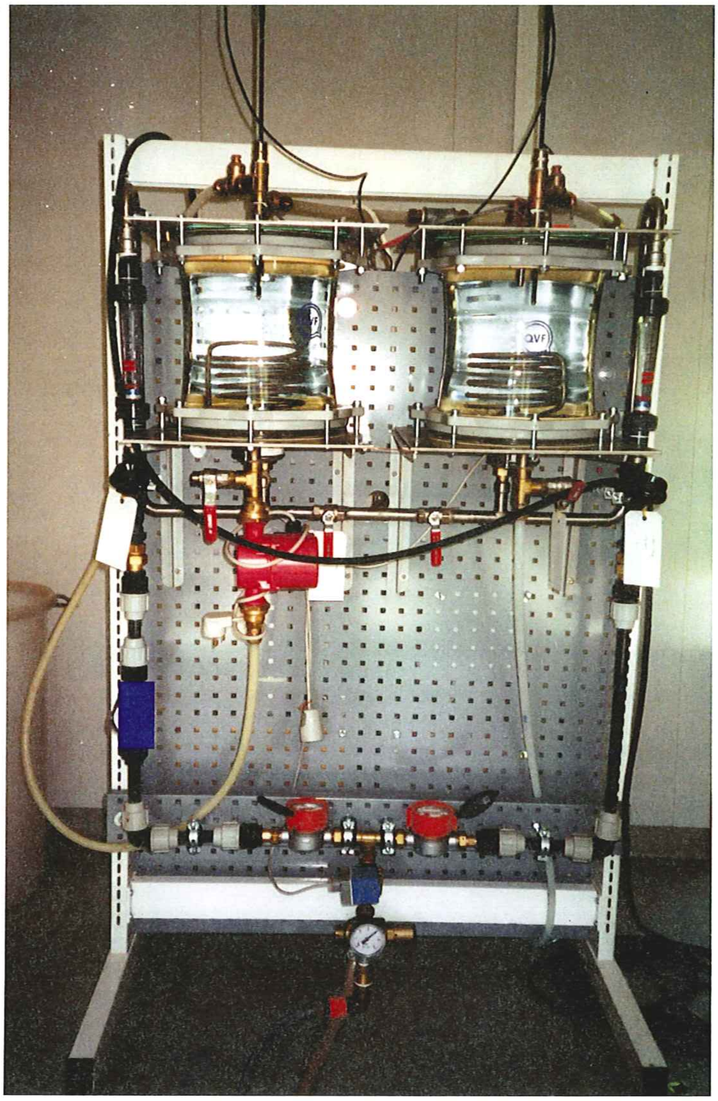
REPORT SNO 4263-2000

An evaluation of a novel test method for anti-scale devices

A case study from Sauherad, Norway



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REPORT

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Abstract

The Danish Technological Institute (DTI) and The Norwegian Institute for Water Research (NIVA) have developed a test method based on research from Cranfield University about magnetic fields applied on re-circulation systems and DVGW W512 for evaluating anti-scale devices for hot water treatment. Test results and experiences from two tests conducted in a Norwegian municipality with scaling problems in hot water installations are presented.

During the first test an old magnetic anti-scale device was examined without re-circulation. Scales were formed on the heater elements both for the treated and non-treated water (control), although the anti-scale device reduced the scale formation in one case. 3.7% and 5.0% of the influent calcium were converted into scales in the line with and without an anti-scale device, respectively. During the second test a new anti-scale device was examined with re-circulation. Here, the scale formation from the treated water in fact increased. During re-circulation 11.9% and 7.0% of the influent calcium were converted into scales in the line with and without an anti-scale device, respectively.

The anti-scale devices were not able to prevent scale formation on the heater elements in the test rig. The results raise some questions about the efficiency of the tested anti-scale devices and the test methodology itself. To gain more experiences with this system the tests should be repeated with various anti-scale devices, and the system itself should be tested with pressurized water.

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1. Varmtvannsberedere	1. Hot water tanks
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An evaluation of a novel test method for anti-scale devices

- A case study from Sauherad, Norway

Preface

In many areas of the world groundwater rich in calcium and magnesium causes formation of scales on the heating elements in hot water tanks. This problem occurs both in industry and in private homes, and results in large repair and maintenance costs.

