{O}^T$ is able to convert into $[\text{Ca}^{2+} \cdot (\text{H}_2\text{O})_n]^T$, as it is not in an eigenstate and assumptions (a) and (d) do not necessarily apply. In other words, the hydrate may be involved in collisions and may lose some angular momentum while changing.

If we claim that Ψ^T is "frozen", we also have to analyze the convertibility of Ψ^T into Ψ^S . Following mechanisms (a) and (b), we need an external magnetic field and different "*a*" constants for different hydrogens, which in turn are provided by the HMF. Without the external field a possible alternative is breakdown of the Born–Oppenheimer model. At high temperatures, therefore, free conversion of Ψ^T into Ψ^S or into hydrate $\text{Ca}^{2+} \cdot n(\text{H}_2\text{O})$ can be expected, whereby the memory effect is obviated. In the absence of both high temperature and of the external magnetic field neither mechanism is feasible, and consequently Ψ^T is "frozen".

As described above, the clathrate in the **S** state can be converted into the hydrate:

Now, without the external magnetic field, it suffices that only one water molecule attains a phase difference from the others (α_i) to prevent the re-formation of the clathrate. Ψ^S can therefore be expected to vanish completely within a short time. With the external field, (1) Ψ^S does not vanish, since the hydrate readily reverts to Ψ^S due to mechanism (b); (2) there is a transition between Ψ^S and Ψ^T and the system reaches equilibrium between them. When the magnetic field is removed, Ψ^S vanishes while Ψ^T , being "frozen", serves as a nucleus for a potential crystallite in the bulk.

Distinction must be made between the above S–T transition (which is possible via mechanisms (a) and (b)), and conversion of T into hydrate, which is forbidden. For the transition to take place, both the reactant and the product still have to be antisymmetric. This is possible via a change in rotation levels of the clathrate. These rotation energies are very low and the kinetic collisions of the clathrate suffice to provide the necessary energy. The crucial point is that the time required for the transition is very short [19], and it thus may happen simultaneously with the transition in the rotation levels, caused by external collision.

By contrast, the conversion of T into hydrate takes longer than a typical collision; thus the kinetic energy of the collision is channeled into translational rather than rotational energy. As a result, the antisymmetry should be preserved throughout the process, which is impossible for conversion of T as discussed above.

Temperature

According to our model, an increase in temperature in the presence of the magnetic field induces a higher rate for attaining equilibrium:

which in turn enhances the formation of T-clathrates; this is true so long as the temperature remains below the level at which the Born–Oppenheimer model

breaks down. Thus, on the one hand, higher temperature throughout the magnetic treatment is a positive factor, while after treatment a lower temperature is preferable, so as to prevent destructive collisions. Crystallite growth is influenced positively by a higher temperature, with attendant higher diffusion rate of the ions; however, this effect can also be provided by mechanical agitation.

Magnetic Perturbation

Clearly, paramagnetic ions can form a nonhomogeneous magnetic field, which permits transition while avoiding destructive vibrations. Accordingly, obviation of the memory effect can be expected in this case. Similar effect should be expected in the case of magnetic induction in close proximity to the MTW.

Field Intensity

The most controversial issue is why fields suffice to produce the phenomenon. Moreover, an estimate is desirable of the order of field intensity which is essential for the formation of Ψ^T and for its equilibrium with Ψ^S .

The influence of field intensity on the probability of transition is twofold and is reflected in Δ , the energy difference between S and T states, and in V — the perturbation factor $|\langle S|\bar{V}|T\rangle|$ (since the perturbation operator $\bar{V}$ depends on the field intensity B).

The probability of transition (see eq. 4 in [18]), obeys

$$P(t) \propto \frac{2V}{u} \quad \text{where } u^2 = \Delta^2 + 4V^2. \quad (11)$$

In our case, although Δ and V are very small in absolute value (B itself being very small), what is important is the ratio between them, which may be quite high. It is now clear why, in the circumstances described, a weak magnetic field suffices for the transition between Ψ^S and Ψ^T to take place. Applying the mechanism (a), the non-vanishing asymmetric component of the perturbation is proportional to $B(a_{H_1} - a_{H_2})$ as per eq. 6. The energy difference between S and T due to the

interaction with the field, is $2\mu B$; thus V and Δ are linear with B . Consequently, $P(t)$, the probability of the **S**–**T** transfer (eq. 10), is field-dependent only indirectly via $(a_{H_1} - a_{H_2})$ which in turn is caused by the HMF.

The role of B is, first, to align the spins and, second, to enable rephasing to take place by causing different Larmor precession frequencies, i.e. $(a_{H_1} - a_{H_2})$ other than zero. In order to produce different " a " constant, the HMF (which equals $q v \times B$, q being the ion charge and v the water velocity) must be strong enough to distort the hydrate. The amount of distortion is hard to estimate, but it seems to be proportional to HFM. Note that there should be, on the one hand, some B_{min} to permit alignment of the spins and, on the other hand, v_{max} to avoid destructive turbulence effects. If this is true, we predict that for each B (above B_{min}) there should be some v_{min} which will enable the phenomenon to occur:

$$v_{min}(<v_{max}) \cdot B(>B_{min}) = \text{constant.} \quad (12)$$

MAGNETIC STRUCTURE

At this point an interesting experimental finding should be analyzed, viz. that the polarity sequence (alternating permanent magnet poles N–S, S–N, N–S etc.) of the external magnetic field through which the water is flowing, is of major importance. The efficiency of the treatment is said [3, 15] to depend on the water flowrate and on the spacing of the magnets. the analysis yields an optimum time for the water to be affected under a magnetic pole.

The existence of an optimum time points to conflicting effects accumulating with time. On the one hand, the longer the hydrate "feels" the HFM, the higher the probability of its attaining the eigenstate. note that before the stabilization is achieved, the hydrate molecules continue to dissociate (even faster than individual molecules), and the correlation between the hydrogens must be attained repeatedly before steady state can be achieved. On the other hand, the longer the ionic solution resides in the magnetic field, the more strongly the charges are polarized, as the force acts on opposite ions in opposite directions (an effect measured in our laboratory with very clear-cut results). This polarization produces a force opposite

in direction to HMF. Thus we face a counter-effect which could be the reason for the optimum time feature. This may also be the reason for the positive effect of alternating polarities, as the hydrate has more opportunities to stabilize while the proper cycle permits the polarization to reverse at each stage.

If this hypothesis is true, we can predict that higher ionic strength will reduce the optimum time but also will, in general, reduce the effectiveness of the process (which can be expressed by the number of new crystallites compared to that of old ones [3]). Another prediction is that an electric field exerting the force opposed to the HMF will have the same two consequences.

SUMMARY

- (1) Magnetic treatment has been proved effective in large-scale industrial use and recently also in laboratories, in preventing the scale formation.
- (2) A quantum-mechanical model was introduced to predict the formation of eigenstate stable clathrates in the magnetic field, the latter aligning the spins and the HMF perturbing them to cause re-phasing. These stable clathrates do not dissociate and do not exchange water molecules with the solution. They thus serve as nuclei for future crystallites.
- (3) Certain experimental observations were analyzed on the basis of the model, especially the alternating-pole array and the optimum time effect.
- (4) A few predictions were made which may indicate directions of future research, designed to check and improve the dependence of the model on ionic strength, electric field, cooling, agitation, magnetic induction, paramagnetic ions and correlation between v_{min} and B .

It is admitted that the model, at present, is a working hypothesis but it is essential at the present state of research.

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