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Raziskava vpliva naprave za magnetno obdelavo vode na izločanje vodnega kamna v industrijskem stroju za pomivanje steklenic z uporabo vrstične elektronske mikroskopije

SEM Examination of the Influence of a Magnetic Water-Treatment Device on the Scale Precipitation in an Industrial Machine for Bottle Cleaning

Viljem Kozic - Lucija Črepinšek Lipuš - Jurij Krope

Testirana je bila tržna magnetna naprava za nadzor vodnega kamna v industrijskem stroju za pomivanje steklenic. Vzorci vodnega kamna, ki so se izločili na testnih ploščicah iz raznih materialov, so primerjani za magnetno obdelano in neobdelano vodo. Utežni rezultati in morfološko – kemični rezultati analize z elektronskim vrstičnim mikroskopom – so pokazali praktično enako kemijsko sestavo, vendar v primerih magnetno obdelane vode približno 20-odstotno zmanjšanje količine oblog, z manj trdimi, neadhezivnimi, prašnatimi strukturami. V primeru izločanja na korozivni jekleni ploščici je magnetna obdelava povzročila obilnejše nastajanje železovega hidroksida, vendar je bila čvrsta obloga prav tako manj strjena kakor v preostalih primerih.

(Ključne besede: obdelava vode magnetna, kamen vodni, mikroskopi elektronski, mikroskopi vrstični)

A commercial magnetic device for scale control was tested in an industrial machine for bottle cleaning. Scale samples, which had precipitated on test plates of different materials, were compared for magnetically treated and non-treated water. Gravimetrical results and morphological-chemical results from a scanning electron microscope analysis showed practically the same chemical composition, but an approximately 20% decrease in the amount of scale and less-compact, non-adhesive, powder-like structures in the cases of magnetically treated water. In the case of precipitation on a corrosive steel plate, the magnetic treatment caused the abundant formation of iron hydroxide, but the structure of the precipitate was also less compact than in the other cases.

(Keywords: magnetic water treatment, scale (deposits), scanning electron microscopy)

1 UVOD

1.1 Nastajanje vodnega kamna

Nastajanje vodnega kamna je pojav, pri katerem se minerali, prvotno raztopljeni v vodi, odlagajo na stenah cevi in površinah toplotnih izmenjav.

Obloge vodnega kamna so sestavljene iz mineralov, ki s povišanjem temperature postanejo manj topni. Med njimi je najpogostejši kalcijev karbonat [1]. Kalcijev karbonat ima tri polimorfe: kalcit, aragonit in vaterit; z romboedrično, ortorombsko oziroma šesterno strukturo [2].

Vaterit je najmanj stabilna faza, aragonit je metastabilna faza in kalcit je najstabilnejši. Kalcit je v splošnem manj topen kakor aragonit, vendar je

1 INTRODUCTION

1.1 Scale Formation

Scale formation is a process in which minerals, originally dissolved in water, are deposited on pipe walls and heat-exchanger surfaces.

Scale deposits are composed of minerals that become less soluble with increasing temperature, calcium carbonate being the most common [1]. Calcium carbonate has three kinds of polymorph: calcite, aragonite and vaterite, with rhombohedral, orthorhombic and hexagonal structures, respectively [2].

Vaterite is the least stabile phase, aragonite is metastable and calcite is the most stable. Calcite is generally less soluble than aragonite, but aragonite is often the first phase to precipitate out of solution aragonit pogosto prva faza, ki se izloči iz raztopine in nato sčasoma prekristalizira v kalcit. Hitrost prekristalizacije je odvisna od *pH*, temperature in nečistoč. Kalcit je večinoma v povezavi s trdim vodnim kamnom, medtem ko aragonit daje bolj mehke oblike, ki so laže odstranljive.

