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Studies on the magnetic water treatment in new pilot scale drinking water system and in old existing real-life water system

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ABSTRACT

Influence of altering magnetic field on chemical properties of water, scale formation and morphology was studied using polyethylene and copper pipes located both in a laboratory pilot-system and in an apartment complex formed by five different buildings each having four or five different homes. In the pilot network, magnetic field decreased calcium scaling by 15% in the both studied piping materials. Also, surface film on the copper pipe appeared to be less compact by the magnetic exposure. In the studies conducted in the apartment complex, magnetic field effectively mobilized earlier accumulated iron and copper from the copper pipe surfaces especially dealing with a hot water circuit.

1. Introduction

It is known for decades that the magnetic water treatment (MWT) is an effective technique both in preventing a scale formation and in detaching already formed scale in industrial water systems as well as heating boilers, hot water systems and even in drinking water systems. Especially, heat transfer in hot water systems will be decreased by scale giving rise to increased energy consumption and operating costs. In addition, in drinking water systems scale increases clogging of pipes, corrosion of pipe materials and formation of biofilms.

Although the existence of MWT-effects is documented, the issue itself has still been controversial. For example authors [1,2] report scale reduction obtained by MWT and some others have found smaller impacts [3]. Phenomenon is now more widely accepted in spite of the fact that first commercial device was patented already in 1945 [4]. During the past 60 years many studies were conducted, several devices were developed and used without understanding of the mechanisms. Many laboratory studies of magnetic water treatment for scale control explained the formation of less compact scales by the increased amount of aragonite, which is needle-like and less adhesive than rhombohedral calcite crystals. Some researchers have found that aragonite increased after MWT under very different conditions [1,5–11]. It was also found that the nucleation rate depends on the method and time of the solution exposure to the magnetic field [12]. Wang et al. have found that the nucleation of $CaCO_3$ in the bulk solution was enhanced by dynamic treatment, which was carried out by static exposition of pure solution to an alternating magnetic field [13]. Gabrielli et al [14] have electrochemically confirmed that the magnetic field produced by alternately arranged magnets was more effective than a homogeneous magnetic field as well as the effectiveness was higher with increasing the flow velocity up to 1.8 m/s and increasing the number of the passes through the magnetic field. In addition, Holysz et al. [15] observed combined effect of static magnetic treatment and presence of Mg^{2+} or Fe^{2+} ions on calcium carbonate precipitation, i.e., these ions may also have an important role in scale-control by MWT.

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In 2002, Kobe et al. showed that the crystallization product of $CaCO_3$ was a function of applied magnetic field [8]. They also performed calculations regarding the structure of the ground electronic states for two structural forms, i.e., calcite and aragonite, of $CaCO_3$. In their calculations they showed that electronic state of the aragonite is placed 28 eV above the ground electronic state of calcite and formation of calcite is energetically favored over that of aragonite. They also pointed out that when conducting fluid moves in the presence of magnetic field a complex interaction between magnetic field and the flow takes place, i.e., very high electric and magnetic fields are inherent in the motion of the fluid and fluid can exchange energy with the electromagnetic field. Because the energy requirement for the formation of aragonite can be achieved with the magnetic field of 45 T, is can be obtained already in the presence of typical magnetic field of 1–1.5 T when accompanied with turbulent motion of a conducting fluid. Besides, they proposed that due to the fact that close to the surface of a conducting pipe the electric field can be as high as 10^6 V/m able to modify the electronic structure of molecules usually lowering energies of the excited electronic states relative to the ground states.

Alimi et al. have earlier showed using permanent magnets that the effect of magnetic treatment depends on properties of the pipe [16]. They noticed that magnetic treatment affects calcium carbonate crystallization by increasing the total precipitate quantity and by favoring its formation in the bulk solution instead of its incrustation on the walls. This was observed for all used pipe materials but, it is strongly dependent on their physico-chemical properties, i.e., the magnitude of the effect depends on pipe conductivity and surface roughness. Cho et al. have studied the effect of MWT on the amount of fouling deposit on to the heat-transfer surfaces as a function of flow velocity [17]. No-treatment resulted in much more severe fouling than using MWT while the flow velocity of 2.3 m/s produced the lowest deposit with MWT. They also published photographs that show clearly the beneficial impact of MWT. Recently, Zaidi et al. presented the implementation of magnetic field in various applications, particularly in the crystallization of calcium carbonate, water purification, coagulation and sedimentation of colloids particles, and wastewater treatment [18]. Their main conclusions from the literature review was that magnetic field application has the potential to improve the physical performance in terms of solid-liquid separation mainly through aggregation of colloidal particles and in influencing the biological properties through the improvement of bacterial activity.

