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Maria Orb

REDUCING FORMATION OF SCALE WITH MAGNETIC DESCALER

Research

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INTRODUCTION

Water is essential in our daily lives. Water found in natural environment always contains various dissolved substances, including calcium and magnesium salts, that cause the hardness of water. Although hard water does not pose health hazards, it nevertheless leads to inconveniences in the households, by causing scaling on the heating elements during heating, and that in turn causes congestion of pipes, reduction of life of heating devices and increases energy consumption.

There are several options for softening water and for reducing the formation of scale. This paper focuses on the magnetic treatment of water that, despite it became known already in the 1930s, is not a widespread method.

As up to now there are only a few reports on scientific proof of the efficiency of magnetic treatment of water in literature and a common understanding as to what happens to water in the magnetic field is lacking, this method is often met with scepticism [1, 5]. On the other hand, such equipment is on sale and the users claim that magnetic devices are beneficial for controlling the formation of scale [2].

The research addresses building and principles of operation of permanent magnetic devices. As the building of a magnetic device is uncomplicated, a magnetic descaler for treating water is made of available materials and its efficiency in the reduction of scaling is studied.

The objective of research is to determine whether and to what extent magnetic descaler (incl. home-made) reduces the formation of scale compared to untreated water.

Research allows making recommendations for water treatment for reduction of scale build-up.

The hypothesis was proposed that magnetic treatment considerably reduces the formation of scale deposit and building an efficient home-made magnetic descaler is possible.

1. THEORETICAL BACKGROUND

1.1. Hardness of water

Natural water usually contains dissolved calcium and magnesium salts. Based on the content of Ca and Mg ions fresh water can be divided into hard water (high content of Ca and Mg ions) and soft water (low content of Ca and Mg ions). Hardness can be expressed as the content of Ca^{2+} in water (mmol/L). The common Ca^{2+} concentration in drinking water remains between 1 and 5 mmol/L. Magnesium salts are usually soluble and thus their concentration is lower. Limestone and chalk are the major sources of Ca- and Mg ions. Water hardness depending on the content of Ca and Mg ions is provided in Table 1.

The most widely used units of measurement of hardness are:

- mmol/L
  1 mmol/L is equivalent to 40.08 mg/L Ca^{2+} ions or 24.31 mg/L Mg^{2+} ions
- German degree of hardness (°dh)
  1°dh equals 10 mg/L CaO or an equivalent amount of other Ca and Mg compounds

Table 1. Classification of water based on hardness [10]

Very soft water	< 0.75 mmol/L	0 – 2 °dh
Soft water	0.75 – 1.5 mmol/L	2 – 5 °dh
Slightly hard water	1.5 – 3.0 mmol/L	5 – 10 °dh
Hard water	3.0 – 4.5 mmol/L	10 – 21 °dh
Very hard water	> 4.5 mmol/L	> 21 °dh

There are two types of hardness: permanent hardness and temporary hardness. Permanent or non-carbonate hardness is associated with $MgCl_2$, $CaCl_2$, $MgSO_4$. Temporary or carbonate hardness is due to the presence of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. Non-carbonate hardness and carbonate hardness together are called total hardness of water.

It is more practical to use soft water at home. Soft water makes soap foam and leaves skin silky and the formation of scale deposits is reduced; the latter actually being the most relevant problem caused by hard water. Rain water and distilled water are examples of soft water, also the water in the internal water bodies in Estonia – rivers and lakes, is quite soft while water in dug wells and bore wells is usually harder and seawater is extremely hard. The hardness of water varies a lot depending on the location (well), where the water is extracted at that moment and also on the season. In Estonia no standards are applied in regard of drinking water. Scientific proof on health hazards of hard water is non-existent.