Mnogi avtorji so poročali, da imajo različni kovinski ioni, celo z milijonskimi deleži, vpliv na obliko izločanja polimorfov kalcijevega karbonata. Herzog je s sodelavci poročala o pozitivnem učinku ionov Fe^{2+}, ki so že z milijonskimi deleži zavirali nastajanje kalcita in pospeševali nastajanje aragonita [3]. Tudi prisotnost ionov Zn^{2+} daje celo z miljardinskimi deleži prednost nastajanju aragonita [4]. Ioni Mg^{2+} še posebej vplivajo na obliko kristalizacije in povzročajo spremembe v morfologiji kristalov kalcijevega karbonata [5]. Zaradi zapletenosti kristalizacije polimorfov in zapletenega vpliva primesi je v praksi nadzor kristalizacijskega procesa otežkočen.

and recrystallizes into calcite over time. The rate of the recrystallization depends on the *pH*, the temperature and the presence of impurities. Calcite is usually associated with hard scale, whereas aragonite gives rise to a softer type of scale that is easily removed.

Many authors have reported about various metallic ions that have an effect, even in ppm levels, on the precipitation behavior of calcium carbonate polymorphs. Herzog and coworkers reported about the influence of Fe^{2+} ions, which even in ppm levels inhibited the formation of calcite and promoted the formation of aragonite [3]. Also Zn^{2+} ions, even in ppb levels, can cause the preferential formation of aragonite [4]. Mg^{2+} ions have a strong influence on the crystallization behavior and induce a morphological change in the calcium carbonate crystals [5]. The complicated crystallization behavior of the polymorphs and the complicated effects of the additives make artificial control of the practical crystallization process very difficult.

1.2 Preprečevanje vodnega kamna

V uporabi so mnoge kemijske metode za preprečevanje ali nadzor izločanja kalcijevega karbonata [6]. Ena metoda je razgradnja hidrogen karbonatnih ionov v ogljikov dioksid z dodajanjem kislin, vendar znižanje *pH* povzroča težave s korozijo in razgradnjo konstrukcijskih materialov. Druga metoda je kationska izmenjava [7], katere stroški pa so zelo veliki.

Najbolje sprejeta metoda za nadzor vodnega kamna je obdelava s pragovnimi inhibitorji, med njimi dodatki polifosfatnih komponent, ki v zelo majhnih koncentracijah zavirajo rast kalcitnih kristalov. Mehanizem zaviranja še ni povsem razjasnjen. Ena možnost je, da adsorbirani fosfonatni ioni deaktivirajo mesta rasti na kalcitnih kristalih [8]. Polifosfonatni inhibitorji vodnega kamna so dragi in pod strogimi okoljevarstvenimi predpisi.

Običajne kemijske metode spremenijo kemijsko sestavo raztopine in se ne morejo uporabljati na nekaterih področjih, kakršni sta živilska industrija in industrija pijač, kjer so predpisane stroge zahteve glede kakovosti vode. Varovanje okolja in gospodarnost sta dva močna razloga za razvoj in uporabo različnih oblik nekemijskih metod za preprečevanje vodnega kamna.

Razvite in uporabljane so mnoge fizikalne metode za nadzor vodnega kamna. Na tržišču so različne naprave za električno obdelavo vode. Nova takšna naprava je Geno-K4 [9], ta sestoji iz elektrolitske celice, ki nepretrgoma proizvaja droben razpršen prah kristalov kalcijevega karbonata. Ta prah se dovaja v tok vode in vzpodbuja kristalizacijo kalcijevega karbonata v sredici vode, kar zmanjša obseg kristalizacije na površinah tehnološke opreme.

Druga nova metoda uporablja ultrazvočno polje, ki zavira kristalizacijo kalcitne kristalne oblike

1.2 Scale Prevention

Many chemical methods are used to prevent or control calcium carbonate precipitation [6]. One method involves the degradation of hydrogen carbonate ions into carbon dioxide by adding acids, but the resulting lowered *pH* causes problems with corrosion and the degradation of construction materials. Another method is cation exchange [7], but its costs can be very high.

The most popular scale-control method is treatment with threshold inhibitors, such as polyphosphonate compounds, which in very low concentrations act as agents for inhibiting the growth of calcite crystals. The inhibiting mechanism is however, not understood precisely, yet. One possibility is that the adsorbed phosphonate ions deactivate growth sites on the existing calcite crystals [8]. Polyphosphonate scale inhibitors are expensive and are subject to strict environmental regulations.

Traditional chemical methods change the solution chemistry and cannot be used in some fields, such as the food and drink industries, where strict requirements for water quality are demanded. Thus environmental protection and economic considerations are two strong motivations for developing and using various types of non-chemical scale-prevention methods.