Magnetic anti-scale devices have become an increasingly popular method for reducing scale problems. However, the mechanisms of this treatment are not fully known, and the method is not always successful.

During this work we have developed the Nordtest-method for testing different magnetic anti-scale devices. The method was applied in the municipality of Sauherad in Norway.

This work has been a co-operation between The Danish Technological Institute (DTI) and The Norwegian Institute for Water Research (NIVA). We will thank Mr. Jens Brusgaard Vestergaard at DTI for a fruitful co-operation and Nordtest for project funding.

Oslo, 11 August 2000

Henning Mohn

Contents

Summary

The Danish Technological Institute (DTI) and The Norwegian Institute for Water Research (NIVA) have developed a test method based on research from Cranfield University about magnetic fields applied on re-circulation systems and DVGW W512 for evaluating magnetic anti-scale devices for hot water treatment. During this project tests have been carried out in Denmark and Norway by using a pilot-scale test rig designed and built according to the new method. In this report results and experiences from two three-week tests conducted at a small Norwegian water work, in a municipality where scaling problems are widespread in hot water installations, are presented.

The rig has two transparent hot water tanks and connectors for anti-scale devices. 130 litres of calcium rich ground water of edible quality was daily let into the system, in one- or two-minute flow periods. Calcium removal and build-up of scales on the heater elements were studied with two different anti-scale devices, and with and without re-circulation. Evaluation of system performance is based on visible scale formation and chemical analyses of influent and effluent water, acid-dissolvable calcium from scales, and the zeta potential of particles.

During the first test an old magnetic anti-scale device was used in one of the test lines, while the other line was a control without water treatment. This test did not involve re-circulation. Scales were formed on the heater elements both for the treated and non-treated water, although the anti-scale device reduced the scale formation to a certain extent. In this test 3.7% and 5.0% of the influent calcium were converted into scales in the line with and without an anti-scale device, respectively.

The operational differences between the first and second test were that during the latter water was recycled and repeatedly treated, and a new anti scale device was used. During the second test the formation of scales in the hot water tank was in fact higher with “treated water” than in the control. This indicates that the new anti-scale device had no positive effect during re-circulation operation of our test system. In this test 11.9% and 7.0% of the influent calcium were converted into scales in the line with and without an anti-scale device, respectively.

During the tests scales were formed on the heater units both with the old anti-scale device without re-circulation, and with the new device with re-circulation. We will, however, emphasise that our results are based on only two single tests on one particular raw water quality and hence our results are not sufficiently representative to draw wide, final conclusions. The test method should be applied repeatedly with various magnetic anti-scale devices and water qualities for further evaluation of the method itself and the efficiency of various devices. More test results are also needed in order to develop a more thorough understanding of the mechanisms involved in scale reduction by magnetic fields.

The test rig was quite simple to operate, and the method appears to be suitable for demonstration purposes. The method itself might be appropriate for evaluating different combinations of various anti-scale devices and water qualities, both when the rig is operated with and without re-circulation of water.

The test system can simulate household installations well, except for the fact that the water in the test rig is not under pressure and the free water surfaces in the hot water tanks are more or less open to air. However, we are yet unsure whether this affects the carbonate system and causes test bias.

1. Introduction

In this NORDTEST-funded project The Danish Technological Institute (DTI) and The Norwegian Institute for Water Research (NIVA) have developed a test method based on research from Cranfield University about magnetic fields applied on re-circulation systems and DVGW W512 for evaluating magnetic anti-scale devices for hot water treatment. During this project tests have been carried out in Denmark and Norway by using a pilot-scale test rig designed and built according to the new method. In this report results and experiences from the two three-week testes conducted at a small Norwegian water work, in a municipality where scaling problems are widespread in hot water installation, is presented.

2. Preparations and test procedure

The test rig was built for Danish conditions with regard to electrical grounding and currency, and hence had to be slightly modified before installation at the Norwegian water work. Two transformers converting three-phase 240 volts into three-phase 400 volts were attached to the rig.

