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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.

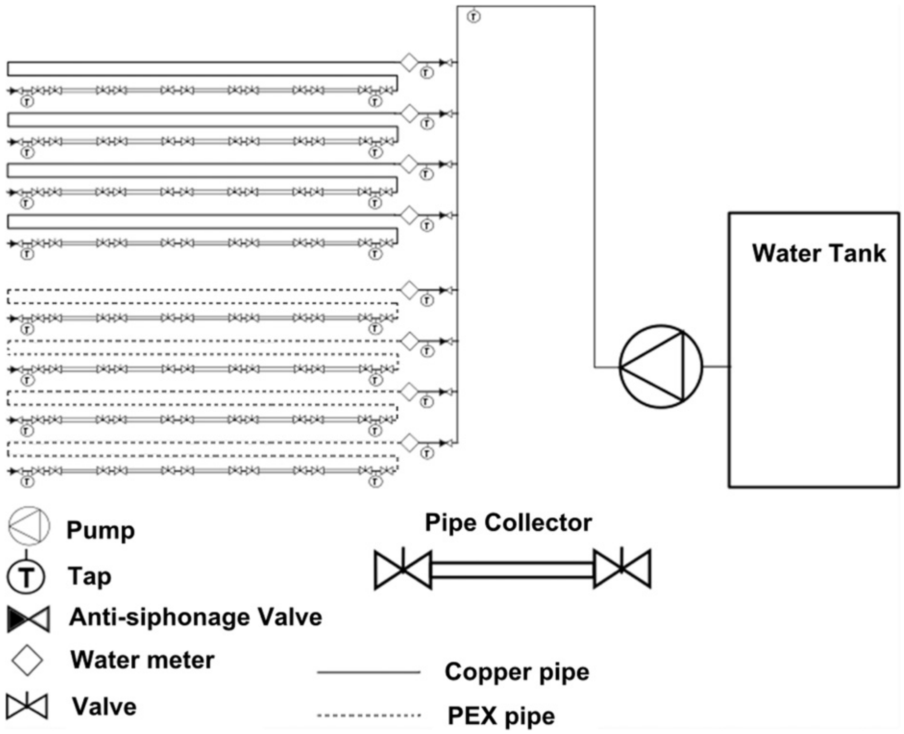

Fig. 1. A schematic drawing of the pilot scale water distribution network.

Morphologies of the surfaces copper pipes were evaluated with field emission scanning electron microscope FE–SEM (Zeiss Ultraplus). Before the samples were analyzed they were coated with a thin carbon layer to achieve a conductive layer using JEOL Jee-420 vacuum evaporator. The used acceleration voltage was 15 kV.

2.2. *Full-scale studies in an apartment complex with five different buildings*

In addition to the pilot-scale studies, a real-life living lab research was done in an apartment complex formed by five different buildings each having four or five different housings. Totally there were 22 housings in this complex built in 1987 in Kirkkonummi, Finland. In Fig. 2 schematic diagram of the water system is shown as well as location of the two apartments (C8 and D18), where water samples were collected. Also water lines starting from the service building are shown in Fig. 2. In buildings only copper pipes were used in all apartments and water pumped into the distribution network was drinking water made from ground water in local Kirkkonummi water work.

MWT-device obtained from Bauer Watertechnology Ltd PJ-20i HST was installed in to the incoming pipeline (water from the water work) existing in the service building. In the service building hot water is produced using central heating. In the service building both hot and cold waterlines are divided into three outgoing waterlines as shown in Fig. 2. Hot water is continuously circulating in all three separate hot water lines.

In these real life studies water samples for both hot and cold were taken after 4 h stagnation time from the service building, apartment C8 and apartment D18. First water samples were taken on 22nd of March 2013 before installation of MWT. Second water samples were taken after 3 months use and third water samples after one year use.

The pipe samples were analyzed by X-ray powder diffraction with equipment D8, parallel rays through Göbbelmirrors, 1.2 mm divergence slit and long Soller slits on the detector side. Radiation source was Cu Kα with energy dispersive detector, SolX which eliminates fluorescence. The sample was placed in a fixed horizontal position using a Goniometer in θ–θ formation. The analysis was performed while the sample was placed on a sample holder made of crystal Si which does not cause diffraction pattern at θ–θ geometry. The diffractograms were matched against ICCDs "PDF 4+" (version 2010) with element filter allowing H, C, N, O, Na, Mg, Si, P, S, Cl, K, Ca, Fe, Cu, Zn and Pb. Matching was performed with EVA software from Brunker. A semi-quantitative measure of phase distribution, S-Q, regardless limited penetration depth was obtained through comparison of intensities against intensity correlation factors, I/Ic, given in the PDF database.

Table 1
Water quality parameters for the incoming water in the pilot network.