1.2. Scale

Natural water comes into contact with calcium and magnesium carbonates in soil. These carbonates are not water-soluble, but, reacting to carbon dioxide present in water, water-soluble bicarbonates are formed:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2 \qquad (1)$$

During heating of natural hard water, bicarbonates dissolve and scale deposits settle on the heating element:

$$Ca(HCO_3)_2 \xrightarrow{t^o} CaCO_3\downarrow + H_2O + CO_2 \qquad (2)$$

As scale is an effective insulator, it adds to the higher electric bill of water consumers, depositing on heating coils of boilers, washing machines and dish-washers or plates of heat exchangers. A layer of scale of one mm increases energy consumption by 10% during the heating of water, while a layer of 1 cm increases it already by 50% [2]. Scale causes silting of shower sieves and water pipes, leaking of flush tanks, increases detergent consumption for laundry, makes tea taste of lime, makes skin on hands coarse, and shortens the life of heating devices. Figure 1 shows the increase in energy consumption depending on the thickness of scale layer.

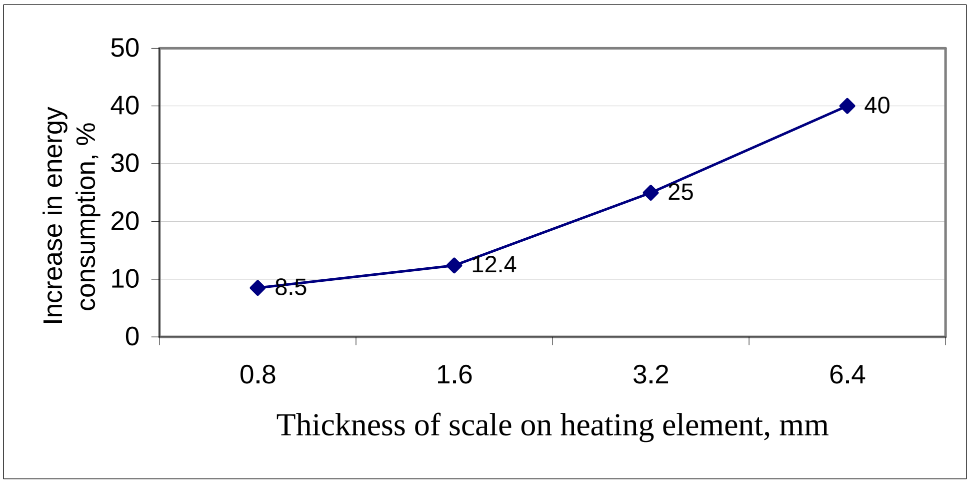

Figure 1. Increase in energy consumption depending on the thickness of scale [2]

Scale can be removed from surfaces with the help of chemicals (acids). Formation of scale sediment can be inhibited by softening or magnetic treatment. Over time, soft water also „dissolves” scale that formed earlier and saves detergents, washing powder and soap up to 50% [6].

1.3. Water softening

Boiling

Boiling is the least complicated method of water softening. Boiling decomposes bicarbonates present in natural water according to the equation (2) and it results in soft water, but also scale deposits on the walls of heating element. Boiling removes only temporary hardness of water.

Water softeners

Water softeners are used for preventing formation of mineral sediments (caused by water hardness, etc.). Application of chemical methods means using the following compounds for softening water:

– carbonates of alkaline metals, silicates, orthophosphates – form a sediment with Ca^{2+} ions:

$$Ca^{2+} + Na_2CO_3 \rightarrow CaCO_3\downarrow + 2Na^{+} \qquad (3)$$

– polyphosphates and organic complexing agents, such as ethylenediamine tetraacetic acid (EDTA) Na salt or trilone-B – bind Ca^{2+} and Mg^{2+} ions into stable coordination compounds.

Ion exchange

Ion exchangers are small particles of solid matter (granules) that exchange their ions with other ions in the solution. For instance, if hard water is forced through Na cation filter, Ca^{2+} and Mg^{2+} ions in the water are replaced by Na^{+} ions. Thus the filtered water contains sodium salts in an equivalent amount to Ca- and Mg-salts. The general salt content and anion content in particular is not decreased, but due to the high solubility of Na-compounds no scale or non-readily degradable compounds with the major components of detergents or surface active agents arises from the heating of such water. The process is cyclical – after Na^{+} ions have been replaced by Ca^{2+} and Mg^{2+} ions, filter has to be regenerated.