The objective of the research was to study MWT in typical drinking water systems with typical medium hard drinking water as well as to compare the effects of MWT in pipes made from two different pipe materials, i.e., copper and PEX (cross-linked polyethylene). In addition, studies on the impact of installation of MWT-device in old existing water systems built with copper pipes suffering from pitting corrosion in hot water circulation were done by comparing water quality after installation of MWT with the water quality before installation. Respective pipe samples were also collected and studied.

2. Materials and methods

2.1. Pilot scale laboratory studies

A novel pilot scale water distribution system was built in the laboratory. Pilot scale network encompasses eight parallel lines of looping pipes that are mounted on the laboratory walls. Four of the lines are constructed of copper pipes and four of the lines are constructed of high density cross-linked polyethylene (PEX) pipes. Each pipe line consists of an 11 m long water pipe that incorporates water sampling taps and five pipe collectors. Pipe collectors are detachable pieces of pipe that can be removed and replaced in a way that does not disturb the scale formation or biofilm formation in the rest of the water distribution network. The network is isolated from the house plumbing. A schematic representation of the pilot scale water distribution network is in Fig. 1. When the distribution network was in operation a timer controlled automated circuit successively flushed each pipe line for five minute four times during normal office hours. Each of these flushes allow 25 l of water through each pipe line and because the inner diameter for both the copper and the PEX pipe was 16 mm the water flow velocity was the same in each pipe line.

Water to the pilot network is taken from the cold water intake to a 60 l stainless steel storage tank. From the tank water is pumped to a vertical manifold where eight individual pipe lines originate. Four lowest of those pipe lines were made from PEX and rest from copper as shown also in Fig. 1. Each of these eight lines has five pipe collectors, which can be easily removed from the system and analyzed. Two adjacent lines, i.e., lowest of copper lines (Cu IV) and highest PEX line (PEX I) were both equipped with the MWT-device obtained from Bauer Watertechnology Ltd. PJ-20i HST which produced an altering frequency magnetic field of a maximum 26 mT intensity orthogonal to the water flow. One copper line as well as one PEX line was chosen in order to compare efficiency of magnetic water treatment in pipes made from two different materials. Other lines acted as reference lines.

The studied drinking water was chemically purified surface water from the municipal waterworks Rauman Vesi located in the city of Rauma.

For this study previously unused distribution network was taken into use and MWT-devices were also installed into the lines before those were filled with water and regular water flow was started in April 2013. Water flow simulates flow conditions and water consumptions for a typical office building. Water samples were measured regularly during the 9 months testing period. After nine months pipe samples were detached and analyzed.

Two liter water samples were collected at nine sampling locations of the pilot scale distribution system. First sample representing the incoming water was taken from the sampling tap located before the network is divided into eight different pipelines. The water samples representing the impact of pipe materials as well as pipe materials and MWT were taken from sampling taps after each of the eight pipelines. The sampling was performed at 7.30 am once a month (Monday), after stagnation of overnight, between 27.3.2012–3.12.2013.

Chemical analyses were performed in all water samples. Temperature, pH, dissolved oxygen, redox and electrical conductivity were measured using YSI professional plus meter (YSI, Yellow Springs, Ohio, USA). The amounts of free chlorine, total chlorine, sulfate, chloride and microbial nutrients ammonium, phosphate, nitrite and nitrate were analyzed with a Hach Lange DR 2800 spectrophotometer (Hach Lange GmbH, Düsseldorf, Germany) according to the manufacturer's instructions. Alkalinity was analyzed via potentiometric titration (SFS 3005, 1981). Total hardness was defined as a sum of calcium and magnesium levels in the water (SFS 3003, 1987). Copper and Iron contents were measured using a method SFS–EN ISO 11885:2009.

Pipe collectors were taken out from the pilot system after nine months of use. From those samples surface calcium content was measured. The specimens were filled with 0.1 M hydrochloric acid and let stand for 60 minutes turning them upside-down at 15 min intervals. The acid was then drained and to ensure complete solubility of calcium, surfaces were still rinsed with 10 ml acid. Calcium content of the acid was analyzed with ICP–OES according to standard SYP600/SFS–EN ISO11885. Using this result, the calcium attached onto inner surface, as $\mu g/cm^2$, was calculated.