Water parameter	Incoming water (pilot network)	
	Avg	Std
Temperature	21.1	3.23
Acidity pH	8.17	0.49
Oxygen%	82.0	17.0
Oxygen mg/l	7.26	2.19
Oxidation-Reduction Potential mV	203.0	37.3
Conductivity SPC µs/cm	359.1	30.4
Chlorine (free) mg/l	0.03	0.04
Chlorine (total) mg/l	0.07	0.08
Phosphate mg/l	0.01	0.01
Nitrite mg/l	0.02	0.01
Nitrate mg/l	0.77	0.36
Ammonium mg/l	0.05	0.03
Sulfate mg/l	104.4	12.4
Chloride mg/l	11.84	1.48
Alkalinity mmol/l	0.614	0.09
Hardness mmol/l	1.463	0.16

3. Results and discussion

3.1. *Laboratory studies*

In Tables 1–3 measured average water quality parameters and respective standard deviations for incoming water, all four copper

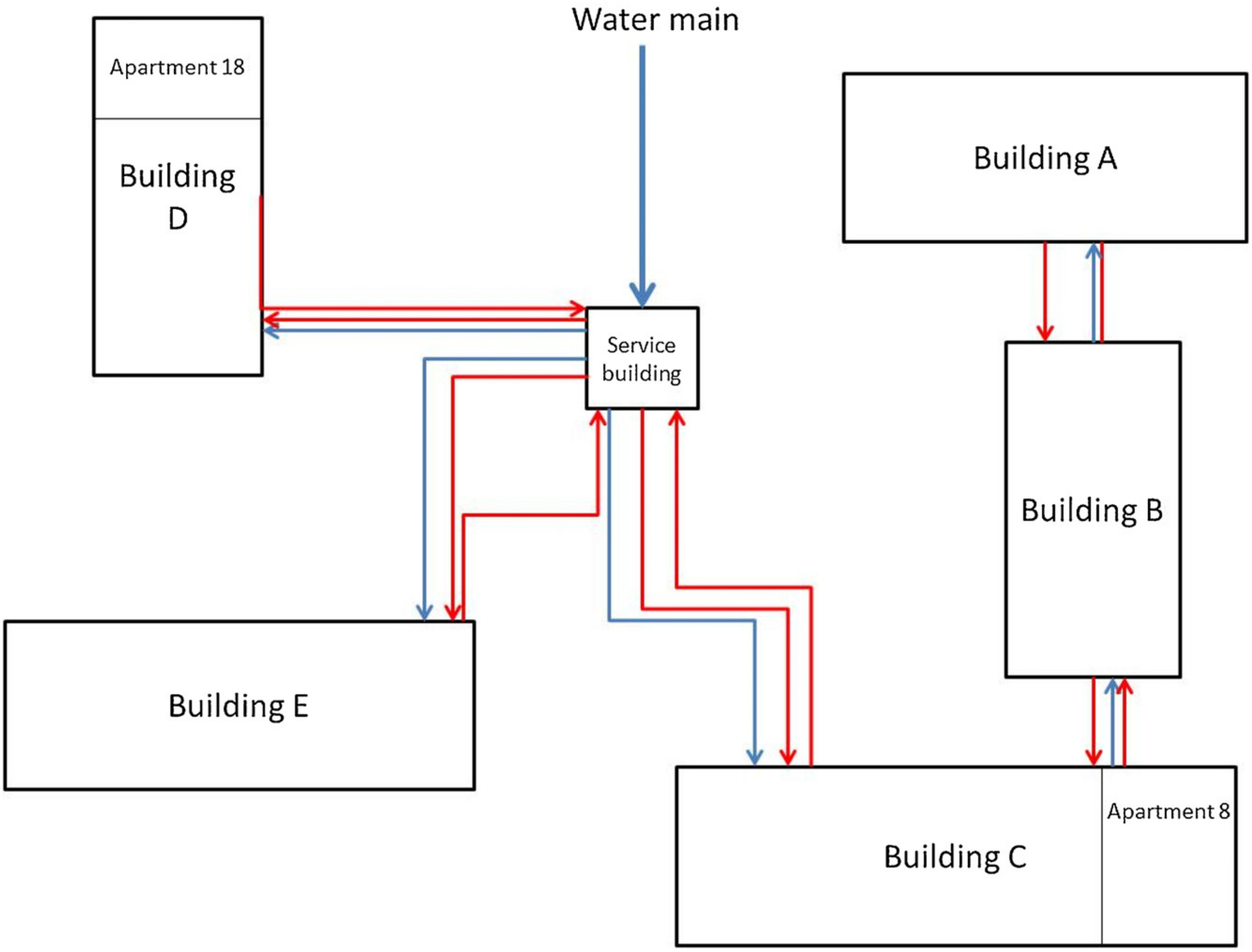

Fig. 2. The schematic diagram of the water system of an apartment complex formed by five different buildings each having four or five different housings located in Kirkkonummi, Finland. Red arrows and lines demonstrate the flow directions for hot water, and blue arrows and lines and flow directions for cold water. Heating of the water takes place in Service building (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2
Water quality parameters from the pilot network copper lines.