Reversed osmosis

The method of reversed osmosis is applied for removing dissolved salts from water. This is a water purification technique based on membrane technology. Water flows through a special membrane after a multistage prefiltering process that removes from water most (up to 99.8%) of the substances dissolved there (minerals, salts). The membrane also removes bacteria and viruses [7].

1.4. Magnetic treatment

Magnetic treatment is treatment of water applying magnetic devices. Both permanent and electric magnets are used for creating magnetic field. The use of magnetic devices is simple – the device is fitted to a cold water pipe, through which water flows into a building. Passing through the pipe, water also passes through magnetic field (see Figure 2). Actually water is a diamagnetic (i.e. water is not magnetised), but as water contains additives to a lesser extent, the properties of water properties are still subject to change. Less scale is formed while heating water that has been subject to magnetic treatment.

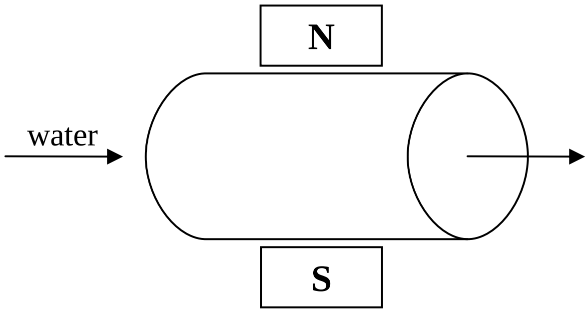

Figure 2. Water treatment in magnetic field

Today several explanations have been given as to the effect of magnetic treatment of water. One of the most widespread explanations is the following: magnetic treatment does not cause any changes in the chemical composition of water, what is changed is the crystal structure of calcium carbonate that is precipitated during the heating process – calcite is replaced by mineral aragonite [2].

Tests have shown that the purer the water the smaller the effect of magnetic treatment. It has been shown that during magnetic treatment of water a competing process inhibits crystallisation of calcium carbonate that consists of the activation of colloid particles of silicium dioxide, and after that they adsorb calcium ions and the formation of scale is reduced [3].

The effect of magnetic treatment has been also explained by its impact on the inner structure of water and hydrogen bonds, presence of various additives, impact on the electron configuration of atoms etc. [4].

The following effects have been specified as the benefits of magnetic treatment:

– pipelines and heating devices are not congested with scale,
– shower sieves or flush boxes are not blocked, or their blockage is considerably slowed down (depending on water),
– washing up of surfaces coming into contact with water (in kitchen, bathroom, WC) is substantially easier, cleansing of utensil used for boiling is easier and kitchenware and tableware retain their shine,
– it is easier to wash hair and do laundry and less detergents are required for washing,
– skin irritations resulting from hard water and dry skin are reduced or disappear,

– operation of a magnetic device is maintenance-free and no accessories are required [2].

1.4.1. Aragonite and calcite

Chemically, both aragonite and calcite are $CaCO_3$, but their crystal structure is different. During boiling of untreated water mostly calcite and in case of magnetically treated water mostly aragonite is formed. Aragonite is considerably more soluble (up to three times), crystals are denser and non- adhesive, the resulting sediment is a dusty powder that is easily removed by flowing water. A thin powdery sediment remains on the walls of heating devices and pipes. In case of stagnant water sediment settles on the bottom of the utensil (boiler, water tank). Calcite, on the other hand adheres to the surfaces that come into contact with water and a nonsoluble and strong layer of scale is formed there [2].

From the above a conclusion can be drawn that if we take an equal amount of untreated and treated water, boil both and to pour water out from both flasks and weigh the latter, the flask which contained magnetically treated water, should weight less than the flask which contained untreated water.

Differences of the crystals of calcite and aragonite can be observed on Figures 3 and 4.