It was decided that two different magnetic anti-scale devises should be used during the tests. One of these were rather old (6-10 years old), the other was a brand new model, specially designed for this project. Prior to the water work tests the rig was operated in one of NIVAs laboratories with a soft water (low Ca and Mg content) in order to reveal its reliability and maintenance needs. The rig is presented in Figures 1 and 2. The red pumps, attached on the front and the back of the rig, were only in use during re-circulation operation. To make the anti-scale device anonymous it is hidden behind the blue field in Figure 1.

The rig was thereafter brought to Nedre Sauherad water work at Kåøya in the small municipality of Sauherad in Norway. The water source is ground water, which is not altered at the water work. The tests were conducted in May and June 2000. Water quality characteristics are presented in Table 1.

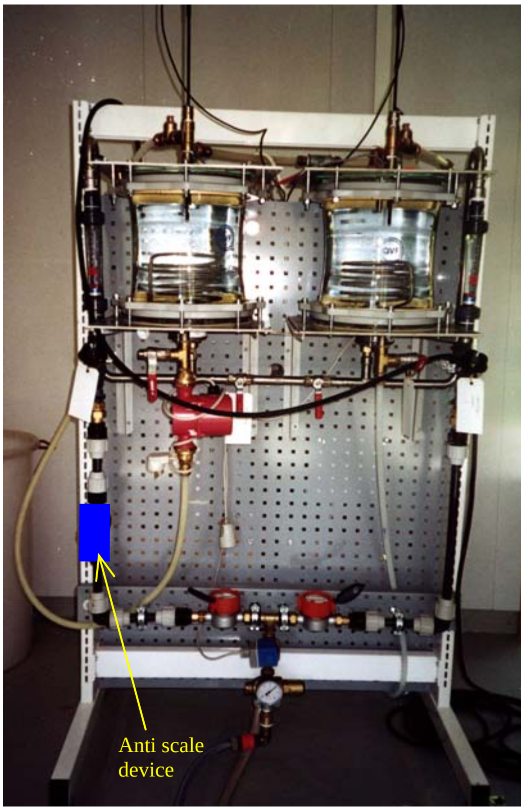

Figure 1. Test rig, front view.

Table 1. Inlet water quality
(data from the municipality of Sauherad, 1997).

Parameter	**Average value**
Alkalinity	2,4 mmoles/l
Ca	38 mg/l
Cl	21 mg/l
Colour	1 mg Pt/l
Fe	0,005 mg/l
K	6 mg/l
Mg	7 mg/l
Mn	0,005 mg/l
NO2-N	0,001 mg/l
NO3-N	2 mg/l
Na	15 mg/l
Total-P	0,004 mg/l
pH	8
SO4	14 mg/l
Turbidity	0,3 FTU

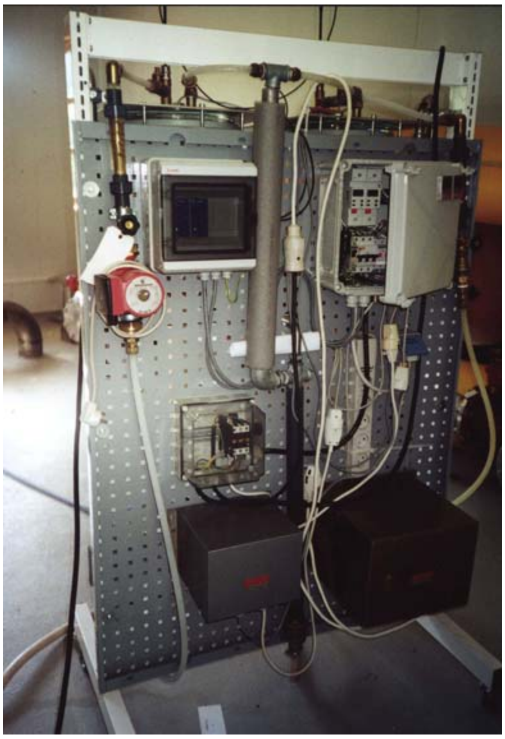

Figure 2. Test rig, rear view

The inlet water hose was connected directly to the main water supply pipe for the nearby village, adjacent to the high-pressure air/water tank. The first test was conducted with the old magnetic anti-scale device, without re-circulation of water. During this test cold water passed the anti-scale device once prior to heating. The second test was based on the new anti-scale device with re-circulation of hot water. During this test hot water was repeatedly treated in the anti-scale device. To be able to determine the efficiency of the anti-scale devices, parallel tests without any anti-scale devices were conducted in the second hot water tank throughout both tests.