Water parameter	Cu I		Cu II		Cu III		Cu IV	
	Avg	Std	Avg	Std	Avg	Std	Avg	Std
Temperature	21.2	2.87	21.3	2.54	21.5	2.04	21.4	2.29
Acidity pH	8.29	0.35	8.33	0.28	8.36	0.25	8.41	0.23
Oxygen%	84.0	14.9	84.0	14.9	83.8	14.62	83.1	16.36
Oxygen mg/l	7.36	1.77	7.36	1.77	7.28	1.55	7.23	1.73
ORP mV	198.4	35.9	198.4	35.9	197.0	35.9	194.3	35.5
SPC μs/cm	358.0	29.5	358.0	29.5	358.9	30.5	358.6	30.0
Chlorine (free) mg/l	0.03	0.05	0.03	0.05	0.05	0.06	0.06	0.07
Chlorine (total) mg/l	0.07	0.09	0.07	0.09	0.09	0.10	0.10	0.10
Phosphate mg/l	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00
Nitrite mg/l	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.01
Nitrate mg/l	0.79	0.41	0.79	0.41	0.78	0.41	0.76	0.37
Ammonium mg/l	0.05	0.03	0.05	0.03	0.05	0.03	0.04	0.03
Sulfate mg/l	106.0	14.3	106.0	14.3	105.7	13.6	104.5	12.3
Chloride mg/l	11.75	1.49	11.75	1.49	11.54	1.52	12.12	1.79
Alkalinity mmol/l	0.620	0.09	0.620	0.09	0.623	0.10	0.625	0.08
Hardness mmol/l	1.445	0.16	1.436	0.16	1.445	0.15	1.463	0.15

lines and all four PEX lines in pilot network are presented respectively.

No distinct differences between different lines were seen in Tables 1–3, especially when standard deviations are also taken into consideration. However, it will be worthwhile to study hardness, alkalinity and pH values more closely by plotting the values for all lines into the same graphs. Hence, average hardness values measured on all eight lines as well as on incoming water are presented in Fig. 3.

As seen in Fig. 3 hardness value for copper line IV equipped with magnetic water treatment device is equal to incoming water. All other lines without magnetic treatment device possess slightly

Table 3
Water quality parameters from the pilot network PEX lines.

Water Parameter	PEX I		PEX II		PEX III		PEX IV	
	Avg	Std	Avg	Std	Avg	Std	Avg	Std
Temperature	21.5	1.68	21.5	1.64	21.3	1.98	21.3	2.08
Acidity pH	8.36	0.21	8.38	0.20	8.36	0.21	8.40	0.21
Oxygen%	83.0	13.0	82.8	14.8	84.4	13.2	83.8	15.7
Oxygen mg/l	7.16	1.31	7.17	1.42	7.36	1.44	7.37	1.71
ORP mV	190.8	42.2	189.1	40.7	190.0	40.1	187.1	39.1
SPC µs/cm	358.1	29.7	355.5	32.2	359.1	29.7	358.3	30.6
Chlorine (free) mg/l	0.04	0.06	0.04	0.07	0.03	0.05	0.04	0.07
Chlorine (total) mg/l	0.07	0.08	0.06	0.08	0.06	0.08	0.06	0.08
Phosphate mg/l	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01
Nitrite mg/l	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.01
Nitrate mg/l	0.79	0.41	0.77	0.40	0.73	0.37	0.78	0.42
Ammonium mg/l	0.04	0.03	0.04	0.03	0.04	0.03	0.04	0.03
Sulfate mg/l	105.0	12.3	105.3	12.2	105.8	13.0	106.2	13.9
Chloride mg/l	11.9	1.54	11.7	1.55	11.8	1.59	11.6	1.62
Alkalinity mmol/l	0.620	0.09	0.616	0.09	0.618	0.09	0.615	0.10
Hardness mmol/l	1.454	0.15	1.445	0.15	1.436	0.15	1.436	0.15

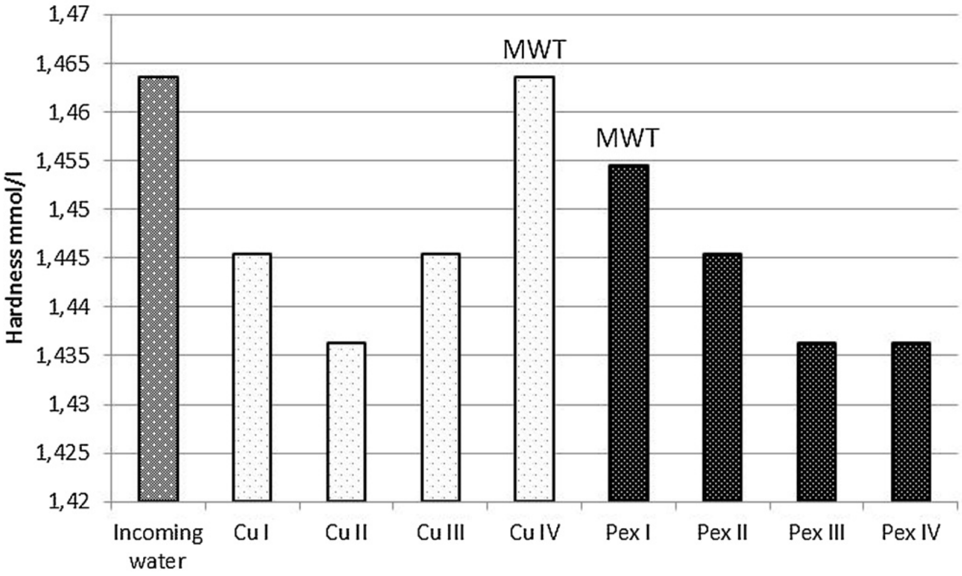

Fig. 3. Measured hardness values for all eight lines as well as for incoming water. Values are averages of eleven measurements made once per month during the first eleven months.