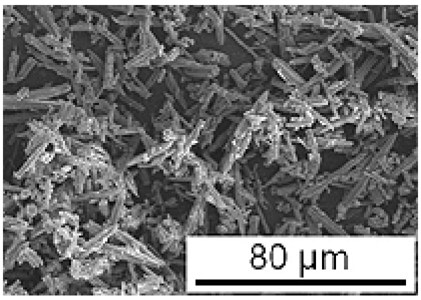

Figure 3. Aragonite [2]

Figure 4. Calcite [2]

The content of aragonite and calcite on the walls of beakers and the differences herein can be established by X-ray diffraction analysis [9]. X-ray diffraction analysis is based on the diffraction of X-rays and it provides information on the main components of the mix of solid substance. The accuracy of the determination of concentration depends on the composition, generally remaining on the level of semi-quantitative determination.

1.4.2. Magnetic descaler Elcla

There are various companies that produce magnetic devices for water treatment. Devices used for magnetic treatment of liquids differ by several parameters. Low-performance equipment with the capacity of up to 1 m^3 p.h. is sold in a large selection. The output of industrial transformers reaches 5000 m^3/h and more. In case of lower output, permanent magnets are used for generating magnetic field, while electromagnets are used for industrial purposes. The construction of equipment containing permanent magnets is less complicated and their operation is easier. Magnetic descaler Elcla, used in this research is just one of many magnetic devices for water treatment.

The construction of the magnetic device Elcla is extremely simple – a pipe that is surrounded by permanent magnets. In some models (Elclamini) water flows straight through the sheets of magnet.

According to the requirements, the product comes in different sizes: Elclamini (for washing machines, boilers) and Elcla 1…8 (for private houses, apartment houses). The main users of Elcla magnetic descalers are large factories and plants but also owners of residential buildings, private individuals. Permanent magnet devices are shown in Figure 5.

Figure 5. Permanent magnet devices (Elcla) for water treatment [2]

The residual induction of Elcla permanent magnet (ferrite) is 3900 Gauss, Elclamini (Nd-Fe-B-magnet) - 14 000 Gauss, that is actually not subject to change over time.

Elcla magnetic descalers are able to resist temperatures up to 450 C, Elclamini – 310 C. The devices are not shock-tolerant.

It is feasible to connect Elcla magnet directly to the cold water pipe entering the house or apartment, if necessary, it can also be fitted to hot water pipe. Elcla magnet can be also installed separately to specific heating devices (water pipeline before hot water boiler, washing machine, dish-washer and/or bathroom).

The best results are yielded by a device which is fitted to the cold water pipe and during the heating water temperature in the system rises to a maximum of 80 C. Elcla functions also while applied to only cold or only hot water. At 100 C the effect of magnetic treatment of water starts to diminish.

Elcla's effect is maintained for hundreds of metres of pipeline (such as in the factories). In the pipelines, under the pressure, the effect of the magnetic field remains for 48 hours, while outside the pipeline the effect lasts less. In case of a single device it is advisable to install Elcla as close to the device as possible. The performance increases when a second magnetic device is used in case of a water circulation system. [2].

1.4.3. Permanent magnets

In this work the permanent magnets of computer hard disc were used for building a magnetic device (Figures 6 and 7).

Permanent magnet is a piece of magnetic material that retains its magnetic properties within a longer time period and remains magnetised also without the presence of an external magnetic field.

Ferromagnetics iron, nickel or cobalt or their alloys are used as permanent magnets. The last half-century has added rare earth metals with high magnetic permeability: dysprosium (Dy), gadolinium (Gd), terbium (Tb) and respective alloys. As is well known, ferromagnetic (Fe, Ni, Co etc.) materials are drawn towards a magnet and diamagnetic materials (Ag, Cu, Sn et.al., also water, graphite) are repelled by a magnet while paramagnetic materials (Al, Cr, Ti etc.) are slightly magnetised.

Also such alloys are known where component metals are not ferromagnetic while the alloy is [4]. Neodymium magnets are powerful permanent magnets (residual induction up to 1T) comprising an alloy of iron, neodymium and boron. Its drawbacks include mechanical fragility and a relatively low Curie temperature - 312°C (Curie temperature is a temperature at which a material loses all its magnetic properties). Neodymium magnets are also used in power engines, sensors, loudspeakers, computer hard discs, permanent magnetic devices etc.

