

The Mechanism of the Influence of Magnetic Treatment of Water on the Processes of Scale Formation and Corrosion

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Industrial practice has shown that insertion of a magnetic water treatment unit before a heat exchanger can affect the processes of scale formation and corrosion in it. The mechanism of the effect of the magnetic field on the characteristics of a water system has not so far been revealed.

However, since 1945 more than 7000 plants of S.A. (Belgium) built to the design of Th. Vermeiren¹ have been installed in various countries of the world; similar plants have been manufactured in Norway and Great Britain². Magnetic units which reduce scale formation have been produced in the USA, Czechoslovakia and other countries. In our country magnetic units are in series production.

It is difficult to make use of a great many technical publications to determine the mechanism of magnetic treatment since the data given in them are inconsistent and are often nonreproducible³. Attempts at laboratory modelling of the conditions of industrial use of magnetic units have been unsuccessful in the majority of cases.

Investigations carried out at Moscow Power Institute, Moscow State University, Kharkov Engineering-Economic Institute and by other organisations have shown that with certain water-chemistry and temperature conditions magnetic units may generate seed crystals⁴. In a heat exchanger placed after a magnetic unit the process of deposition of scale on these crystals in the water will compete with scale formation on the heat transfer surfaces, thus increasing the operational time between cleans of the heat exchanger, under conditions of effective sludge removal. It has already been established experimentally that the required conditions for formation of seeding crystals in a magnetic unit are that the water is supersaturated with respect to scale-forming substances in the magnetic unit and that the water contains substances with ferromagnetic properties^{5,6}. As far as the mechanism of generation of solid phase of scale formers in the magnetic units is concerned, this has not been studied exhaustively⁷.

Here we consider one possible mechanism of the effect of magnetic treatment on scale formation and corrosion, based on wellknown physico-chemical laws and laboratory and full-scale experiments.

Under the influence of the magnetic field the concentration of ferromagnetic substances can change⁸. Water which has been treated magnetically will differ from the entry water in having a lower content of steel corrosion products in colloidal and coarsely-dispersed states, which under certain conditions possess ferromagnetic properties. A magnetic unit can be considered in this case as a unique magnetic filter, widely used for removing corrosion products from water. When installing a magnetic unit in lines supplying heat exchangers the quantity of ferromagnetic substance G removed will increase and attain a maximum value G_{max} during the course of a certain intermediate time τ_{int} . Our calculations and experiments with water systems showed that the duration of the transient process in the magnetic unit lies between several hours and several days.

To study the behaviour of ferromagnetic substance in a laboratory magnetic unit and the possible change in properties of supersaturated aqueous solutions connected with it we introduced into the magnet gap ferromagnetic material 90-95% of which consisted of magnetite particles 30-50 μ in size. The results of the laboratory investigation showed that the maximum mass of magnetite G_{max} removed in the magnet gap depends on water velocity in the gap v and magnetic field strength H . Examination of the data shows that the apparatus can be characterised by a parameter such as the maximum velocity of the water in the magnet gap v_{max} , the ferromagnetic material being removed in the gap and creating a suspended layer with a developed surface only when $v < v_{max}$. The value of v_{max} depends on many parameters, primarily on the magnetic field strength H , the gradient of the magnetic field strength $grad \bar{H}$, the hydrodynamics of the flow, the characteristics of the ferromagnetic material, temperature, and flow direction relative to gravity. In our case the experimental data are well described by the expression

$$G_{max} = A \bar{H} |g| v_{max} / v \quad (1)$$

Theoretical approach, based on analysis of the forces acting on the ferromagnetic particles in the gap of the magnetic unit, gives the following relation:

$$G_{max} = 0.765 \frac{\mu_0 l}{m \rho_m} |g| \frac{\mu_0 (\mu - 1)}{16 \delta} \frac{(|\bar{H}| |grad \bar{H}|)_{min} d_m^3 v_0}{16 \delta v} \quad (2)$$

