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An Analysis of the Prospects of the Use of Magnetic Water Treatment in Foundry Engineering

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Abstract

Scientists are currently focused on creating technologies that produce positive results without affecting the environment. One such technology is magnetic water treatment. In this paper, an analytical review of publications devoted to the application of magnetic treatment of water in various branches of engineering, agriculture, and medicine is carried out. Current views on the structure of water molecules, as well as the theories explaining the influence of the magnetic treatment of water on its properties, are reviewed. The results of studies of the influence of water treated by a magnetic field on the properties of molding sand are analyzed, including those in which the authors of the article took part. It is shown that the magnetic treatment of still water can increase the green strength of the molding sand containing this water from 0.035 to 0.052 MPa, and that of water in motion to 0.075 MPa. Thanks to this, the amount of binder in the molding sand can be reduced. It is concluded that the use of magnetically treated water in foundries is promising.

Keywords:

water, magnetic field, magnetic water treatment, molding sand, green strength

1. INTRODUCTION

G. Piccardi suggested in the 1930's that there was an interrelation between the geomagnetic field and water properties [1]. However, the first real interest among specialists in magnetic water treatment arose after 1945, when the Belgian engineer T. Vermeiren patented a simple and effective way to combat salt deposits in steam boilers [2]. Water containing hardness salts was passed through a magnetic field. In a fairly short period, studies on the effects of magnetic and electromagnetic water treatment in various industries were conducted (Fig. 1):

- in the power industry to reduce the formation of scales in heat exchangers [3–11];
- in the production of building materials [12–17];
- in agriculture to increase the yield of various crops [18–20];
- in the neutralization of wastewater [21];
- in medicine and biology [22];
- in foundry engineering for the preparation of molding sands [22–28].

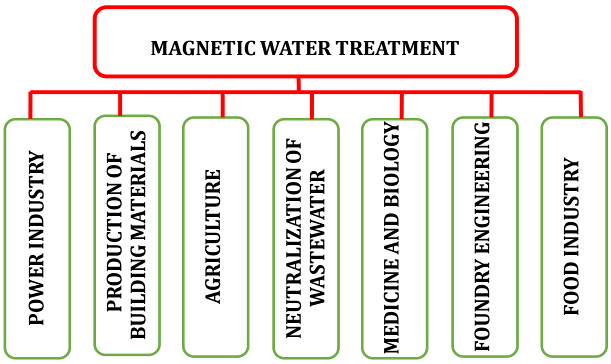

Fig. 1. Magnetic water treatment applications

In the majority of cases, the authors noted a positive effect of magnetic or electromagnetic water treatment. However, V. Ochkov [29] was skeptical about the data available in the literature. He explained the positive results of magnetic water treatment as a) accidental; b) a manifestation of the "human factor"; c) a marketing campaign by the manufacturers of special equipment.

The present review focuses on the analysis of the positive effect of electromagnetic water treatment on the properties of the molding sands in which it is used. Theories that have appeared in recent years are used to explain the available results.

2. STRUCTURE OF WATER AND HYPOTHESES EXPLAINING CHANGES IN ITS PROPERTIES UNDER MAGNETIC TREATMENT

In 1933, D.J. Bernal and R.H. Fowler [30] created the classical theory of water structure. They first showed that each water molecule is surrounded by four others. Due to the existence of directional intermolecular bonds, the arrangement of molecules resembles tetrahedral coordination.

W. Ramsay and J. Shields [31], W. Sutherland [32], G.W. Stewart [33], R. Mecke [34], M. Yel'yashevich [35], M. Magat [36], N. Bjerrum [37], L. Pauling [38], J. Lennard-Jones and J. Pople [39] made great contributions to the development of water structure theory. In recent years, the fundamental works of X.F. Pang [40, 41] have been published.

The predominant opinion is that "most hydrogen-bonded chains of water molecules can mutually unite and form some closed configurations by connecting the head and tail of the linear chains with hydrogen bonds. These closed configurations can include chains with hydrogen bonds containing 2 (dimer), 3, 4, 5, 6, or more water molecules" [40]. This view can be used to explain the magnetizability of water.

Numerous experiments have shown that water can be magnetized under the influence of a magnetic field, although the magnetization effect is small. Based on the analysis of a large amount of experimental data, the authors [21, 22, 41–44] showed that this changes its optical and electromagnetic properties, surface tension force, dielectric permittivity, viscosity, crystallization and boiling temperatures. For example, the authors [42] indicate that the surface tension of water after magnetic treatment decreased from 72.44 mN/m to 57.62 mN/m (1 T intensity field with treatment time for 13 min at 25°C). The authors [43] point out that the refractive index of magnetized water was increased by 0.1% from 1.333 to 1.335 under the influence of a magnetic field (10 T at 25°C). The authors [43] also observed a slightly increasing melting point (5.6 mK) of water after magnetic treatment as well as an increase in water's vaporization enthalpy after magnetic treatment (45–65 mT, 22°C) from 58.86 to 68.86 kJ/mol. The studies [41] also showed significant differences in infrared absorption spectra and Raman spectra of magnetized and ordinary water. Raman spectra peaks for the magnetized water are larger than that without magnetized water (the positions of these peaks do not change). The strengths of the 1500 cm^{-1} peak in the magnetized and pure waters are 148 and 124, respectively. The authors [41] explain this result by the intensification of "ring proton currents" in the closed chains of water molecules.