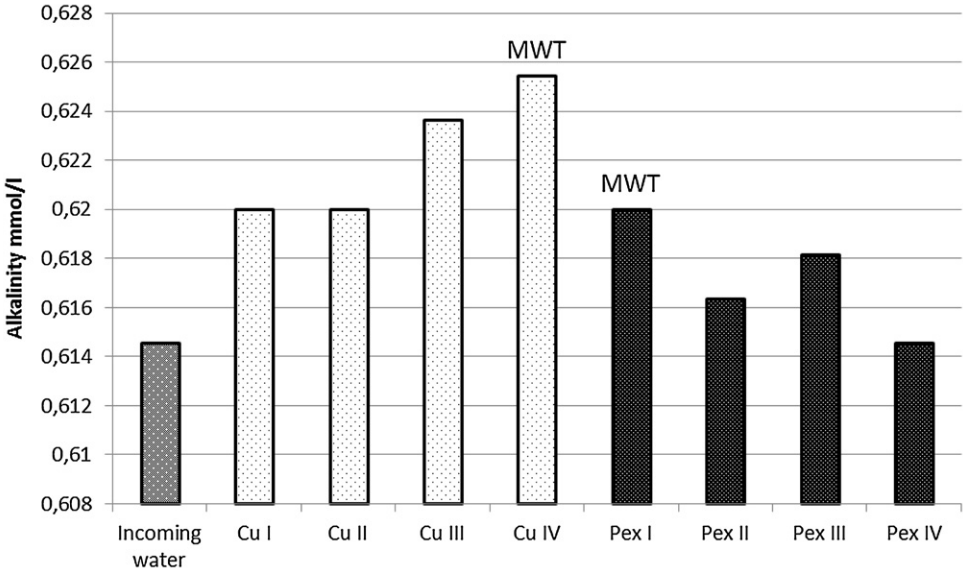

Fig. 4. Measured alkalinity values for all eight lines as well as for incoming water. Values are averages of eleven measurements made once per month during the first eleven months.

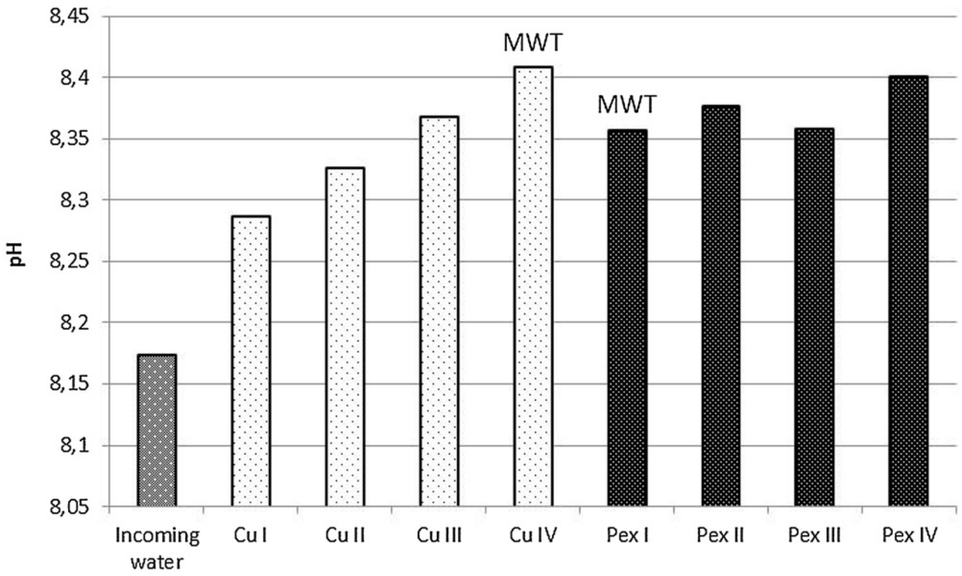

Fig. 5. Measured pH-values for all eight lines as well as for incoming water. Values are averages of eleven measurements made once per month during the first eleven months.

lower values. Hardness value for PEX line I equipped with magnetic water treatment device is between value for incoming water and for lines without magnetic water treatment device. In spite of the fact that this observation is based on only 10 sampling rounds and natural variations between equal sampling points are almost as high suggesting that the part of the calcium present in incoming water will attach on to the inner walls of pipes and MWT has ability to decrease the attachment tendency, i.e., higher amount of hardness (i.e., calcium and magnesium) comes out from pipes having MWT-device. It also might indicate that the impact of MWT is more pronounced in copper pipes than in PEX pipes. In Fig. 4 alkalinity values for all eight lines as well as for incoming water are plotted.

For alkalinity, which in practice is the sum of CO_3^{2-}, HCO_3^- and OH^- ions, the highest values for both materials were measured in lines with MWT. Due to the fact that also variations in pH have impact on alkalinity measured pH-values for all eight lines as well as for incoming water are plotted in Fig. 5.