The tests were conducted according to the procedure presented in the main report. The methods used for chemical analyses are presented in the Table 2.
Further details about the methods are available upon request.

Table 2. Analytical methods.

Parameter	**Method**
pH	Glass electrode in field
Conductivity	Accredited laboratory method, NIVA
Alkalinity	Accredited laboratory method, NIVA
Ca	Accredited laboratory method, NIVA
Mg	Accredited laboratory method, NIVA
Zeta potential	Method from Malvern Industries, UK
Water volume	Volume meter at the test rig
Water flow	Flow meter (rotameter) at the test rig
Hot water temperature	Digital thermometer at the rig
Hours of operation	Hour counter at test rig

3. First test: Single treatment

The first test had the following objectives:

- To determine how useful the test procedure is for evaluating anti-scale devices without re-circulation.
- To evaluate how well the test procedure simulates a full-scale household hot water tank installation.
- To determine the effect of the old anti-scale device for one particular water quality.
- Draw conclusions and make recommendations based on one test without re-circulation.

3.1 Preparations

Prior to the first test the water circuit was washed with diluted hydrochloric acid (50 ml conc. HCl in 10 litres tank volume gave pH=1) to remove all residues of calcium and metals from pipes and hot water tank. Thereafter the system was rinsed thoroughly with drinking water to remove all acid with dissolved contaminants, and regular operation was started with a filling- and heating-sequence as described in the method.

Throughout this test the older anti-scale device was affixed to the left water circuit, in which water passed though once. The right water circuit was a control line without an anti-scale device. The two water circuits can be seen in Figure 1. The operation of the test rig corresponded with the methodology described in the main report, with some minor exceptions (presented in the end of next section).

3.2 Results

Due to a holiday the test was terminated after 20 days of operation instead of after 21 days. At this stage a visible and significant scale layer had been formed on both heater units. The visual differences between the scale formed from the treated and the non-treated water were negligible. The results demonstrate that the water had sufficient calcium to cause scaling, and scaling was formed in the test rig just as it occurs in hot water installations in the nearby the village. Although the anti-scale device did not improve the situation significantly, the chemical analyses demonstrate that it had some effect. The results are further described below.

The scale present after 20 days of operation is shown in Figure 3. The figure shows the heater that receives treated water, which looked rather identical to the other heating element. The scale was white, slightly fluffy and covered more than one third of the surface of the heating coil. There was also a significant amount of loose scale on the bottom of the hot water tanks, indicating a great loss of scale from the coils.

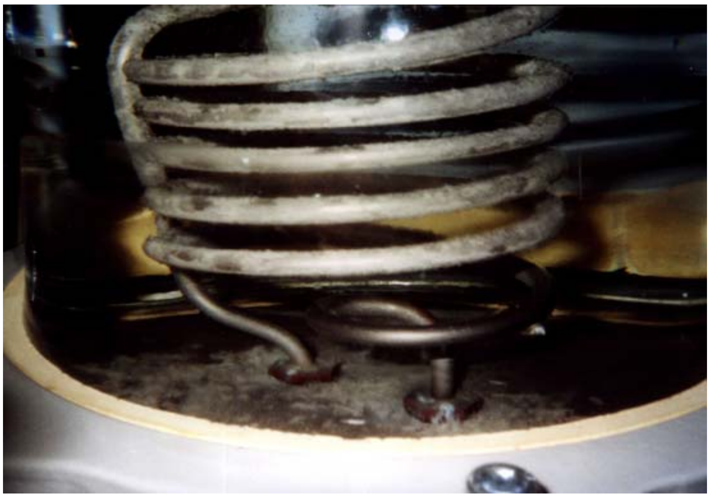

Figure 3. Heating coil covered with calcium scale.

