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DR. PAUL GERHARD SCHUMACHER  
DR. IVO WAGNER  
DR. VOLKER WEHLE

## Centralized Addition of Corrosion Inhibitors to Drinking Water

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Title of the original article: "Zentrale Dosierung von Inhibitoren zum Trinkwasser unter ökologischen und technischen Aspekten am Beispiel der Stadtwerke Göttingen AG"

To supply drinking water, the Stadtwerke Göttingen AG have been mixing ground water with reservoir water since 1980. After the change-over, there were occasional corrosion problems, for example increased formation of rust water. The measures taken to solve the problem and the results of several years' investigation into the corrosion protection of the pipe network and the use of suitable inhibitors are discussed in the following.

### 1. PHOSPHATE-CONTAINING CORROSION INHIBITORS

The analytical data of the various drinking water sources in the town of Göttingen are set out in Table 1. The soft drinking water ultimately supplied is produced by mixing very soft reservoir water with the town's own hard ground water.

The pH value of the mixed water was corrected by mechanical partial deacidification of the ground water. Since the changeover had been expected to produce problems, for example increased rusty water formation, in old pipelines and in domestic installation, a silicate/phosphate mixture with a low total phosphate concentration was added to inhibit corrosion. Thereafter, there were only occasional rust water problems in the supply network in areas of low consumption and prolonged stagnation periods; there was also a marked reduction in the number of complaints from householders [1].

Despite the satisfactory corrosion behavior, the empirical choice of products had to be evaluated and corrected where necessary because the effect of phosphates and silicates on corrosion behavior in the drinking water supply industry had meanwhile been studied in more detail. According to the results obtained, certain minimum concentrations have to be added to obtain optimal protection against corrosion [2].

## 1.2 INTERRUPTING THE ADDITION OF INHIBITOR

Since the centralized addition of corrosion inhibitors is a cost and environmental factor, tests had to be carried out to determine whether centralized addition could be interrupted after the

	Göttingen water	Mixed water	Reservoir water
Temperature [°C]	7 ± 3	6 ± 2	6 ± 3
Conductivity at 20°C [mS/m]	92 ± 7	25	10.8
pH value	7.1 ± 0.1	7.7	9.5
K <sub>S4,3</sub> [moles/m <sup>3</sup> ]	5.9 ± 0.5	1.22 ± 0.04	0.42 ± 0.08
Alkaline earth metal ions [moles/m <sup>3</sup> ]	5.3 ± 0.3	1.15 ± 0.05	0.45 ± 0.03
Cl <sup>-</sup> [moles/m <sup>3</sup> ]	1.7 ± 0.2	0.40 ± 0.05	0.19 ± 0.01
SO <sub>4</sub> <sup>2-</sup> [moles/m <sup>3</sup> ]	2.0 ± 0.4	0.45 ± 0.02	0.25 ± 0.06
O <sub>2</sub> [mg/l]	11	13	12

### 1.1 DOSAGE OPTIMIZATION

Accordingly, tests were carried out in Göttingen to evaluate the empirically established inhibitor dosage. To this end, the corrosion and iron release rates were determined [3]. In addition, the conventional methods of weight loss measurement and surface layer analysis were used.

In evaluating the test results, it is important to bear in mind that high corrosion rates and low iron release rates lead to the formation of solid surface layers of corrosion products which result in blockage of the free pipe diameter. On the other hand, a high iron release rate leads to rust water problems [4,5].

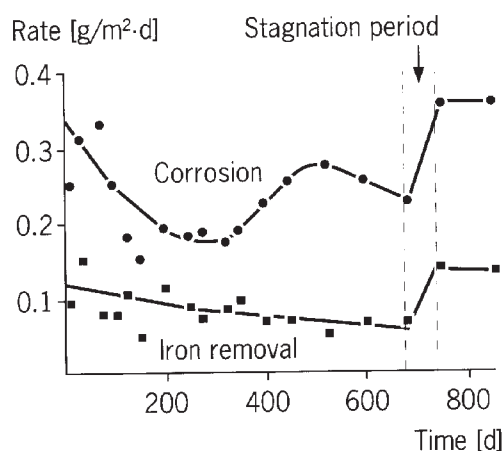
As a practical consequence of these studies [1], the inhibitor combination was changed from the product originally used to a mixture of higher phosphate content.

formation of an inhibiting surface layer. The results obtained at the time were not consistent, although in most cases both the corrosion rates and also the iron release rates rose again significantly after addition had been interrupted. In some cases, delays of several months were observed.