Many physical methods for scale control have been developed and used, and various devices for electric water treatment are marketed. One new device is Geno-K4 [9], which consists of an electrolytic cell that continuously produces a fine dispersed powder of calcium carbonate crystals. This powder is supplied to the water flow, stimulating the crystallization of calcium carbonate in the bulk of the water, which consequently reduces the precipitation on the equipment surfaces.

Another new method uses an ultrasonic field, which retards the crystallization of the calcite

[10]. Zelo podoben učinek j ebil ugotovljen z ultravijoličnim sevanjem [11].

1.3 Magnetna obdelava vode

Najbolj uporabljana fizikalna metoda za nadzor vodnega kamna je magnetna obdelava vode (MOV), pri kateri voda teče skozi magnetno polje. Naprave za MOV so doslej proizvajala in prodajala številna mednarodna podjetja več ko 50 let v izvedbah od majhnih gospodinjskih do ogromnih industrijskih naprav [12]. Kljub nekaj desetletni praktični rabi ostaja učinkovitost teh naprav negotova zaradi nepopolnega razumevanja, kako magnetno polje vpliva na vodni disperzni sistem. Poleg tega se poročani učinki na tem področju včasih ne ujemajo ali niso ponovljivi. To je verjetno zato, ker imajo celo majhne spremembe v sestavi vode in odstopanja v obdelovalnem postopku močan vpliv na jedrenje in kristalizacijo komponent, ki tvorijo vodni kamen.

Številne raziskave, izvedene na laboratorijsko pripravljenih vodnih disperzijah, so potrdile učinek MOV ([13] do [15]). Nekaj zanimivih rezultatov je bilo ugotovljenih, ko je bila mirujoča voda izpostavljena različnim oblikam magnetnih polj [16], vendar so učinki močneje izraženi, ko se voda pretaka skozi magnetno polje, ki je pravokotno na smer toka vode [17].

Vendar mehanizem MOV še ni povsem razjasnjen, ker se opaženi magnetni učinki ne morejo preprosto pojasniti z neposrednimi elektromagnetnimi interakcijami med diamagnetnimi komponentami, ki delajo vodni kamen v vodni disperziji. Predvsem je interakcijska energija med magnetnim poljem in ionom bistveno manjša od termične energije kT in je zato učinek medmolekularnih trkov zanemarljiv. Tako se eksperimentalno opaženi učinek, ki se ohranja še po MOV, t.i. »magnetni spomin«, ne more pojasniti na ta način.

Obstaja nekaj hipotez o mehanizmu MOV ([18] in [19]). Ena možnost je, da magnetno polje povzroča deformacijo difuzijske plasti, ki obdaja dispergirane delce v vodni disperziji ([20] in [21]). Ta deformacija vodi v začasno znižanje odboja in posledično v pospešeno kristalizacijo. V magnetnem polju se bodo premaknjeni proti – ioni dlje časa zadržali v Sternovi plasti in na ta način se lahko pojasni magnetni spomin.

Učinek preprečevanja oblog vodnega kamna je verjetno rezultat spremenjene kristalizacije komponent, ki tvorijo vodni kamen v sredici vode, kar posledično zmanjša obseg oblaganja na površinah tehnološke opreme. Torej je z vidika dodajanja fino razpršenega prahu kalcijevega karbonata MOV podobna novi napravi Geno-K4.

crystal form [10]. A very similar effect has been demonstrated with ultraviolet radiation [11].

1.3 Magnetic water treatment

The most used physical anti-scale method is magnetic water treatment (MWT), where the water flows through a magnetic field. MWT devices have been produced and marketed by a number of international companies for over 50 years with applications ranging from small domestic to gigantic industrial devices [12]. Despite several decades of practical use the efficiency of these devices still remains unclear due to an incomplete understanding of how the magnetic field affects water-dispersion systems. Additionally, reported effects in this area are sometimes not consistent or not reproducible. This is probably because even small variations in the water composition and differences in the treatment process can have a great influence on the nucleation and crystallization of scale-forming components.