Hypotheses explaining the essence of the magnetic field effect on water and aqueous solutions can be divided into three groups.

The first group of hypotheses proceeds from the fact that water always contains impurities. According to the theories of this group, the spontaneous formation and decay of colloidal complexes of metal cations: Ca^{2+}, Mg^{2+}, Fe^{2+} and Fe^{3+}, occurs under the influence of a magnetic field in the treated water and fragments of their deca further form the centers of nucleation of inorganic salts. In the presence of Fe^{3+} cations and the smallest ferromagnetic Fe_2O_3 particles in water, the formation "of colloidal hydrophobic sols of Fe^{3+} cations with chlorine Cl^- anions and neutral H_2O molecules having the general formula $[xFe_2O_3 \cdot yH_2O \cdot zFe^{3+}] \cdot 3zCl^-$, which may cause the formation of nucleation centers whose surface adsorbs calcium Ca^{2+} and magnesium Mg^{2+} cations (forming the basis of the carbonate hardness of water)" [45]. It should be noted that the theories of this group satisfactorily explain the positive effect of magnetic treatment of water to prevent or reduce scale formation in pipes and heat exchangers.

Hypotheses of the second group explain the effect of a magnetic field on water by means of the polarization of dissolved ions and the deformation of their hydration shells under the action of the magnetic field [46]. In addition, it is assumed that the effect of the magnetic field on the Ca^{2+}, Mg^{2+}, Fe^{2+}, and Fe^{3+} ions dissolved in water may also be associated with the generation of a weak electric current in the moving water flow or with pressure pulsation [47].

Hypotheses of the third group postulate that the magnetic field directly affects the structure of water associates due to the dipole polarization of water molecules, which are formed from many H_2O molecules bonded to each other by low-energy intermolecular Van der Waals forces, dipole-dipole interactions and hydrogen bonds, which can cause the deformation of hydrogen bonds and their partial breakage, and the migration of mobile protons H^+ within associative elements of water and uniting of H_2O molecules into temporary associates – clusters [40, 48].

The above hypotheses do not fully cover all of the assumptions and views on the essence of phenomena occurring during the magnetic treatment of water. At the same time, a large number of experiments confirming changes occurring in water under the influence of a magnetic field eliminates doubts as to the validity of the observed phenomena.

3. THE USE OF MAGNETIC WATER TREATMENT IN FOUNDRY ENGINEERING

An essential reserve for improving the quality of casting into sand molds is to improve the properties of molding materials used for their production. An important point in this is the use of environmentally friendly technologies and materials.

The strength of green molding sands depends mainly on the properties (the adhesive properties and the contact angle) of the liquid and semi-liquid films covering the sand grains (water, moistened clay, etc.). Thus, by influencing these films, it is possible to influence the strength properties of the molding sands as a whole.

Boldin et al. [49] explain the formation of the strength properties of green molding sand by the polarity of the water molecule and the presence of an electric double electric charge on the micelles of the clay binder.

The authors [49–52] explain the formation of the strength of green molding sand by the fact that on the surface of solid particles (sand and clay), a double electric layer is formed by hydrogen ions and hydroxyl groups. There is a spontaneous, unipolar orientation of dipoles and liquid ions on the surface of sand and clay. The degree of orientation of the particles decreases with distance from the surface. At the same time, according to Boldin et al. [49], the disoriented particles have a "wedging" effect and prevent particle convergence.

It can be assumed that magnetically treated water will have dipoles with preferential orientation with respect to the surface of mineral particles (sand and clay). This will decrease the "wedging" effect and provide a better particle approach and, consequently, the greater strength of the sand.

In a number of studies [22–28], water, clay slurries, aqueous solutions of sols included in the molding sand, and the green molding sand were subjected to magnetic treatment. In addition, different starting materials were used, from which different compositions of molding sand were prepared. The action was carried out both by electromagnets and permanent magnets, and the mixing time of the components was different. Therefore, it is impossible to compare the quantitative indicators of the effect of magnetic treatment.

Let us analyze the results of individual works separately in order to identify general patterns.

V. Klassen [23] supplies data on the increase in the compressive strength of the green molding sand mixture (93.2% quartz sand, 4.8% clay, and 2.9% water) 2 times after magnetic treatment of water with a simultaneous increase in gas permeability.

In [27] the magnetic treatment of water allowed the strength of the sand-cement molding sand to be increased by 30%.