After 20 days of operation influent and effluent water samples were taken from the test rig. Thereafter 50 ml of concentrated HCl was added to the two water circuits, the influent water was shut off and the re-circulation pumps were started to dissolve all particulate matter in the systems. After one hour of re-circulation no particulate matter could be observed and new samples were taken from the liquid for analyses. Based on these analyses mass balances were set up and scaling capacity was determined. The results are presented in Table 3. After each acid wash the water circuits were thoroughly rinsed with cold water.

Table 3. Results from the first test (no re-circulation)

	Influent	Circuit w/anti-scale device (left)	Circuit without anti-scale device (right)
pH, normal operation		8.49	8.49
conductivity, mS/m	34.5	34.1	34.0
total alkalinity, mmoles/l	2.42	2.34	2.34
temperature, hot water, C		79.8 - 80.1	79.8 - 80.1
Ca, g/m3 (neutral pH)	40.2	38.7	38.2
Mg, g/m3 (neutral pH)	7.0	n/a	n/a
volume meter, start, m3		17.335	16.225
volume meter, end m3		19.856	18.413
volume used, m3		2.521	2.188
energy meter, start, kwh		28545.26	n/a
energy meter, end, kwh		28723.30	n/a
energy used, kwh		178.04	n/a
specific energy use, kwh/m3		70.63	n/a
heater time, hours		89.02	n/a
grams Ca in, neutral		101.33	87.96
grams Ca out, neutral		97.55	83.58
grams Ca lost (scale)		3.78	4.38
% of infl. Ca lost (scale)		3.73	4.98
Ca, g/m3, pH=1		256	291
grams Ca in circuit pH=1		2.56	2.91
recovery of Ca, %		67.7	66.5
zeta potential, mv	-2.3	-2.1	-1.9

The analyses show that the quality of the water treated with the old anti-scale device was close to identical to the non-treated water, and quite similar to the influent water quality. In general, the water tested had a relatively high calcium content, rather high alkalinity and a neutral to basic pH. 3,7 – 5,0% of the influent calcium remained in the system as calcium scale. The mass of calcium scale formed during the tests were calculated both from the difference between influent and effluent Ca concentrations at neutral pH and the total water volume led trough the circuits, and on the basis of the dissolved Ca concentrations at acidic conditions and total volume of the circuits (10 litres). The results demonstrate that less calcium scale was formed in the circuit with an anti-scale device (3,78 g) than in the circuit without treatment (4.38 g), even though more water passed through the circuit with the anti-scale device. The samples taken after acidification verify these findings, although only approx. 2/3 of the calcium mass was recovered during low pH operation. The incomplete mass balances indicate that some of the calcium removed from the water phase during regular operation was lost and/or nondissolvable at low pH. Insignificant differences between influent and effluent zeta potential values indicate that no altering of electrical particle charge occurs throughout the test system.

The volume of water that passed trough the circuit with anti-scale device and the circuit without this device was 2,52 m^3 and 2,19 m^3, respectively. This is quite close to the expected water volume according to the method description (5 l/min * 26 min/day * 20 days = 2600 litres after 20 days), and demonstrates steady operational conditions.

During this test there were some minor operational irregularities. The energy meter on the right circuit failed during the test, and the water samples were not analysed for magnesium. Specific energy consumption and efficiency factors for both circuits can therefore not be calculated. In spite of these problems the results are sufficient for an initial evaluation of the methodology itself.

The test demonstrated that the test methodology and test rig itself might be suitable for testing anti-scale devices in single treatment operation without re-circulation, but the anti-scale device did not prevent scale formation. The test rig was easy to install and to operate. Because of the easily visible and accessible pipes, valves and heating tanks on test rig, the performance and operational procedures can be explained and taught to water work operators without significant problems. In fact, the water work staff found the rig interesting and they were helpful in looking after it while in operation.

By testing anti-scale devices in this rig without re-circulation of water, the situation is quite close to a real household installation. In the municipality of Sauherad magnetic anti-scale devices have become increasingly popular method to reduce scaling problems in hot water tanks. The success rate, with these devices is, however, varying from location to location and there is an increasing interest in finding an efficient method for evaluation of various treatment devices.