A number of investigations carried out on laboratory-prepared water dispersions have confirmed MWT effects ([13] to [15]). Some interesting results were found when static water was exposed to various types of magnetic fields [16], but stronger effects are present when water flows through the magnetic field, which is perpendicular to the stream [17].

The MWT mechanism, however, is not clear yet, because the observed magnetic effects cannot be explained simply by direct electromagnetic interactions among the diamagnetic scale-forming components in water dispersions. First of all, the interaction energy between the magnetic field and the ion is much smaller than the thermal energy, kT, therefore, it is negligible in comparison to the effects due to molecular collisions. This means that the experimentally observed remaining magnetic effect, the so-called “memory effect”, cannot be explained in this way.

A number of hypotheses about the MWT mechanism exist ([18] and [19]). One possibility is that the magnetic field induces a deformation of the diffuse layer surrounding the dispersed particles in the water ([20] and [21]). This deformation leads to a temporary decrease in the repulsion barrier and, consequently, to an increased crystallization. In the magnetic field, the shifted counter-ions will remain absorbed in the Stern layer for a longer time; therefore, the magnetic memory can be explained.

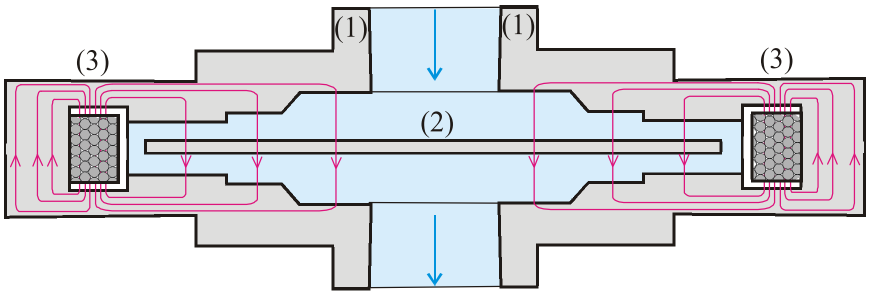
The anti-scale effect is possibly caused by accelerated or modified crystallization of scale-forming components in the bulk of the water, which consequently reduces the precipitation on the equipment surfaces. Therefore, from the point of view of adding fine dispersed powder of calcium carbonate, MWT is similar to the new Geno-K4 device.

2 PREIZKUSI

V polnilnici mineralne vode Radenska v Sloveniji se MOV uporablja za nadzor vodnega kamna v toplotnih menjalnikih in stroju za pomivanje steklenic. Karbonatne obloge na testnih ploščicah iz različnih materialov so bile proučevane s tržno magnetno napravo EM IV, prikazano na sliki 1.

2 EXPERIMENTS

At the mineral-water company Radenska, in Slovenia, MWT is extensively used for scale control in heat exchangers and bottle-cleaning machines. The carbonate incrustations on test plates of various materials were investigated for the commercial magnetic device EM IV, presented in Fig. 1.



Sl. 1. *Naprava EM IV za magnetno obdelavo vode*
Fig. 1. *EM IV device for magnetic water treatment*

Okrov naprave (1) je iz litega železa in notranja plošča (2) je jeklena. Magnetno polje povzroča solenoid (3), nameščen znotraj okrova. Voda vstopa na vrhu naprave in prečno obliva notranjo ploščo ter se nato spodaj vrača k izhodu na dnu. Solenoid ustvarja 100 Hz utripajoče magnetno polje povprečne gostote 0,05 T.

Postopek pomivanja steklenic obsega neprekinjeno nameščanje steklenic v tekoči trak in obdelavo le teh z več zaporednimi fazami:
- vodna kopel s temperaturo do 34 °C,
- obdelava z natrijevim hidroksidom - vroča kopel do 65 °C, obrizgavanje do 90 °C in vroča kopel do 70 °C,
- vmesno spiranje s toplo vodo do 50 °C,
- obrizgavanje s toplo fosforno kislino do 50 °C,
- spiranje z vodo – najprej s toplo vodo do 45 °C in nato s postopnim ohlajanjem steklenic do končnega spiranja s svežo hladno vodo.

Napajalna voda je lokalna podtalnica z naslednjimi podatki: temperatura 12 °C, *pH* = 7,4, električna prevodnost 0,047 S/m, stopnja nasičenja s kisikom 32% in celotna trdota 13,5 nemških trdotnih stopinj. Ionska sestava je podana v preglednici 1.