As seen in Fig. 5 the pH of the water increases in every pipeline compared to the incoming water. Hence, it is evident that the variations in OH^- -ion concentrations cause deviations when comparing together measured hardness and alkalinity. A small increase in the pH in all eight pipelines compared to the incoming water is most likely due to the reactions taking place in the inner wall of pipeline when a new material is in contact with water. This difference may disappear after longer use of pipes. In addition, in Tables 2 and 3 it can be seen that MWT might slightly lower oxygen content of the water. It is rather difficult to make any concrete conclusions about effectiveness of MWT-device based on only water quality measurement. Results give indication that both lines equipped with MWT possess slightly higher values for hardness and alkalinity as well as lower values for oxygen than other lines constructed from the same materials. In order to verify the influence of MWT on pipe materials, pipe samples were detached from four pipelines and calcium content of those were analyzed. Results are collected in Table 4.

According to Table 4 more Ca^{2+} was found from copper lines than from PEX-lines. Hence, these results reveal a stronger tendency of calcium to attach on copper surfaces than to the PEX surfaces. However, in both pipe materials with MWT (Cu IV and PEX I) approximately 15% less calcium were precipitated onto the walls than in the reference lines without MWT (Cu III and Pex II).

Table 4
Surface calcium contents determined from four different pipelines. MWT-devices have been operating 11 months in lines PEX I and Cu IV.

Specimen	Surface calcium content, μg/cm^2
Cu III	1.53
Cu IV	1.31
Pex I	0.48
PexII	0.57

Table 5
Water quality parameters for incoming cold water in Kirkkonummi.

Parameter	Value
pH	7.9
Oxygen (mg/l)	10.6
Alkalinity (mmol/l)	0.52
Sulfate (mg/l)	60
Cu (μg/l)	6.5
Bicarbonate/sulphate ratio	0.53

The hardness in the lines with MWT (Pex I and Cu IV) appeared to be higher than that in the respective reference lines (PeX II and Cu III) as indicated in Fig. 3. This supports the observation of decreased attachment of calcium carbonate onto surfaces caused by the MWT.

FE–SEM images of the copper surfaces are in Fig. 6. Quasi-quantitative elemental analyses revealed that calcium contents in the target sites were low, less than 1%. Besides the primary component copper other observed elements over one percent molar level were oxygen, zinc, aluminum, sodium, iron and magnesium. Appearance of a less compact structure caused by the magnetic field is evidently referring to an ability of magnetic field to induce morphological rearrangements onto the surfaces cover with scales and oxidation products.

Most likely scaling tendency would have been more pronounced if the timeframe of the study has been longer. The timeframe of this study, i.e., 11 months, is not a long period compared to the whole 50 years typical life-time of pipelines. During longer period also the impact of MWT-device would have been more significant. In addition, these measurements were made with totally new materials, which both were first time set to a contact with water, and hence, the results are also affected by the relevant oxidation reactions that take place on the surface of material in contact with water.