In Göttingen, test pipes which had already been operated for some time with different dosages or different flow behavior were used for further studies. The original throughflow was retained, but no inhibitor was added. Over a period of one year with no addition of inhibitor, no throughflow occurred for a stagnation period of one month for technical reasons.

Figure 1

**Influence of the stagnation period on the corrosion and iron release rates in inhibitor-free pure water**



For the pipe operated continuously with no inhibitor, the results indicate slightly varying corrosion and iron release rates which rose by around 20% and 40%, respectively, after the stagnation period (Figure 1).

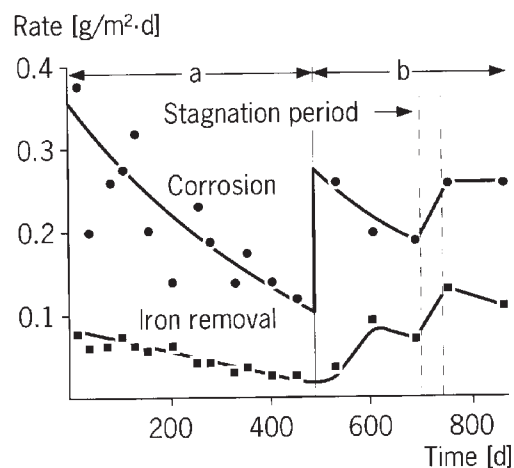
When inhibitor was added, there was as expected a continuous reduction in the corrosion and iron release rates. After the addition had been interrupted, however, corrosion immediately jumped to around twice the original level and stayed there (Figure 2). However, the iron release rate also rose continuously again and, towards the end of the test, reached levels above 0.1 g Fe/m<sup>2</sup>·d which were higher than before the addition of the inhibitor. In the stagnation period, this effect was additionally intensified.

The corrosion and iron release rates showed particularly extreme development when the addition of inhibitor was stopped in the test pipes

Figure 2

**Corrosion and iron release rates after interruption of the addition of the inhibitor**

- a With silicate/phosphate inhibitor
- b Without inhibitor



operated at intervals (Figure 3). Here, too, the corrosion and iron release rates fell significantly as a result of the addition. After the addition had been interrupted, the corrosion rates rose extremely quickly to four times the original level and then fell slightly again. The stagnation phase was reflected in a constant increase in the corrosion rates. The iron release rates also rose suddenly to three times the original levels and then continued to rise slowly.

These results clearly show that interrupting the addition of inhibitor has an adverse effect both on the corrosion behavior of the test pipes – with and without interval operation – and on the iron release rates.

## 2. PHOSPHATE-FREE INHIBITORS

Although the need for continuous inhibition was confirmed, the use of phosphate remained controversial. The year 1986 saw the develop-

ment of a new phosphate-free inhibitor based on a carbonate-activated silica [6] which completely eliminated the need for phosphate when used in soft and medium-hard water.

## 2.1 CARBONATE-ACTIVATED SILICATE

The Stadtwerke Göttingen decided to continue the test pipe trials with the new inhibitor systems based on carbonate-activated silicate, terminating them after more than 400 days. In addition to the corrosion and iron release rates, the relative instability of the surface layers and the crystallographic structures of the corrosion products in the surface layer were determined.

The test pipes were operated with four different test waters after a two-month running-in period: non-inhibited mixed water, phosphate/silicate-inhibited mains water, water containing carbonate-activated silicate inhibitor in concentrations of 6 and 12 mg SiO<sub>2</sub>/l.

The corrosion and iron release rates were comparable with those of earlier trials. The non-inhibited test pipe showed a uniform corrosion rate of 0.7 g/m<sup>2</sup>-d and a uniform iron release rate of 0.2 g/m<sup>2</sup>-d. In the case of the inhibited water, there was a steadily falling trend with respective rates of 0.4 and 0.1 g/m<sup>2</sup>-d.