V prehodnem območju med lužno in kislinsko obdelavo postane voda prenasičena, ker je

The housing of the device (1) is an iron casting and the inner plate (2) is made from steel. The magnetic field is induced by a solenoid (3), placed inside the housing. Water enters through the top of the device, flows radially over the inner plate and then returns to the bottom output. The solenoid produces a 100-Hz pulsating magnetic field with an average field density of about 0.05 T.

The bottle-cleaning process consists of continuously inserting bottles into a conveyor and treating them in several successive steps:
- water bath with temperature up to 35 °C,
- treatment with natrium hydroxide – hot bath up to 65 °C, high-pressure splashing up to 90 °C and then hot bath up to 70 °C,
- intermediate washing with warm water up to 50 °C,
- splashing with warm phosphoric acid up to 50 °C,
- splashing with water – first with warm water up to 45 °C, then with successive cooling of the bottles until the final splashing with cold fresh water.

The supplied water is local ground water with following data: temperature 12 °C, *pH* = 7.4, electric conductivity 0.047 S/m, oxygen saturation degree 32% and total hardness 13.5 German hardness degrees. The ion composition is given in Table 1.

In the intermediate zone between the alkaline and acidic treatments the water gets oversaturated

Preglednica 1. *Sestava napajalne vode*
Table 1. *The supplied water composition*

Kationi Cations	(g/m^3)
Ca^{+2}	62
Mg^{+2}	21
Na^{+}	8
K^{+}	4,5

Anioni Anions	(g/m^3)
Cl^{-}	26
SO_4^{-2}	24
NO_3^{-}	22

Mikroelementi Microelements	(mg/m^3)
Fe^{+2}	50
Zn^{+2}	20
Mn^{+2}	8
Cu^{+2}	1,6

med postopkom spiranja njena temperatura 60 °C in $pH = 9$. To vodi v obilno izločanje vodnega kamna.

Magnetna naprava je bila vgrajena na dovodno cev, da bi se preverila alternativna rešitev za nadzor vodnega kamna. Preizkusi so bili izvedeni v dvomesečnih zagonih z magnetno napravo in brez nje v stalnih obratovalnih razmerah. Testne ploščice so bile nameščene v pomivalni stroj, da bi se obloge analizirale utežno in kvalitativno. Vzorci so bili morfološko in kemično razpoznani z elektronskim vrstičnim mikroskopom JEOL JSM-840A, ki je dodatno opremljen z mikrostrukturnim programom Digiscan FDC.

Za testne ploščice so bili izbrani trije materiali:

- nerjavno jeklo (11X5CRNI189) za simulacijo pogojev izločanja na stenah pomivalnega stroja ter na tekočem traku,
- steklo za simulacijo pogojev izločanja na steklenicah in
- jeklo (FE 360B) za razširitev opazovanj še na korozijske ostanke.

3 REZULTATI IN RAZPRAVA

Značilno enomesečno izločanje vodnega kamna je pri hitrosti toka vode 160 l/min znašalo 0,25g/cm^2. Relativne količine, pri katerih so kot referenca vzete steklene ploščice v neobdelani vodi, so podane v preglednici 2. Povprečna relativna količina oblog na vseh testnih ploščicah je bila v primeru MOV približno za 20% manjša kakor v primeru neobdelane vode.

Kakovostna analiza je pokazala, da MOV ni bistveno spremenila sestave vodnega kamna, ampak je vplivala na njegovo morfologijo. Izjema so bili vzorci na navadnem jeklu, pri katerih je MOV povečala delež železovih hidroksidov. Slika 1 prikazuje primerjavo posnetkov z vrstičnim elektronskim mikroskopom med vzorci iz obdelane in neobdelane vode.

Prstom podobne ploščice, ki so razvidne na posnetku vzorca na jeklu z MOV, so kristali lepidokrokita (γ – FeOOH).

V primerih brez MOV so nastajale bolj trde in adhezivne obloge. Takšen vodni kamen lahko zadržuje natrijev hidroksid, ki delno nevtralizira kislino v naslednji fazi obdelave. To povečuje porabo kemikalij in zahteva pogosto čiščenje stroja. MOV je

because its temperature is 60 °C and $pH = 9$ during the washing process. This leads to abundant scale precipitation.