Figure 6. Computer hard disc

Figure 7. Permanent magnets within a hard disc

2. MATERIAL AND METHODOLOGY

2.1. Home-made magnetic device for water treatment

The operating principle of the home-made magnetic device is similar to that of the factory-made ones. In this research a magnetic device was built using a plastic water pipe (a PVC hose as this is not magnetised) and permanent magnets. Neodymium magnets present in the computer hard discs were used as permanent magnets and they were fitted around the PVC hose (two magnets in total). Magnetic descaler is shown on Figure 8. Water was forced through the PVC hose for treatment and thus it also was forced through a magnetic field.

Figure 8. Home-made magnetic device

2.2. Public water supply in the town of Jõgeva

In this work water from the public water supply in the town of Jõgeva is used. The study conducted in 2006 [8] showed that water in Jõgeva is rather hard: the total hardness is 3.3 mmol/L, temporary hardness is 3.11 mmol/L, causing therefore a lot of scale. In the tests water from two sources is used: tap water from the Jõgeva Co-ed and the apartment house at Rohu 4. Water from Jõgeva Co-ed is used both in the comparative test (untreated water) as well as for treatment with the home-made magnetic device. In Rohu 4 the magnetic descaler Elcla is installed to the water system of an apartment house.

As in this work water samples from different sources are studied, it must be ensured that similar water samples are obtained for comparison. For that purpose the carbonate hardness of samples is measured (if the carbonate hardness of the samples is not equal, the heating of the samples would cause a different amount of scale). Titration with hydrochloric acid is used for measuring temporary hardness.

2.2.1. Determination of carbonate hardness

Titration is a method for determining the content of substances/ions/elements that is based on the reaction of the analyte (titrated substance) with the reagent of known concentration (titrant).

Carbonate hardness is determined by titration with hydrochloric acid. Ca and Mg bicarbonates react with hydrochloric acid from the equation (4).

$$\frac{Ca(HCO_3)_2}{Mg(HCO_3)_2} + 2H^+ \rightarrow \frac{Ca^{2+}}{Mg^{2+}} + H_2O + 2CO_2 \qquad (4)$$

Knowing the volume of hydrochloric acid used up in the reaction and molar concentration and the volume of water, the molar concentration of bicarbonates in the water can be determined from the equation (5), and that, expressed in millimoles per litre, is a characteristic of temporary hardness. Methyl orange is used as an indicator in titration.

$$C_{Ca(HCO_3)_2} = \frac{V_{HCl} \cdot C_{HCl}}{2 \cdot V_{H_2O}} \qquad (5)$$

2.3. Estimating the impact of a magnetic device

Research was conducted in November 2006, in Jõgeva, a small town in Estonia. The process is described below.

1. Titration before heating of water

10 cm^3 of water under study was poured into the beaker and two drops of indicator, methyl orange, were added, as a result the water acquired an orange hue. HCl solution was dropped from burette until water turned pinkish (Figure 9). The reading was recorded and the test was repeated four times, each time using a new water sample. Also water samples treated with magnetic devices were titrated with hydrochloric acid. The results of titration with hydrochloric acid are provided in Annex 1.

Figure 9. Water before (left) and after (right) titration with hydrochloric acid

2. Heating of water and comparison of scale formation

In order to compare the efficiency of magnetic devices as reducers of formation of scale, the formation of scale in magnetically treated and untreated water was compared.

First, an empty flask was weighted, then 600 ml of untreated water was measured into it. Water was heated to the temperature 93-97 C, but so that water does not boil although slow bubbling starts (Figure 10). While pouring the heated water out, the flask was shaken so that the suspended scale would be removed with water. Heating was repeated 10 times while each time a new water sample was used.

The heating of water for 10 times was required for the formation of a larger amount of scale, as only technical scales were available (accuracy 0.01 g). Also, the repeated heating of water creates a situation which is closer to real life where water in boilers and kettles is heated repeatedly.