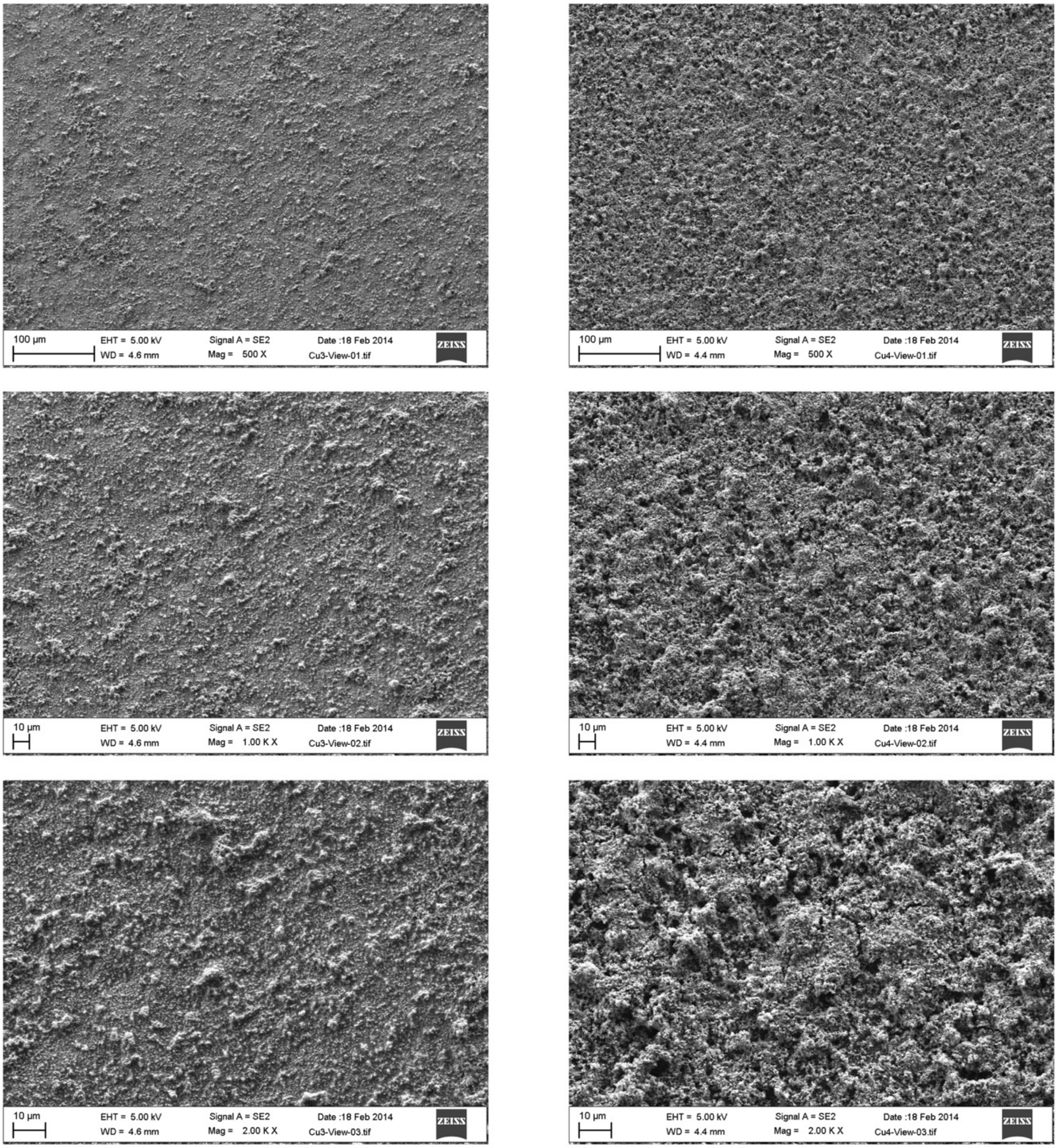

Fig. 6. FE–SEM images of the surface scales on copper pipes. Magnitudes from up to down: 500, 1000 and 2000. Left: no magnetic treatment (Cu III), Right: with magnetic treatment (Cu IV).

3.2. *Studies in an apartment complex with five different buildings*

In real-life studies existing old water system installed in 1990 was used. Recently several leakages due to the pit corrosion of copper pipes have been observed in hot tap water system. Instead, no leakages due to corrosion were observed in cold water systems. Throughout the years water quality has been varied but typical values representing the quality of the incoming water during this study are collected in Table 5.

According to the water quality risk for pitting due to low bicarbonate/sulfate ratio (recommendation >1) exists. Water samples from apartments C8 and D18 of the old terrace house together with incoming water samples were collected three times. One time before MWT-device was installed and two times after that. First one of these was done 3 months and second one year after taking MWT — device into use. In Table 6 measured Cu^{2+}-ion contents of the waters are collected.

Before installation of MWT-device a small increase in the amount of Cu^{2+} were observed to occur within copper, both in cold water and hot water compared to the incoming water. After installation of MWT-device the amount of released Cu^{2+} increases in hot water lines already after 3 months use quite drastically. After one year of use measured Cu^{2+} values are also high in cold water lines in spite of the fact that the amount of Cu^{2+} is even smaller

Fig. 7. Photographs showing the inside of the pipe. On left pipe sample from the hot water circulation before installation of MWT and on right pipe sample after one year of use.

Fig. 8. Photographs representing different kind interactions between drinking water and pipe material. On left water sample from hot water circulation pipe after 5 min shaking with silica balls before installation of MWT and on right similar water sample after one year use of MWT.