The magnetic device was inserted into the water input pipeline to test it as an alternative solution for scale control. Experiments were performed in two-month runs with and without MWT under constant operational conditions. Test plates were inserted into the washing machine to analyze the precipitate gravimetrically and qualitatively. Samples were morphologically and chemically identified by JEOL JSM-840A scanning electron microscope (SEM) including the micro-structural program Digiscan FDC.

Three different test plate materials were chosen:

- stainless steel (11X5CRNI189) to simulate the precipitation conditions on the heat exchanger, washing machine walls and conveyor,
- glass to simulate the precipitation conditions on the bottles,
- steel (FE 360B) to extend the research on corrosion products.

3 RESULTS AND DISCUSSION

The typical scale deposition for one month at a water flow rate of 160 l/min was 0.25 g/cm^2. The relative amounts, where glass plates in untreated water are taken as a reference, are presented in Table 2. The average relative amount of deposit on all the test plates was about 20% lower in the case of MWT than in the case of untreated water.

A qualitative analysis showed that MWT did not affect much the chemical composition of the scale, but it did have an influence on the morphology. The exceptions were the samples on steel, where MWT raised the portion of iron hydroxides. Figure 1 shows the comparison between the SEM micrographs of samples from treated and untreated water.

The finger-like plates, which can be seen in the micrgrph of the sample on steel with MWT, are crystals of lepidocrocite (γ – FeOOH).

In the cases without MWT, more compact and adhesive linings were formed. Such scale is able to retain natrium hydroxide, partially neutralizing the acid in the following phase. This raises the consumption of chemicals and demands frequent cleaning of the ma-

Preglednica 2. *Relativne količine oblog na testnih ploščah*
Table 2. *Relative amounts of deposits on test plates*

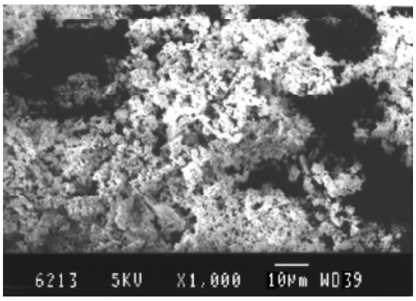
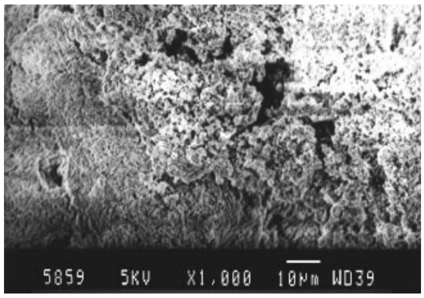
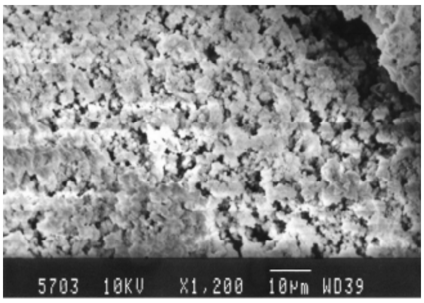
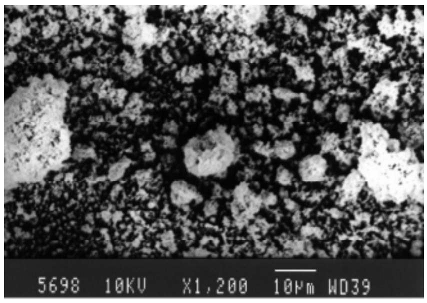
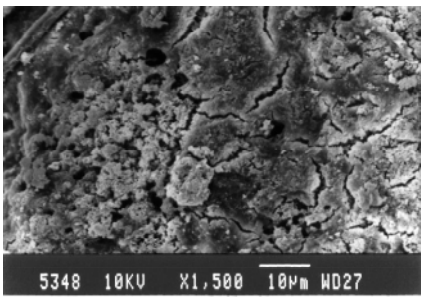
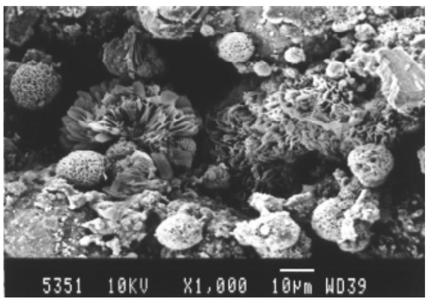
Material testne ploščice Material of test plate	Steklo Glass	Nerjavno jeklo Stainless steel	Jeklo Steel
neobdelana voda untreated water	1,00	1,13	2,15
MOV MWT	0,83	0,92	1,81