where d_a = diameter of the magnetic gap of the apparatus; l = thickness of the suspended layer of ferromagnetic material in the gap; m = a coefficient which takes into account the hydrodynamics of the suspended layer; ρ_m = density of the ferromagnetic material; f = a coefficient which depends on the shape of the ferromagnetic particles (for a sphere $f = 0.33$, for an ellipsoid of rotation $f = 1$); μ_0 = absolute magnetic permeability in vacuo; μ = magnetic permeability of ferromagnetic material; d_m = mean effective diameter of ferromagnetic particles; $(|\bar{H}| |grad \bar{H}|)_{min}$ = minimum of product of modulus of strength of magnetic field by its gradient, negative with respect to water flow direction; δ = water viscosity.

Based on these same theoretical considerations we can obtain the value of maximum water velocity:

$$v_{max} = \frac{\mu_0 (\mu - 1) (|\bar{H}| |grad \bar{H}|)_{min} d_m^2 v_0}{16 \delta} \quad (3)$$

Expressions (2) and (3) were derived with the following assumptions: the gradient of the magnetic field strength in the gap of the unit coincides in direction with the water velocity; the Stokes force of friction acts on the ferromagnetic particles in the suspended layer.

An experimental rig was set up to study the behaviour of water systems, saturated with some components, in the magnet gap. The initial solutions taken were distilled water, saturated with atmospheric air, and a solution of calcium bicarbonate, saturated with respect to calcium

carbonate, so as to carry out an analogy between the processes of separating gaseous and solid phases from supersaturated solutions in a magnetic unit.

The gas separation tests were conducted as follows. The distilled water was thermostatted at 25°C, saturated with atmospheric air and passed through a heat exchanger in which it was heated to 25–70°C. Solubility of the main components of the air, nitrogen and oxygen, falls with increase in temperature, while degree of supersaturation of the water S_w increases:

$$S_w = \frac{\text{solubility at initial temperature}}{\text{solubility at final temperature}} \quad (4)$$

When operating the rig in the water circuit the air bubbles were removed, the volume of bubbles being measured with a microburette. Thus it was possible to record the rate of gas removal from the water in the heat exchange section and in the magnet gap. The rate of gas removal over the water circuit of the rig was recorded under three different operational modes of the apparatus: 1) $H = 0$, $G = 0$; 2) $H = 260$ kA/m, $G = 0$; 3) $H = 260$ kA/m, $G = 30$ –40 mg.

In the third mode of operation, ferromagnetic particles were introduced into the gap at the start and were retained by the field for the entire duration of the test.

The results of the experiments on gas removal indicate that in modes 1 and 2 the sizes of the air bubbles and the intensities of gas removal in the magnetic unit did not differ. Transition to mode 3 led to a 15–20-fold fall in diameter of the air bubbles. In other words, the magnetic field by itself does not influence the intensity of gas removal but introduction of ferromagnetic material absorbs the dissolved air on its developed surface. It is as a result of this that there is a substantial increase in intensity of gas removal in the unit.

Similar tests were carried out for a qualitative evaluation of the behaviour of a solution supersaturated with calcium carbonate, in the magnetic unit. In this case it was established visually and by chemical analysis that at the surface of the magnetite particles, suspended in the gap, intense sorption of calcium carbonate takes place, with formation of gas bubbles (carbon dioxide, nitrogen, oxygen).

The investigation enabled us to formulate the probable mechanism of the effect of a magnetic pretreatment apparatus on the processes of scale formation and corrosion in heat exchange systems:

the magnetic apparatus retains ferromagnetic material in the gap, as a result of which over a certain intermediate period of time τ_{int} a suspended layer with a well developed surface is formed;

if the water supplied to the magnetic unit is not stable, i.e. it is supersaturated with respect to a certain component (gaseous, solid), it will be absorbed at the surfaces of the particles suspended in the magnet gap;

the substance removed from the supersaturated solution can either accumulate in the gap (in practice the magnetic treatment plant often becomes fouled with iron-scale deposits), or it can be washed away by the flow of water in the form of seeding crystals (supersaturated with respect to salt composition) or by the free gaseous phase with corresponding supersaturation; in this case dynamic equilibrium is established between the processes of sorption and washing away;

the ferromagnetic particles in the magnet gap may coagulate, forming agglomerates covered by a layer, calcium carbonate for example, which can also serve as centres of crystallisation.