Figure 3

### Corrosion and iron release rates after interruption of the inhibitor addition in interval operation

- a With silicate/phosphat inhibitor
- b Without inhibitor

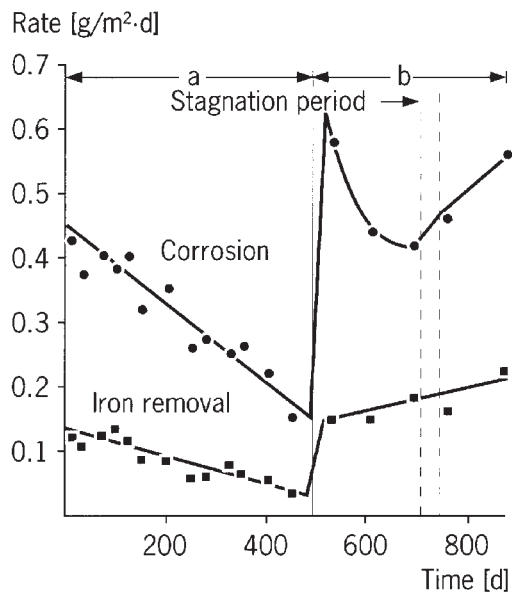


Table 2

### Composition and mechanical stability of the surface layer after a test period of 400 days

	Analytical value in [g/m <sup>2</sup> ] and as a part of the surface layer weight [%]						Stability as iron erosion [g/m <sup>2</sup> -d]
	Calcium		Phosphate		Silicate		
	[g/m <sup>2</sup> ]	[%]	[g/m <sup>2</sup> ]	[%]	[g/m <sup>2</sup> ]	[%]	
Without inhibitor	15	2.8	2	0.4	16	3.0	40
Released from mains supply (phosphate inhibitor)	5	1.1	25	5.3	12	2.6	20
With 6 mg/l SiO <sub>2</sub>	8.5	1.6	4	0.8	26	4.9	20
With 12 mg/l SiO <sub>2</sub>	10	1.9	2	0.4	26	4.8	10

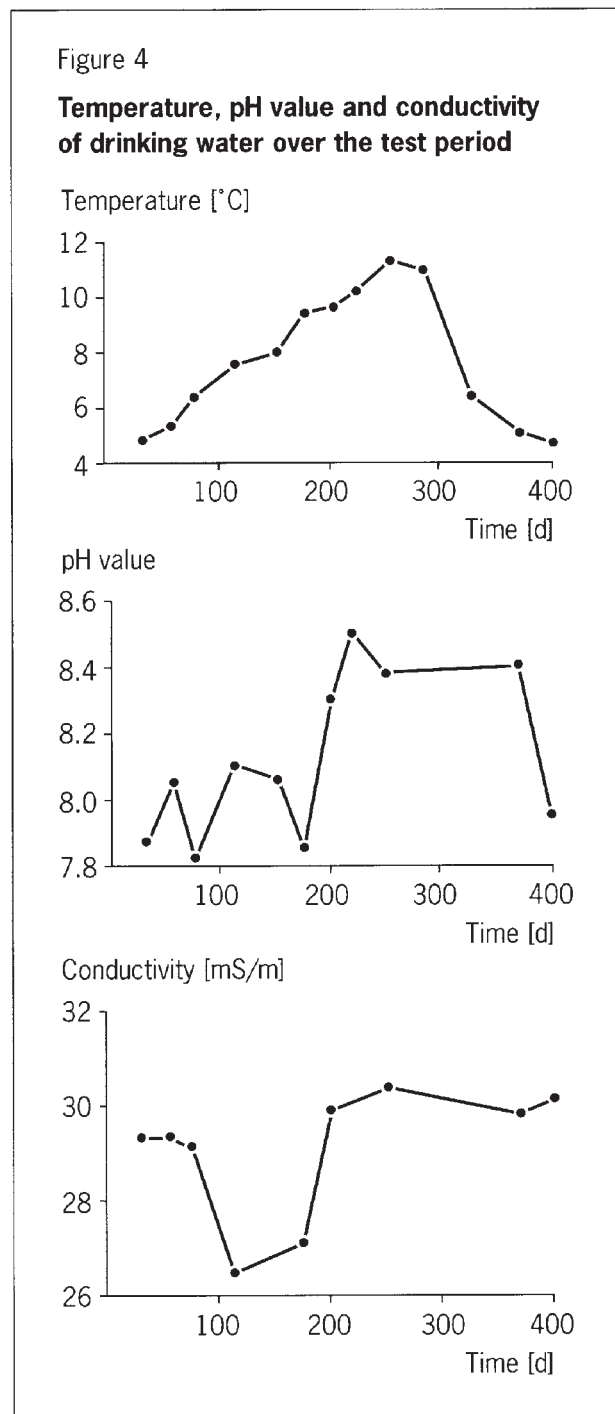
The results of the phosphate-free inhibitor combinations were unsatisfactory in the low dosage, but satisfactory and comparable with those of the phosphate/silicate inhibitor in the higher dosage. Accordingly, it is important to keep to a minimum dosage when using the new inhibitor system.

Analysis of the surface layer revealed an iron concentration of around 55% in all corrosion products. The other compositions and the stability values of the surface layers are set out in Table 2. To determine mechanical stability, water was briefly pumped through the test pipes at twice the normal rate. The material eroded in the first 3 minutes was measured as the iron release rate. According to the results obtained, the non-inhibited mixed water produced the least stable surface layer while the water with the highest silicate content produced the most stable surface layers. Accordingly, even the phosphate-free inhibitor distinctly stabilizes the surface layer.