povzročala neadhezivne, praškaste obloge, ki se zlahka odstranijo, in se lahko pomivalni stroj vzdržuje v bolj čistem stanju.

Rentgenski spektri vzorcev so prikazani na sliki 2. Spektri podajajo sestavo vzorcev le kvalitativno. Na podlagah iz stekla in nerjavnega jekla prevladuje kalcijev karbonat, na korozivnem jeklu pa je v velikem deležu tudi železov hidroksid. Natrij je prisoten v spektrih zaradi natrijevega hidroksida in zlato, zato ker so bili vzorci prevlečeni z njim za potrebe elektronskega mikroskopiranja.

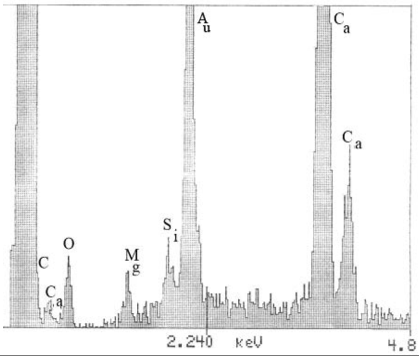
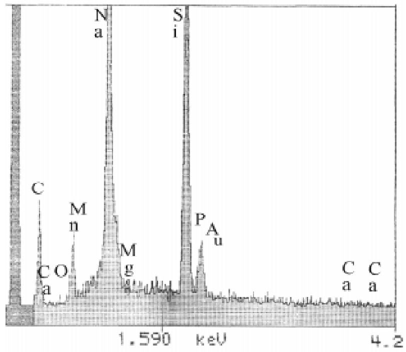
chine. The MWT caused non-adhesive and powder-like linings, which are easier to remove and therefore the washing machine can be maintained in a cleaner condition.

X–ray spectra of the samples are presented in Fig. 2. The spectra identify the compositions of the samples only qualitatively. The main component on the glass and stainless-steel surfaces is calcium carbonate; while on the corrosive steel a high proportion of iron hydroxide is also present. Natrium is present in the spectra because of the natrium hydroxide, and gold is present because the samples were coated with it for the electron microscopy requirements.

Testna ploščica Test plate	brez MOV without MWT	z MOV with MWT
steklo glass	 *kalcijev karbonat* *calcium carbonate*	 *kalcijev karbonat in silikati* *calcium carbonate and silicates*
nerjavno jeklo stainless steel	 *kalcijev karbonat* *calcium carbonate*	 *kalcijev karbonat* *calcium carbonate*
jeklo steel	 *kalcijev karbonat* *z nekaj železa* *calcium carbonate* *with some iron*	 *železov hidroksid* *z nekaj kalcijevega karbonata* *iron hydroxide* *with some calcium carbonate*