One question that arose during the test, was the water pressure in the hot water tanks and air/water interactions. The test system simulates household installations well, except for the fact that the water in the test rig is not under pressure and the free water surfaces in the hot water tanks are rather open to air. However, we are yet unsure whether this affects the carbonate system and causes test bias.

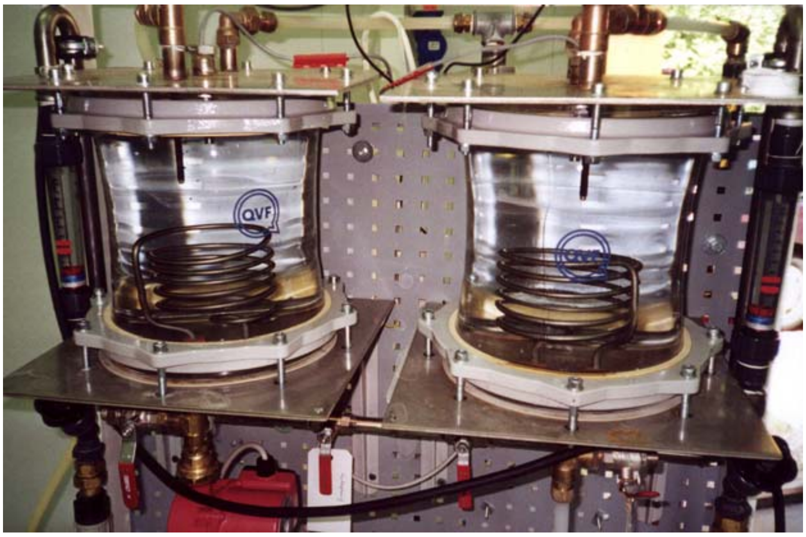

Figure 4. Hot water tanks after cleaning with acid

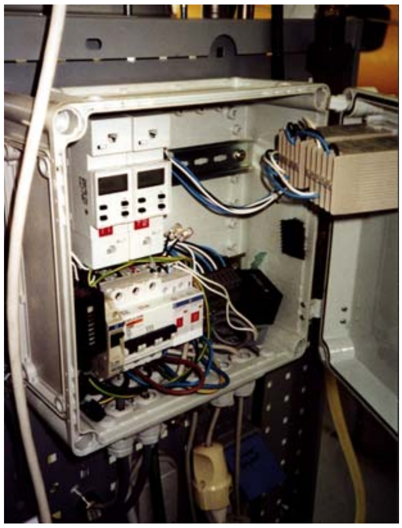

Figure 5. Electric control box

4. Second test: Re-circulation

The second test had the following objectives:

- To determine how useful the test procedure is for evaluating anti-scale devices operated with re-circulation.
- To evaluate whether re-circulation operation is suitable for a full-scale household hot water tank installation.
- To determine the effect of the new anti-scale device for one particular water quality
- Draw conclusions and recommendations based on one test with re-circulation.

4.1 Preparations

Prior to the second test the water circuits were washed with diluted hydrochloric acid in the same manner as described in section 3.1. Thereafter the old anti-scale device was substituted with a by-pass pipe. The new anti-scale device was attached to the recycle loop of the right water circuit before its recycle pump, while the left water circuit was a control unit without any anti-scale device. The arrangements are presented in Figures 6 and 7. The anti-scale device is hidden behind the blue field in Figure 7. The recycle pumps pumped water continuously from the hot water tank though the anti-scale device and back into the heater again.

The rig was operated with the same fill pattern as in the first test; the only differences were the continuous re-circulation pumping and a different anti-scale device. The recycle flow rate was 2 litres per minute, giving a 5 minutes theoretical water retention time of the hot water tanks (based on a plug flow pattern).