The magnetic treatment of mineralised feedwater retards scale formation as a result of contact stabilisation and the introduction of ferromagnetic particles and in this case magnetic treatment can be regarded as heterogeneous catalysis, speeding up the process of phase transition in supersaturated water systems.

In a first approximation the efficiency of magnetic treatment can be assessed by the expression

$$\eta = \frac{\text{area of seeding crystals}}{\text{heat exchange area}} \quad (5)$$

With our approach to magnetic water treatment this characteristic will be

$$\eta = 1.5 \frac{C_c \rho d}{\rho_c d_c} = 11.5 \frac{I d G}{v^2 \rho_m d_m d_c} \quad (6)$$

where C_c = concentration of seeding crystals in the water at the outlet of the magnetic unit; ρ , ρ_c , ρ_m = density of water, of seeding crystals and of ferromagnetic particles; d , d_a = diameter of heat exchanger and of gap in the magnetic apparatus; d_c , d_m = mean effective diameter of the seeding crystals and of the ferromagnetic particles, retained in the gap; v = velocity of water in the gap; G = mass of material retained in the gap; I = intensity of removal of scale onto the surfaces of the particles retained in the gap.

The assumed mechanism leads to establishing the following.

1. The frequent disparity between the results of tests on industrial magnetic units and those from laboratory modelling can be explained by introducing the concept of "period of activation of the magnetic apparatus". Approach to the magnetic apparatus as to a unique filter shows that the surface of the particles retained in the gap can be appreciable only over the course of a certain intermediate time. Consequently, the value of η [see expression (6)] can attain a significant level only at the end of this intermediate period—the period of activation of the magnetic apparatus. The operational time of the magnetic units under actual industrial conditions usually far exceeds their activation periods, which one cannot say of many laboratory tests.

2. Evaluation of the dependence of η on velocity of water in the magnet gap of the magnetic unit deserves attention. Increase in this velocity leads on the one hand to an increase in intensity of removing scale-formers onto the surfaces of the suspended particles⁶, on the other hand it reduces the volume of the solid ferromagnetic particles upon which this sorption takes place [see expressions (1), (2) and (6)], which governs the extremal nature of the dependence η on v :

$$\eta \sim \left(\frac{v}{v_{max}}\right)^b \lg \frac{10v_{max}}{9v + v_{max}} \quad (7)$$

where $b = 0.5$ – 2.0 . The optimal value of v lies within limits $(0.4$ – $0.6)v_{max}$; $v_{max} = 1.8$ – 2.5 m/s. This conclusion is in full accord with industrial and laboratory experiments on anti-scaling magnetic treatment^{4,7}.

3. According to the above mechanism of magnetic treatment of water the magnetic field strength in the gap of the apparatus is not the only parameter and the governing one and consequently it is not possible uniquely to find the dependence of η on H , by comparing different industrial and laboratory apparatus, assessing the anti-scaling effects obtained by them. The efficiency of magnetic treatment is also strongly affected by such characteristics as the configuration of the field, hydrodynamics of the flow, dispersity and magnetic properties of the particles

in the water [see formulae (2) and (6)]. Use in the industrial units of a multi-pole system with opposite mounting of the coils or permanent magnets^{4,7}, enabling the overall magnetic flux to be split into individual fluxes, ensures nonuniformity of the magnetic field over the length of the gap and leads to more effective retention of the ferromagnetic material.

4. Prior removal of gas from the water of heat exchangers when employing magnetic treatment leads to corrosion in them being reduced.

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