## 2.2 CHANGE OF INHIBITOR

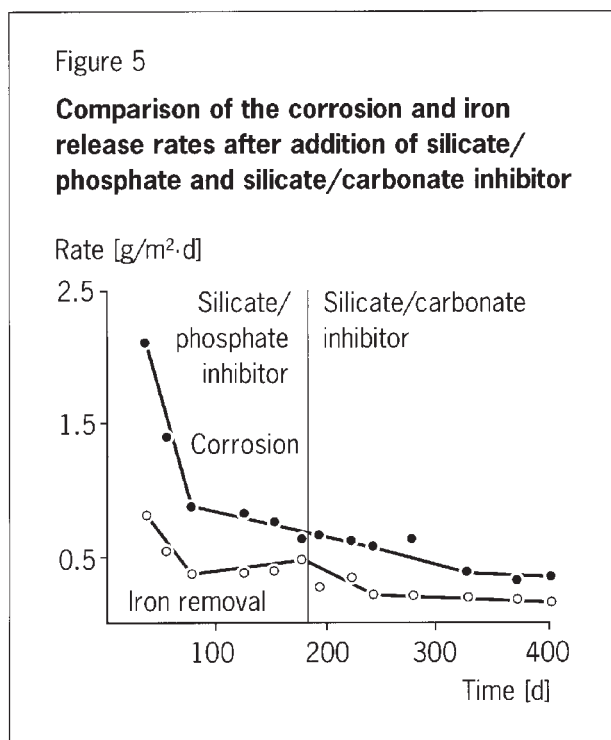
In the changeover to the phosphate-free inhibitor, silicate concentrations of as low as <12 mg/l could be sufficient for stabilizing the surface layers in the pipe network. For final optimization, therefore, the inhibitor was added in a concentration of 7.5 mg SiO<sub>2</sub>/l. To simulate the real situation in the pipe network, the test pipes were operated for several months in advance with the original silicate/phosphate-inhibited drinking water.

From January 1991, the test pipes of mild steel were operated intermittently for four weeks to avoid passivation phenomena. They were then operated with continuous throughflow for one



year for measurement purposes. The temperature, pH value and conductivity of the drinking water were also determined (Figure 4).

All the test pipes showed a continuous reduction in corrosion which was not interrupted even by the changeover to the phosphate-free inhibitor mixture (Figure 5). However, the seasonal changes in temperature are clearly visible.



When the inhibitor was changed, there was a brief, but distinct increase in the iron release rate.

Four relatively old galvanized steel pipes were additionally operated for test purposes. Very low corrosion iron release rates in the tolerance range were observed; the change of the inhibitor system had no measurable effect.

Surface layer stability amounted to 5–10 g Fe/m<sup>2</sup>·d for all the pipes and measuring periods. Accordingly, surface layers of extremely high mechanical stability had formed. The X-ray diffractometric determination of the untreated and oxidized iron corrosion products in the surface layers reveals varying amounts of “green rusts” in addition to magnetite and goethite in the untreated state. As expected, the green rusts disappear through oxidation. It is worth noting that these

divalent iron compounds are converted solely into magnetite and goethite whereas no lepidocrocite, which plays a major role in the formation of rusty water, is formed.

### 3. CONCLUSIONS

By applying modern measurement techniques, the need to add a corrosion inhibitor was demonstrated with reference by way of example to the water supply in Göttingen. The input of phosphate through the addition of a phosphate/silicate inhibitor was successfully optimized. In addition, the suitability of a newly developed phosphate-free inhibitor combination was demonstrated and dosage was optimized in terms of quantity, corrosion effect and surface layer stability.

#### Literature

1. Schumacher, P.G.; Kuch, A.; Wagner, J.: *gwf-Wasser/Abwasser* 129 (1988) 146
2. Wehle, V.; Friehe, W.: *bbr* 34 No. 12 (1983) 1
3. Kuch, A.; Sontheimer, H.; Wagner, I.: *Werkstoffe und Korrosion* 34 (1983) 107
4. Kuch, A.: Dissertation, Universität Karlsruhe, 1984
5. Kuch, A.: *Corrosion Science* 28 (1988) 221
6. EP 01 02 587 Henkel-Metakorin

#### Correspondence authors:

Dr. Paul Gerhard Schumacher, Stadtwerke Göttingen AG  
Dr. Ivo Wagner, Engler-Bunte-Institut der Universität Karlsruhe  
Dr. Volker Wehle, Henkel KGaA, Düsseldorf  
Dr. Wolfgang Hater, Henkel KGaA, Düsseldorf