Figure 6: Left re-circulation loop without anti-scale device (front)

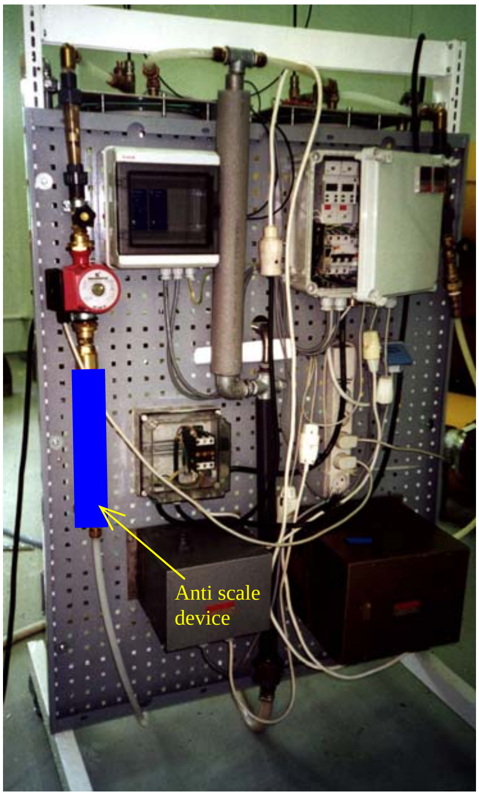

Figure 7: Right re-circulation loop with anti-scale device (rear)

4.2 Results

After 21 days of operation the second test was terminated. A thin, rather compact and greyish scale layer was then seen on the heater unit in the circuit with the anti-scale device, although this scale was significantly thinner than the scale formed in the control circuit. This indicates that the anti-scale device tested had some morphological impact on the scale formation during re-circulation. The subsequent analyses revealed that the compact scale in fact contained more calcium than the thick, fluffy scale structures of the control line with non-treated water.

At the end of the test 790 and 1100 litres of water had passed the water tanks, respectively. This is significantly less than the expected volume (which was 5 l/min * 26 min/day * 21 days = 2730 litres), and demonstrates that the recycle pumping interfered with the main flow regulators and caused an unstable filling pattern. A closer monitoring and control of the flow during the test could have reduced this problem. In spite of these problems, the test results can be used as an initial evaluation of the test method.

Similarly to the previous test, influent and effluent water samples were taken from the test rig after 21 days of operation. The subsequent acid wash followed also the same pattern as last time. Samples were also then taken from the acidified phase, and mass balances were set up. The results are presented in Table 4 below.

Table 4. Results from the second test (with re-circulation)

	Influent	Circuit w/anti-scale device (right)	Circuit without anti-scale device (left)
pH, normal operation	7.48	7.45	7.58
conductivity, mS/m	33.1	31.5	32.4
total alkalinity, mmoles/l	2.252	2.097	2.179
temperature, hot water, C		79.8 - 80.1	79.8 - 80.1
Ca, g/m3 (neutral pH)	38.8	34.2	36.1
Mg, g/m3 (neutral pH)	6.92	7.13	7.09
volume meter, start, m3		18.557	19.977
volume meter, end m3		19.342	21.083
volume used, m3		0.785	1.106
energy meter, start, kwh		n/a	28725.14
energy meter, end kwh		n/a	28874.70
energy used, kwh		n/a	149.56
specific energy use, kwh/m3		n/a	135.18
heater time, hours		n/a	74.78
grams Ca in, neutral		30.43	42.87
grams Ca out, neutral		26.82	39.89
grams Ca lost (scale)		3.61	2.99
% of infl. Ca lost (scale)		11.87	6.97
Ca, g/m3, pH=1		293	252
grams Ca in circuit, pH=1		2.93	2.52
recovery of Ca, %		81.1	84.4
effect factor, calculated		0.096	0.055
zeta potential, mv	-1.2	-8.0	-8.6

During the re-circulation test more calcium was removed from the water treated with the new anti-scale device than from the non-treated water in the control circuit. Correspondingly, most deposited calcium was found in the scales in the hot water tank with treated water. 11,97 % and 6,97 % of the influent calcium remained in the system as calcium scale in the treated and non-treated circuit, respectively. These results demonstrate that the new anti-scale device in fact increased the scale formation in the test system instead of reducing it.

The mass of calcium scale formed during the tests was calculated from the difference between influent and effluent Ca concentrations at neutral pH and the total water volume led trough the circuits. These values are verified by the analyses of re-dissolved calcium at acidic conditions after the test and the total circuit volume (10 litres).