Analogical tests were conducted also with water treated by magnetic descaler Elcla and water treated with home-made magnetic device (10 times with both).

After boiling flasks were left to dry and then they were weighted again. The initial and end masses of the flasks are provided in Annex 2.

3. Titration after the heating of water

Titration after the heating of water is necessary in order to be sure that residual hardness was equal (i.e. heating took place under equal conditions).

As a part of scale that formed is suspended in the treated water after heating in the form of aragonite that also reacts with hydrochloric acid, before taking a sample for titration scale was allowed to precipitate in a separate beaker. The measuring of temporary hardness (titration with hydrochloric acid) was conducted similarly as in Clause 1. The results of titration are provided in Annex 1.

Figure 10. Heating of water in a flask

3. RESULTS

Titration of water samples before heating revealed that the carbonate hardness of all samples was equal. This allows us to conclude that prerequisites for the formation of scale were similar, and that in turn allows to make an objective assessment of the sedimentation of scale on the surface of the beaker. The hardness of the treated and untreated water was equal also after the heating. Consequently, the quantity of scale that is formed is equal for treated and untreated water while the difference lies in the sedimentation of scale on the surface of the beaker. The summary of the results of measurement of carbonate hardness before and after boiling are provided in Table 2.

Table 2. Titration results

Sample	**Temporary hardness (mmol/L)**	
	Before heating	**After heating**
Untreated water	3.00	2.25
Water treated with home-made magnetic device	3.00	2.25
Water treated with magnetic device Elcla	3.00	2.25

Subtracting the initial mass of the flask used for heating from its end mass the mass of scale sedimented during the heating of 6 dm^3 of water is determined (Table 3).

Table 3. Mass of deposited scale

Sample	**Mass of scale (g)**
Untreated water	0.33
Water treated with home-made magnetic device	0.09
Water treated with magnetic device Elcla	0.04

Measurements revealed that the amount of scale formed on the surface of flask during the heating of untreated water was the largest, while it was the smallest upon the heating of the water treated with magnetic descalers. The thickness of the scale layer can be also seen by naked eye (Figure 11). The walls of the flask used for heating untreated water are covered with a lot of scale and the flask is opaque. The flasks used for heating water that was treated with home-made magnetic device and magnetic descaler Elcla contained considerably less scale – the flasks are transparent. The flask that was used for the heating of water treated with the magnetic descaler Elcla, is the cleanest.

a b c

Figure 11. Flasks used for heating a) untreated water, b) water treated with home-made magnetic device and c) water treated with magnetic descaler Elcla

4. DISCUSSION AND CONCLUSIONS

The measurement revealed that the sedimentation on the surface of the beaker was extremely different in case of untreated and treated water: magnetic device materially reduced the sedimentation of scale on the flask walls. During the heating of water treated with the magnetic descaler Elcla, the formation of scale was reduced by 8.3 times compared to the amount of scale that formed as a result of heating untreated water, and by 3.7 times while heating water treated with the home-made magnetic descaler. Comparison of masses of the scale is shown on Fig. 11.

