PHYSICAL AND CHEMICAL BASES OF BENIFICIATION

THE EFFECT OF ELECTROMAGNETIC WAVES ON THE PHYSICAL
PROPERTIES OF WATER DURING FLOTATION OF MINERALS

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In previous reports [1] we established that high-frequency electromagnetic waves have a beneficial effect on the flotation of sulfide minerals. When a mineral slurry is activated with currents of frequency 40 Mc for 5 min, extraction of galena and chalcopyrite is increased by 60% and 20%, respectively. This favorable effect was largely attributable to influence of the electromagnetic waves on the surface of the minerals subjected to flotation. In connection with an extensive study of the structural properties of water as a strongly associated liquid, we investigated the effect of electromagnetic fields on the physical properties of water itself before it is fed to the flotation plant.

It is known that water molecules display markedly directed association at the hydrogen bonds, so movement of these molecules will be impeded by continuous combination and rupture at these bonds. The energy of the hydrogen bond of a water molecule can be taken as 5000 cal/mole [2]. In intermolecular and van der Waals interaction of water molecules, oriented interaction greatly predominates over other types of intermolecular interaction. According to London [3], oriented interaction of hydrogen bonds in the case of water is 190 erg/cm², while induced and dispersed interaction are 10 and 47 erg/cm² respectively. Continuous hydrogen bonding between water molecules leads to a short-range order of the molecules, which leads in turn to the appearance of structural properties within the liquid water as a whole.

Bernal and Fowler [4] have made detailed and extensive studies of the structure of water. According to these authors, water has a rather loose quartz-type structure with tetrahedral ordering. It may be assumed that water has an open quasi-crystalline structure, thermal movement of the water molecules tending to increase the degree of disordering, while the orientation effect at the hydrogen bonds increases the degree of ordering.

In each temporary equilibrium position, a water molecule executes vibrations owing to fluctuation of the medium's thermal energy. Frenkel' has shown the particular role of translational movement of water molecules: it has a stepwise character and consists of activated jumps of the molecules from one temporary equilibrium position to the next. From a study of the Raman spectrum of water, Hibben [5] established that the wave number of vibrations of water molecules in a temporary equilibrium position is 150 cm⁻¹. The frequency of the natural vibrations of water molecules is, therefore,

\[ \nu_0 = C \times 150 \text{ cm}^{-1}, \]

where \( \nu_0 \) is the natural frequency of the vibrations of water molecules, and \( C \) is the velocity of light, \( 3 \times 10^{10} \text{ cm/sec} \);

\[ \nu_0 = 3 \times 10^{10} \times 150 = 4.5 \times 10^{12} \text{ sec}^{-1}. \]

According to Frenkel', the mean residence time of water molecules with an energy \( E \) in a temporary equilibrium position can be written as

\[ \tau = \tau_0 \exp \left( \frac{E}{RT} \right), \]

where \( \tau \) is the mean residence time of the water molecules in the equilibrium position, \( \tau_0 \) is the period of natural vibrations of the water molecules, \( E \) is the energy, \( R \) is the gas constant, and \( T \) is the temperature;

\[ \tau = 0.5 \times 1.4 \times 10^{-12} \exp \left( \frac{5000}{1.986 \times 300} \right) = 3 \times 10^{-9} \text{ sec}, \]

This value is the mean residence time of water molecules in the temporary equilibrium position in pure water at a sufficient distance from the surface.

Study of the structural properties of water prove the existence within the liquid phase as a whole of a lattice structure which undergoes continuous disintegration and reformation and has a lifetime of \( 3 \times 10^{-9} \text{ sec} \) in the transient crystalline state. Furthermore, it must be borne in mind that water molecules are markedly polar, with a constant...
dipole moment of 1.84 D. Therefore, water is a mobile-crystalline system in which the dipole molecules continuously undergo sudden displacements. It is, therefore, of interest to determine the effect of an external field on the change in the structural properties of water before it is fed to the flotation plant.

It is known that at relatively slow field changes the relation between electric and magnetic induction on the one hand, and between the electric and magnetic field intensities on the other, is determined by the equations

$D = \varepsilon E$ \quad and \quad $\vec{B} = \mu \vec{H}$

where $\varepsilon$ and $\mu$ are the permittivity and magnetic permeability of the medium, respectively. The values of $\varepsilon$ and $\mu$ are static in a constant electromagnetic field, but change markedly at a field frequency commensurate with the frequency of translational movement of the water molecules ($\varepsilon$ and $\mu$ dispersion) [6]. In a polar field, polarization is associated with orientational movement of the water molecules; for the natural vibrations of water, dispersion begins at electromagnetic vibrations in the centimeter range. However, we should expect to find in water larger associations than bimolecular formations, so the effect of electromagnetic vibrations on the structural properties of water may be displayed at much lower frequencies (in the meter range). In this connection the electrostatic component of the electromagnetic field will play a larger role because $\varepsilon >> \mu$.

The present paper describes experiments on the effect of the frequency of the electric component of the field on the structural properties of water. The experiments were performed in a 25 cc test tube, without screening against the external electromagnetic field, in which two brass foil electrodes were fixed externally. A standard signal generator was used for irradiating the tube. The frequency range was 100 kc to 26 Mc and the irradiation time 30 min. We then measured the spectral distribution of the intensity (extinction) of light absorption by the water in a special apparatus consisting of a UM-2 monochromator, an exciting source (a 12 V incandescent lamp) and a PMU-29 photomultiplier. The photocurrent of the photomultiplier was amplified by a direct current and recorded by a Zeiss sensitive galvanometer (10⁻⁹ A). The monochromator enabled us to determine the intensity of the extinction of light by water in the range 360-691 my. For this purpose we measured the spectral distribution of light by an empty cell and by one filled with water; the difference between these intensities gave the intensity of extinction of light by water.

Figures 1 and 2 show the spectral distribution of extinction intensity for distilled water which was either subjected or not subjected to electric fields of various frequencies. The data were obtained on different days without allowing for the state of the external electromagnetic field. It will be seen that the curves are of two types; in one case, in the frequency range 100 kc to 12 Mc, the extinction intensity is lower than for water not subjected to the field, whereas in the other cases the intensity is higher in this range (data of several series of experiments). This dual character of the change in the optical properties of water may be attributed to differences in the state of the initial water. The change in the extinction of light by water may be due to a change in the absorption of light or to a change in the dispersion of light by a field; either of these would lead to a change in the structural state of water. Therefore, the action of the electric component of a field with different frequencies changes the structure of water owing to disturbance of the natural vibrational frequency of the association and molecules of water ($\nu_0$).

Dissipation of the energy of the electromagnetic field of the water somewhat retards the translational-vibrational movements of the water molecules, which probably produces a more ordered (stronger) quasi-crystalline structure of water. The ordered structure reduces in turn the difference between the free energy of the surface of a solid and that of a liquid, thereby creating better conditions for mineral flotation.