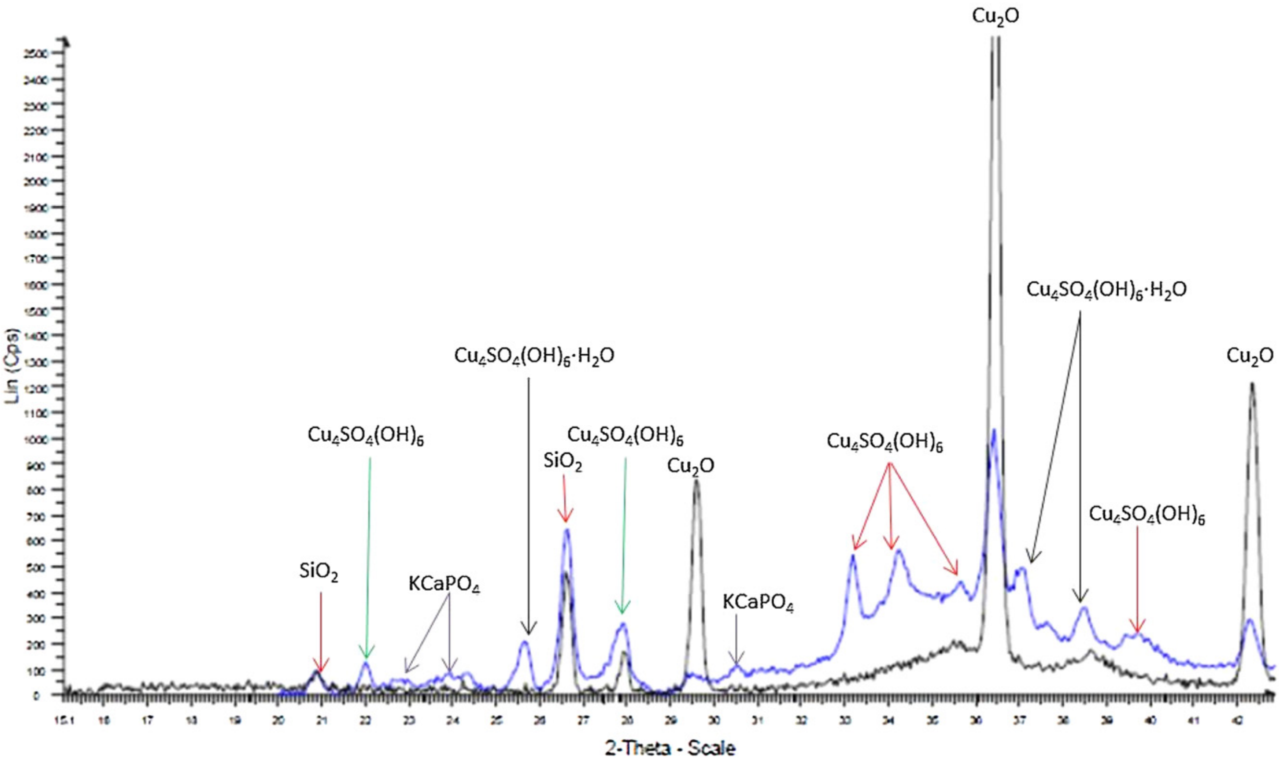

Fig. 9. Diffractograms of pipe samples that has been in contact with cold water. Blue line represents sample before installation of MWT and black line sample after one year use of MWT (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 6
Analyzed Cu^{2+}-ion content in drinking water. All values are μg/l.

	Before MWT			3 months after installation of MWT			12 months after installation of MWT		
	Incoming water	C8	D18	Incoming water	C8	D18	Incoming water	C8	D18
Cold water	6.5	13	15	5.8	11	36	2.6	190	130
Hot water		29	32		96	140		200	170

Table 7
Analyzed Fe^{3+}-ion content in drinking water. All values are μg/l.

	Before MWT			3 months after installation of MWT			12 months after installation of MWT		
	Incoming water	C8	D18	Incoming water	C8	D18	Incoming water	C8	D18
Cold water	88	9	8	37	38	39	34	42	45
Hot water		9	8		38	98		53	52

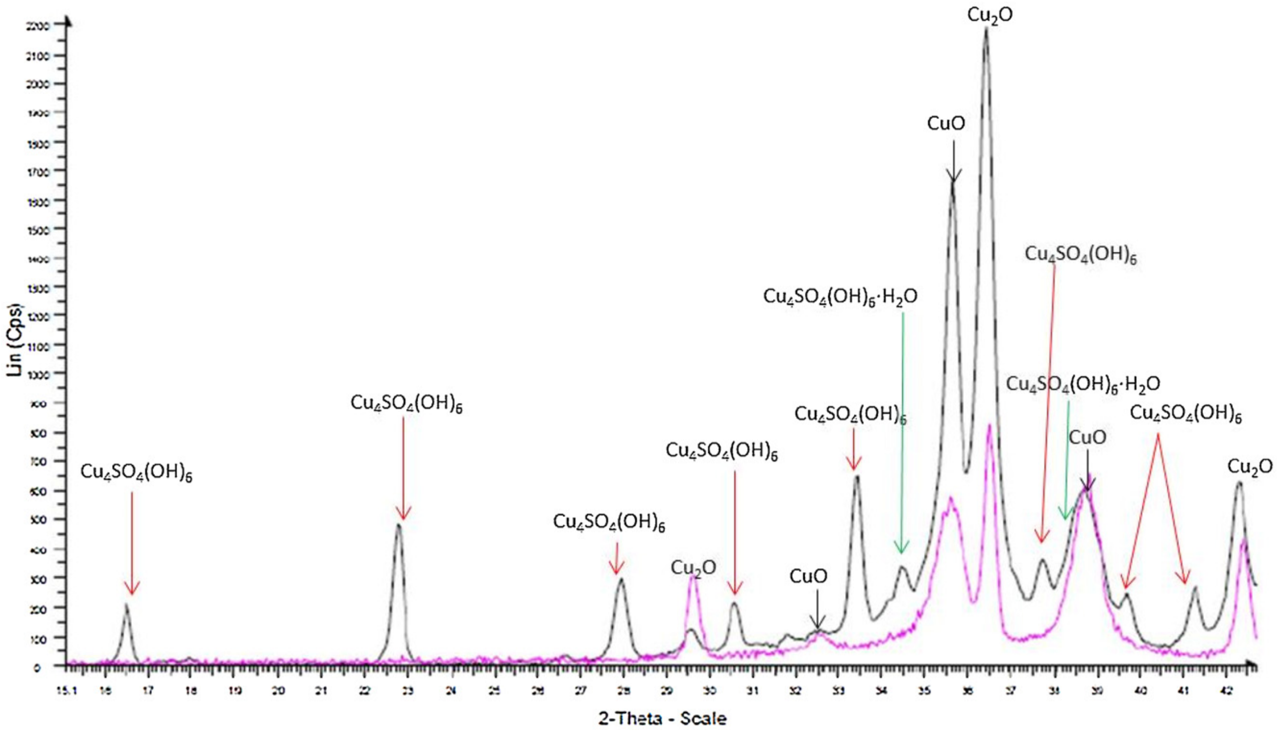

Fig. 10. Diffractograms of pipe samples that has been in contact with hot water. Black line represents sample before installation of MWT and violet line sample after one year use of MWT (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

in incoming water. Increased Cu^{2+} values both in cold and hot water lines are most likely due to the release of corrosion products, i.e., oxidized copper, formed earlier during the several years of use before installation of MWT-device. There were also found chances in the Fe^{3+}-ion content. Ferric ions have tendency to precipitate inside pipe networks and promote corrosion in buildings. In Table 7 changes in the ferric ion content of the water samples are presented. Before MWT-device was taken into use part of the ferric ions that exists in incoming water were not found in water samples taken from the taps in apartments C8 and D18.