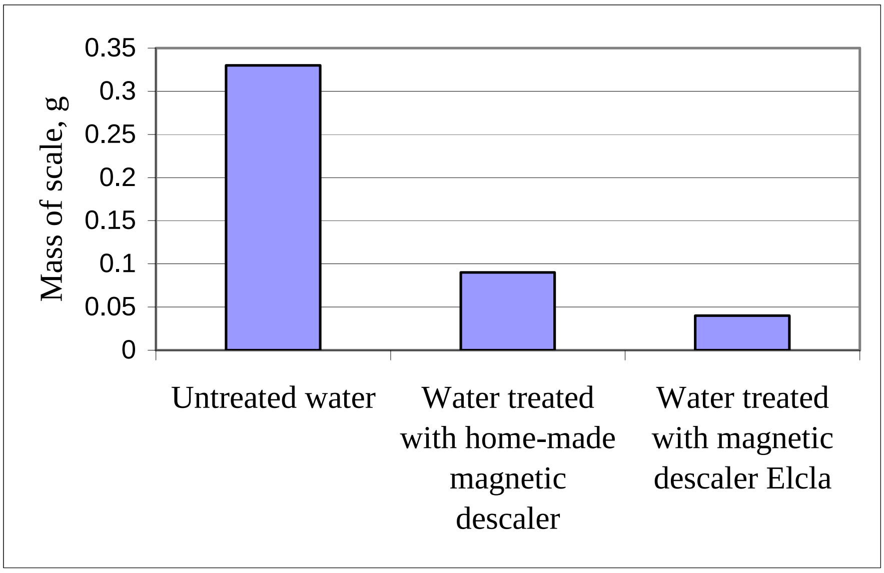

Figure 11. Mass of scale deposit

The result of the home-made magnetic device was less efficient compared to magnetic descaler Elcla. The reasons for the lower performance of the home-made magnetic device can be different:

- The different composition of permanent magnets and the different structure of the device. In the apartment house at Rohu 4 an Elcla descaler with ferrite magnet is used while neodymium magnets were employed in the home-made magnetic device. The magnetic field strength of the neodymium magnets depends substantially on the distance of poles (unlike ferrite magnets, the strength of magnetic field diminishes quickly when the distance grows). As the PVC hose used was quite thick, the impact of the magnetic field could have been weak. Evidently, the efficiency of magnetic treatment is also influenced by the length of magnet. The magnets of the computer hard disc employed are narrow (water was subject to the magnetic field for a short time).

– Inaccuracies in measurement: difference in time of heating water, inaccuracies in weighting of flasks (technical weights) and titration.

Future research should focus on the problem how to improve the performance of the home-made magnetic device – as the efficiency depends on the number of magnets, the distance between the poles and their reciprocal placement, the length of magnet, the material of magnet and the hose used. As this research focused on the sedimentation of scale under static conditions, the formation of scale under dynamic conditions – when water is moving in the pipes that are heated - should be studied. Besides that the composition of water should be observed: what is the impact of various additives, pH etc.

The research confirmed the hypothesis that magnetic devices essentially reduce the formation of scale and it is possible to build a magnetic device for water treatment at home from available materials. Still, it should be mentioned that as some authors think [1, 5] that the efficiency of magnetic devices depends on the additives in the water, the results obtained are valid in regard of the public water supply in the town of Jõgeva.

Use of magnets obtained from old computer hard discs for building of home-made magnetic device could be one option for finding an application for the components of utilised hard drives.

SUMMARY

During the research the measurement of the hardness of water was learned and the effect that magnetic descalers have on the formation of scale was determined. It was revealed that the use of magnetic descalers is effective as they significantly reduce the sedimentation of scale. Comparing magnetic devices and other methods (reversed osmosis, ion exchange, water softeners) as reducers of scale, magnetic descalers are the most effective as they are maintenance-free and operate interminably, they do not lose their magnetic properties. Magnetic devices do not consume any additional resources after completion (no need to add reagents, regenerate materials etc.). Thus it is a environment-friendly method.

Magnetic devices can be made at home. In this research permanent magnets present in the computer hard disk were used for building the device that proved to be quite effective. Using old hard discs to make scale preventers would be a good opportunity to find an application for the components of old hard discs.

In Jõgeva, where the water is rather hard, the acquisition of magnetic descalers by households would be reasonable indeed as in the longer timeframe the life of heating units (boilers, kettles) will be prolonged and the risk of pipeline blockage will be reduced by the use of magnetic descalers.