Yu. Vasin et al. [53] also conducted studies with sand and bentonite mixtures (100 wt. parts of quartz sand, 10 wt. parts of bentonite and 4.5 wt. parts of water). The application of magnetized water increased the strength from 40 to 52 kPa (1.3 times) (Fig. 2) and gas permeability from 287 to 313 units (1.44 times). It is remarkable that the effect of the magnetic treatment of water was retained for more than 1 hour.

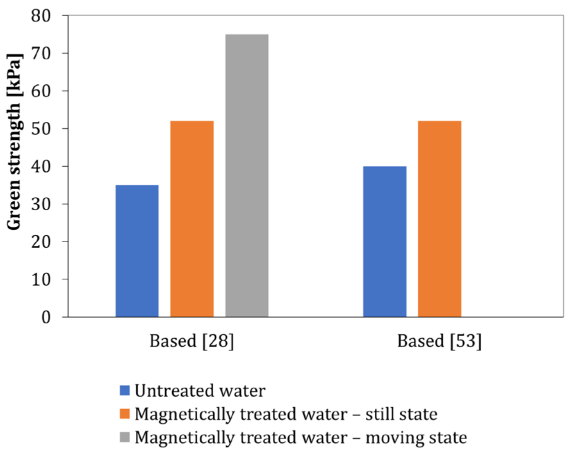

Fig. 2. Green strength of molding sands

The authors of the research [24–27] focused their attention on the study of the effect of movement velocity of sodium silicate, clay slurry, and an aqueous NaOH solution on the strength of different molding sands. The magnetic treatment of still sodium silicate made it possible to increase the strength of the molding sand (97 wt. parts of quartz sand, 3 wt. parts of molding clay, 1 wt. part of NaOH, 5 wt. parts of sodium silicate with a density of 1420 kg/m^3) by 1.6 times. The movement of sodium silicate through the electromagnet at a velocity of 1 g/s additionally increased the strength of the sand by 10% compared to the fixed sodium silicate treatment. It was found that the positive results of the magnetic treatment was retained after even 9 hours [25]. Moving 0.5% aqueous NaOH solution through the electromagnetic treatment apparatus at a speed of 0.6 m/s ensured an increase the strength of the molding sand (90% quartz sand, 1% clay and 3.5% aqueous NaOH solution) 1.35 times compared to the fixed solution treatment [24].

L. Dan et al. [28] conducted research on the effect of various factors on the green strength of the molding sand, which contained quartz sand (76.2%), molding clay from the Chasiv Yar deposit in the form of powder (19%) and water (4.8%). During the experiments, water was treated by electromagnet at still or by stirring in the vessel; the treatment time and the electric power supplied to the electromagnet were varied.

The study [28] showed that even the treatment of still water with an alternating magnetic field increased the green strength of the molding sand containing this water from 0.035 MPa to 0.052 MPa compared to the molding sand that contained untreated water (1.48 times). Stirring with a glass stirrer at ~1 revolution per second increased the green strength to 0.075 MPa (an additional 1.44 times) (Fig. 2).

To achieve maximum results for the green strength of the molding sand, it was sufficient to conduct magnetic water treatment for 2.5 minutes. As in the studies [25, 53], the effect of the magnetic treatment of water was maintained for a long period of time. Even after 120 hours, the green strength of the samples made from sand containing magnetically treated water was 1.3 times higher than that of the control samples.

Analysis of the use of magnetically treated water in foundry engineering has shown the following positive results: a) magnetic treatment of water and water binders indisputably increases the green strength of molding sand and improves its gas permeability; b) magnetic treatment of moving water is more effective compared to the magnetic treatment of still water; c) the positive effect of magnetic treatment of water on the properties of molding sand is maintained for a long time. At the same time, there is no consensus in the literature about the modes of magnetic water treatment required to achieve the best results.

4. CONCLUSIONS

Analysis of the literature on the magnetic treatment of water has shown the following:

- water changes its properties under the influence of a magnetic field: electro-physical, optical, surface tension, temperatures of phase transformations, infrared absorption spectra, Raman spectra, etc.;
- to date, there is no unified theory explaining changes in water properties under the action of a magnetic field;

- the application of water treated by a magnetic field to reduce scale formation in heat exchangers and pipes, in agriculture, in the manufacture of concrete products, in biology and medicine provides a positive effect;
- the use of water magnetization and aqueous binders in molding sands increases their green strength. Magnetic treatment of still water can increase the green strength of the molding sand containing this water from 0.035 to 0.052 MPa, and that of water in motion to 0.075 MPa. It can reduce the amount of binder used in the molding mixtures;
- long-term retention of improved properties of the molding sands opens up the prospect of using the magnetic treatment of water and aqueous binders in the industry;
- to make a final decision on the use of magnetic water treatment in foundry engineering, it is necessary to carry out comprehensive research aimed at establishing the optimal techniques and modes of such treatment.

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