Sl. 2 *Fotografije vzorcev z vrstičnim elektronskim mikroskopom*

Fig. 2 *SEM photographs of samples*

<table>
<tr><td>Testna ploščica
Test plate</td><td>brez MOV
without MWT</td><td>z MOV
with MWT</td></tr>
<tr><td>steklo
glass</td><td>
</td><td>
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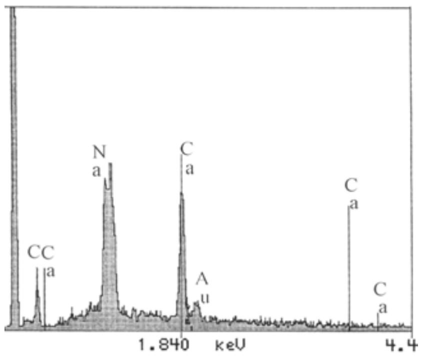
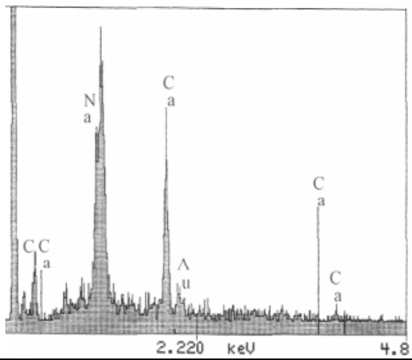
stainless steel</td><td>
</td><td>
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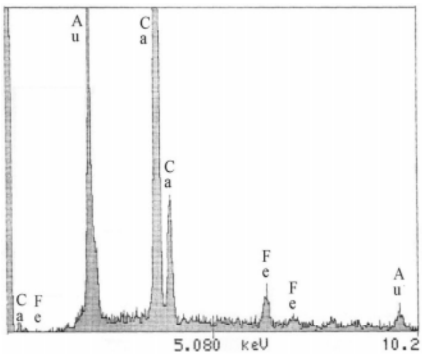
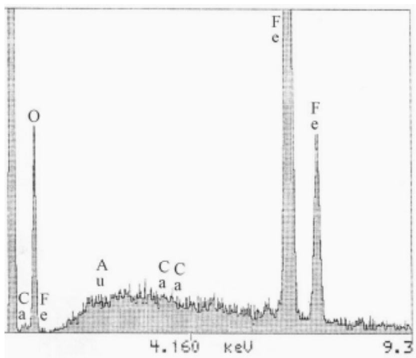
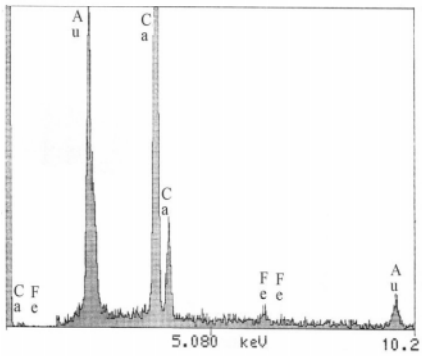
steel</td><td>
</td><td>

radialno rastoče plošče lipidokrokita
radial growing plates of lepidocrocite


manjši okrogli delci
smaller spherical particles</td></tr>
</table>

Sl. 3 *Rentgenski spektri vzorcev (vodoravna os – energija sevanih žarkov X, navpična os – intenziteta žarkov X)*
Fig. 3 *X – ray spectra of samples (horizontal-axis – X-ray emission energy, vertical-axis – X-ray intensity)*

4 SKLEP

Sklepamo, da je bila magnetna obdelava vode učinkovita s pozitivnim vplivom za nadzor vodnega kamna pri vseh uporabljenih testnih materialih (steklo, navadno in nerjavno jeklo) z zmanjšanimi količinami oblog in mehkejšo strukturo. Z uporabo magnetne naprave za pripravo izpiralne vode v pomivalnih strojih za steklenice se lahko vodni kamen bolje nadzira.

Tudi v primeru korozivnega testnega materiala je bila obloga manj kompaktna, vendar se je povečala količina železovih hidroksidov, kar je v skladu z magnetno pospešenim oksidacijskim postopkom komponent, ki vsebujejo železo [22].

V primeru steklenih ploščic lahko iz primerjave rentgenskih spektrov vidimo, da je delež silikatov v oblogah iz magnetno obdelane vode razmeroma večji, kar se ujema z merilnimi rezultati drugih avtorjev [23].

4 CONCLUSION

We have established that magnetic water treatment is effective, with a positive influence on scale control for all the used test materials (glass, steel and stainless steel), with smaller amounts of scale and a softer deposit. Using the magnetic device for conditioning the washing water in machines for bottle cleaning, the scale precipitation can be better controlled.

In the case of the corrosive test material the deposit was still less compact, but the amount of iron hydroxides increased as regards the magnetically enhanced oxidation process of iron-containing components [22].

In the case of glass plates, from a comparison of X-ray spectra it is clear that the proportion of silicates was relatively higher in deposits from magnetically treated water, which is in agreement with the experimental results of other authors [23].

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5 REFERENCES

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