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ANNEXES

Annex 1

Titration of carbonate hardness

Table 1. Untreated water (unheated)

Initial reading (cm^3)	Final reading (cm^3)	V(HCl) (cm^3)
10.6	11.8	1,2
11.8	13.0	1.2
13.0	14.2	1.2
14.2	15.4	1.2
Average		1.2

$$C_{Ca(HCO_3)_2} = \frac{V_{HCL} \cdot C_{HCl}}{2 \cdot V_{H_2O}} = \frac{1.2cm^3 \cdot 0.04998M}{2 \cdot 10cm^3} = 0.0029988\frac{mol}{L} \approx 3.00\frac{mmol}{L}$$

Table 2. Untreated water (heated)

Initial reading (cm^3)	Final reading (cm^3)	V(HCl) (cm^3)
16.5	17.5	1.0
17.5	18.4	0.9
18.4	19.3	0.9
19.3	20.2	0.9
Average		0.9

$$C_{Ca(HCO_3)_2} = \frac{V_{HCL} \cdot C_{HCl}}{2 \cdot V_{H_2Oi}} = \frac{0.9cm^3 \cdot 0.04998M}{2 \cdot 10cm^3} = 0.0022491\frac{mol}{L} \approx 2.25\frac{mmol}{L}$$

Table 3. Water treated with magnetic descaler Elcla (unheated)

Initial reading (cm^3)	Final reading (cm^3)	V(HCl) (cm^3)
17.4	18.5	1.1
18.5	19.7	1.2
19.7	20.9	1.2
20.9	22.1	1.2
Average		1.2

$$C_{Ca(HCO_3)_2} = \frac{V_{HCL} \cdot C_{HCl}}{2 \cdot V_{H_2O}} = \frac{1.2cm^3 \cdot 0.04998M}{2 \cdot 10cm^3} = 0.0029988\frac{mol}{L} \approx 3.00\frac{mmol}{L}$$

Table 4. Water treated with magnetic device Elcla (heated)

Initial reading (cm^3)	Final reading (cm^3)	V(HCl) (cm^3)
10.1	11.0	0.9
11.0	11.9	0.9
11.9	12.9	1.0
12.9	13.8	0.9
Average		0.9

$$C_{Ca(HCO_3)_2} = \frac{V_{HCL} \cdot C_{HCl}}{2 \cdot V_{H_2O}} = \frac{0.9cm^3 \cdot 0.04998M}{2 \cdot 10cm^3} = 0.0022491\frac{mol}{L} \approx 2.25\frac{mmol}{L}$$

Table 5. Treated with home-made device (unheated)

Initial reading (cm^3)	Final reading (cm^3)	V(HCl) (cm^3)
17.85	19.0	1.15
19.0	20.2	1.2
20.2	21.4	1.2
21.4	22.6	1.2
Average		1.2

$$C_{Ca(HCO_3)_2} = \frac{V_{HCL} \cdot C_{HCl}}{2 \cdot V_{H_2O}} = \frac{1.2cm^3 \cdot 0.04998M}{2 \cdot 10cm^3} = 0.0029988\frac{mol}{L} \approx 3.00\frac{mmol}{L}$$

Table 6. Treated with home-made device (heated)

Initial reading (cm^3)	Final reading (cm^3)	V(HCl) (cm^3)
13.9	14.8	0.9
14.8	15.7	0.9
15.7	16.7	1.0
16.7	17.6	0.9
Average		0.9

$$C_{Ca(HCO_3)_2} = \frac{V_{HCL} \cdot C_{HCl}}{2 \cdot V_{H_2O}} = \frac{0.9cm^3 \cdot 0.04998M}{2 \cdot 10cm^3} = 0.0022491\frac{mol}{L} \approx 2.25\frac{mmol}{L}$$

Annex 2

Results of weighting the flasks

Table 1. Masses of flasks

Water heated in the flask	Initial mass of flask (g)	Final mass of flask (g)	Difference (g)
Unheated water	162.42	162.75	0.33
Water treated with magnetic descaler Elcla	145.24	145.28	0.04
Water treated with home-made magnetic descaler	146.68	146.77	0.09

Annex 3

Photographs about the project

Figure 1. Pipetting

Figure 2. Titration with HCl

Figure 3. Home-made magnetic descaler

Figure 4. Water treating with home-made magnetic descaler

Figure 5. Heating of water in a flask

Figure 6. Slow bubbling starts

Figure 7. Weighting of flask

Figure 8. Flasks used for heating untreated water, water treated with home-made magnetic device and water treated with magnetic descaler Elcla