After taking MWT-device into use the Fe^{3+}-ion content of the samples taken from the apartments C8 and D18 are no longer lower than respective content in incoming water. Instead, more Fe^{3+}-ions are found from water samples after taking MWT in use indicating detachment of old precipitations.

In order to verify this behavior pipe samples were detached approximately from the same location of the water system both before installation of MWT-device and after installation of MWT-device. In Fig. 7 the photograph has been shown from inside of the pipe both before installation of MWT-device and after one year of use of MWT-device. By comparing these photographs it can be noticed that peaks formed due to corrosion and scaling are no longer so markedly present after one year use of MWT-device.

In addition, for both of these pipe samples from hot water circulation similar treatment, where precipitations were detached from the inner surfaces of the pipe collectors by shaking for 3 × 10 min with sterile 2 mm glass beads followed by rinsing with 5 ml water. The water samples collected from the pipe before MWT installation was greenish but the water sample after one year use of MWT was brown indicating strong detachment behavior of the corrosion products. These water samples are shown in Fig. 8.

Solids detached during the 5 min shaking treatment were separated from liquid with filtration and analyzed on XRD. Most of the solids detached from cold water pipes were different forms of SiO_2 and small amounts of oxidized copper. Instead, from hot water pipes no SiO_2 compounds were found, only different forms of oxidized copper, mostly cuprite.

Several pipe samples were analysed on XRD both before installation of MWT and after installation. The surface of the pipe samples that have been in contact with cold tap water contained besides copper also oxidized forms Cu_2O, CuO as well as two different forms of $CuSO_4$, i.e., brochantite ($Cu_4SO_4(OH)_6$) and posnjakite ($Cu_4SO_4(OH)_6 \cdot H_2O$). In addition, several forms of SiO_2, together approximately 10%, were found. Silicates were not found from hot water pipes. In circulating hot water pipes copper sulfates brochantite and posnjakite were found close to the points where damages due to the pitting corrosion have occurred. In addition, much smaller proportion of oxidized forms of copper was observed in hot water circulation pipe indicating poor formation of oxidized passive layer. After one year of installation of MWT no more brochantite or posnjakite were found from hot water and cold water pipe samples. This is illustrated in Figs. 9 and 10. Corrosion products of brochantite and posnjakite are copper sulfate products associated with pitting corrosion. Before taking MWT in use in cold water lines posnjakite together with small amounts of brochantite were found but in hot water lines only bronchantite.

4. Conclusions

In this study it was shown in the pilot scale water distribution system that the commercial MWT-device clearly limits the precipitation of $CaCO_3$ on to the walls manufactured from two different materials. The amount of the impact is dependent also on many other factors, e.g., water quality, flow velocity, pressure and total amount of water. In addition, the impact is more pronounced in hot water lines than in cold water lines. This might also partly be due to the higher tendency of $CaCO_3$ to precipitate more at higher temperatures.

In the case of old existing networks it is clearly shown that MWT has strong impact on corrosion products formed on copper pipes. Corrosion products start to release into the water. For a very old pipe it may take clearly more than one year to reach condition where no more oxidized copper is released in to the water flowing through the pipe. It is also noticed that MWT has a strong impact on behavior of iron existing in drinking water.

There was also a slight indication that more oxidized copper i.e., cuprite was formed on inner surface of copper pipe in hot water circulation after installation of MWT. However, the number of pipe samples was too low to draw any conclusion about that and more research is needed. Already in 1975 The National Aeronautics and Space Administration (NASA) tested magnetically treated water, for corrosion rates of steel corrosion coupons [19]. Corrosion rates of 1–50 mils/year were obtained using chemical inhibitors, (4 mils/year considered acceptable), with corrosion rates of 0.0 mils/year obtained for the magnetically treated water. These observations clearly showed the same tendency in spite of the fact that the mechanisms are not known, but observed reasons explaining the MWT effectiveness includes effect on electrokinetic potentials [12], results based generally on electrical double layer theory [20] as well as magnetohydrodynamics [21]. Also, an elusive mechanism of the magnetic memory of water has been proposed [22]. There most likely exist differences in the impact of MWT between different materials. In addition, it must be concluded that these observations are also dependent on MWT-device used in the studies. There are differences between different devices and that may be reason for the contradictory results obtained during the last decades. More studies are needed to find out the mechanisms of MWT on corrosion. Based on these results more studies also in the real water systems are needed but already it can be pointed out that the use of MWT would be advantageous in the real-estates hot water circulation systems and in the drinking water systems. There should also consider more stringent requirements for the technical water quality for copper pipes, including a sufficient (>1) bicarbonate/sulfate ratio.

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