After the 21 days test 2.93 and 2.52 grams of calcium were re-dissolved in the tank with treated and non-treated water, respectively. The mass balances were fairly good, with 81.1% and 84.4% recovery of the influent calcium after acid addition.

The calculated effect factor, which is low when scale formation is low, was 0,096 and 0,055 for treated and non-treated water, respectively.

The differences between influent and effluent zeta potentials were significant for both water tanks. These results indicate a change in the particle charge throughout the recycle line. Since this change occurred in both recycle lines, it is more likely that it was e.g. the turbulence in the recycle pumps rather than the anti-scale device that caused this change. An altering of zeta potential from –1,2 mV to –8,6 or –8,0 mV results in stronger repelling forces between the particles, which theoretically might reduce scale formation.

During this test there were also some minor operational irregularities. Specific energy consumption for the right water circuit could no be determined due to operational failure of a meter. However, the methodology itself can still be evaluated. As compared to the first test, the specific energy consumption's was significantly higher during this test. A reasonable explanation for this increase is the need for additional energy for recycle pumping.

By testing anti-scale devices in the test rig with water re-circulation and free water surface some industrial situations are simulated (cooling towers etc.) This flow situation, however, does not directly simulate the flow in a regular electric household hot water installation, but household installations can readily be modified to re-circulation systems.

This test indicates that the chosen anti-scale device did not reduce scale formation on the heater elements during re-circulation operation and repeated treatment of one particular water quality. Even though the results in this case show that the anti-scale device failed, NIVA emphasises that one single test nether gives sufficient evidence to reject the chosen anti-scale device nor the test method itself.

The flow pattern was unstable and the energy consumption increased significantly during the re-circulation test. One should also carry in mind that during re-circulation operation the anti-scale devices treat hot water. It is likely that not all anti-scale devices are designed for treating hot water.

5. Conclusions

During this Nordtest program two subsequent tests with magnetic anti-scaling devices for hot water systems with single flow and recycle flow, respectively, were carried out according to the proposed test method. The tests are based on one particular ground water quality. Each test had a control line without water treatment, and each test was conducted once.

Non of the anti-scale devices prevented scale formation completely. During the test without re-circulation 3.7% and 5.0% of the influent calcium were converted into scales in the line with and without an anti-scale device, respectively. With re-circulation 11.9% and 7.0% of the influent calcium were converted into scales in the line with and without an anti-scale device, respectively. We will, however, emphasise that our results are based on only two single tests on one particular raw water quality and hence our results are not sufficiently representative to draw wide, final conclusions. One should also carry in mind that during re-circulation the anti-scale devices might be exposed to water with a higher temperature than what they are designed for.

After having gained some experience with this test method NIVA is fairly confident that the test method is useful for examining various anti-scale devices and water qualities, even though some magnetic anti-scale devices appear to perform better in real household installations than in our test system.

To increase the confidence in the method more tests should be carried out with various anti-scale devices. Currently, the test rig water is not under pressure and is more or less open to air. This might affect the carbonate system chemistry, and cause some test bias. Hence, it might be advantageous to test the rig with pressurized water, with no connection between the water table and free air.

Our work indicates that the Nordtest-method is easy to understand and use and the test rig is quite uncomplicated from a technical pint of view. The test system simulates full-scale household installations fairly well, and the free water surfaces in the hot water tanks simulate certain industrial situations (cooling towers etc.) well.

There is obviously a need for more information about the efficiency of magnetic anti-scale devices for hot water installations. With regard to these devices, NIVA is happy to see that both consumers, water works, plumbers and equipment suppliers are interested in learning more about treatment efficiency and the mechanisms involved under various operating conditions.

6. Recommendations

The test method should be applied repeatedly with various magnetic anti-scale devices and water qualities for further evaluation of the method itself and the efficiency of various devices. More test results are also needed in order to develop a more thorough understanding of the mechanisms involved in scale reduction by magnetic fields. Tests should also be carried out with pressurized water.

We observed changes of the zeta-potential (particle charge) during the tests. It would be of great interest to carry out systematic investigations of zeta-potential during future tests.