THE IMPACT OF HANDPUMP CORROSION ON WATER QUALITY

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ABSTRACT

The exploitation of groundwater by means of boreholes for supplying small user groups and rural communities with water has already been widely applied in certain parts of the world for several decades. In recent years this practice has spread all over the globe, and hundreds of thousands of boreholes have been drilled to tap low yielding aquifers.

It is evident that such boreholes require pumps for lifting the water. In developing countries these are usually handpumps, but solar as well as other systems with submersible pumps are also used, depending upon the energy sources available and the financial means of the beneficiaries.

The results presented in this paper originate mainly from the experience gained from handpump-equipped boreholes within the World Bank executed inter-regional UNDP-Handpumps Project (INT/81/026) 2/.

Particular attention is paid to presenting quantitative data on the effect of corrosion on the water quality of wells in terms of iron concentration and other parameters. Furthermore, the corrosion attack on galvanized iron, the effect of biofilms on the corrosion rate, and the difference between internal and external corrosion of rising mains are shown.

INTRODUCTION

The International Drinking Water Supply and Sanitation Decade (IDWSSD) has been a catalyst for drilling large numbers of boreholes in many developing countries, including the semi-arid and arid zones of Africa. The well-known positive

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1/ The views and interpretations in this paper are those of the author and should not be attributed to the World Bank, the UNDP, their affiliated organizations, or any institution, enterprise, etc. referred to in the paper.

2/ World Bank executed UNDP-Project INT/81/026 - Laboratory and Field Testing and Technological Development of Community Water Supply Handpumps aspects of drilling vis-à-vis digging, particular in hard rock formations, are: (1) The time factor and (2) the costs. On the other hand, a drilled well cannot be utilized in the traditional way, that is, with buckets, but requires some type of pump.

In this context, the most applied option for community water supplies in developing countries is the handpump. At the beginning of the IDWSSD, most of the handpumps were supplied with galvanized iron (GI) rising main and pump rod assemblies. Although new materials, such as PVC and stainless steel, have been developed and introduced for handpump applications during the last years, GI is still the standard material for several types of handpumps. It has become evident during the first phase of the Handpumps Project (1981-1986) that corrosion has a significant impact on the quality of groundwater from wells which are equipped with non-corrosion-resistant handpumps. Investigations of handpump corrosion were carried out in West African field trials of the Handpumps Project, especially in the South of the Côte d'Ivoire (Divo) and Ghana (Kumasi). These areas are comparable in terms of environment, hydrogeology, climate, and vegetation. The field investigations were conducted on drilled wells with PVC casings of 4 to 7 inches in diameter, average depths of about 40 m, and well yields in the range of 0.5 to 10 m3/h. The wells are equipped with handpumps and supply the rural communities with water. The groundwater is characterized by a low pH with averages of 6.3 (Divo) and 6.1 (Kumasi).

Corrosion of GI pipes has been studied since the early days of their application, and yet research in this field continues. Because of the complexity of the corrosion phenomenon, there is no single corrosion index or the like which could be applied universally for predicting corrosion.

There are notable differences between the application of GI pipes in water distribution systems and handpumps, for example in terms of operating conditions and water quality. In water distribution systems the water can be and is in fact usually treated before it is distributed, which is not feasible for handpumps, at least not from the economic point of view. Furthermore, in the water industry, the main concern regarding small diameter galvanized pipes is generally internal corrosion. As for handpumps, it is not only a question of internal, but also of external corrosion, at least for those parts of the rising mains which are immersed in water in the well.

RESULTS

Behaviour of galvanized iron exposed to aggressive groundwater

Figure 1 shows the results of field observations regarding zinc and iron concentrations in groundwater from wells with handpumps with GI rising mains and pump rods. This figure clearly illustrates two points: (1) The zinc coating (galvanization) of the handpump rising main and pump rod assemblies had been corroded between 3 to 6 months after installation, and (2) the iron uptake in the water started after the removal of the coating. The pH of the groundwater from the wells considered in Figure 1 was in the range between 5.9 and 6.9 and the electrical conductivity between 250 and 850 µS/cm.

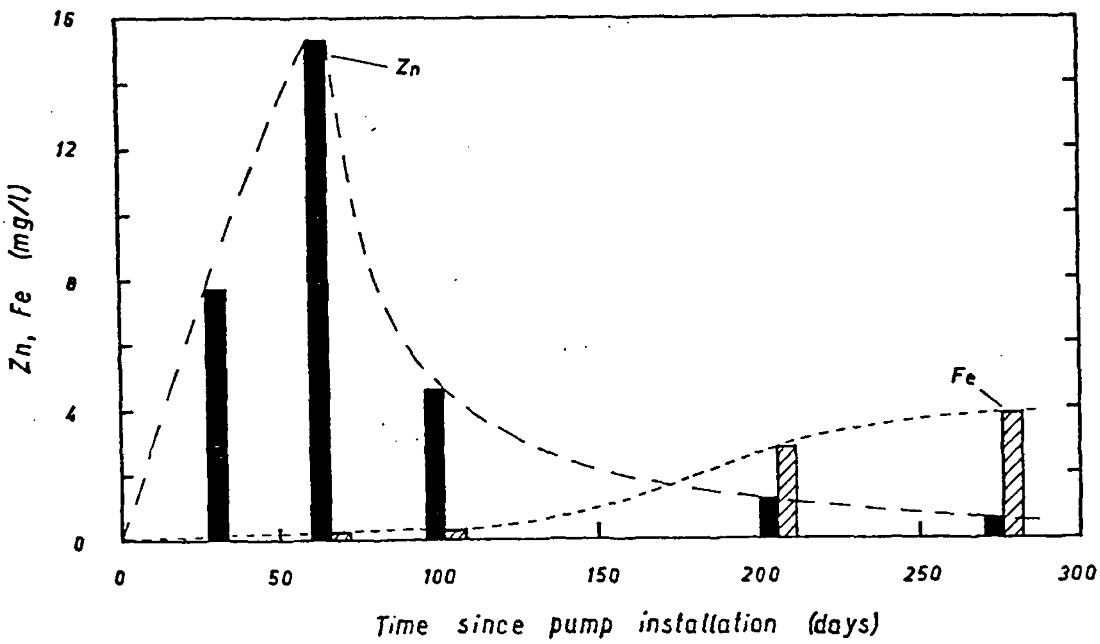

Figure 1. Mean zinc (Zn) and total iron (Fe) concentrations of groundwater from 9 wells with handpumps equipped with galvanized rising mains and pump rods versus time since installation.

Effect of handpump corrosion on water quality

The effect of handpump corrosion on water quality through corrosion products can have a major impact on pump use and user acceptance, which may even lead to the abandonment of handpump-equipped water points. The quality of water, particularly in terms of taste, is an important element influencing the preference given to water sources, if there are any choices.

Iron is the main component caused by corrosion having an adverse effect on the taste of water. It not only gives a bitter (metallic) taste to the water, but also has adverse effects on beverages. Other well known side-effects of high iron concentrations in water are discolouring of food and staining laundry.

In the Niger field trial, where non-corrosion-resistant handpumps had been installed on dug wells, the users of half of the wells indicated that the water quality had deteriorated after pump installation, because of bad taste due to corrosion.

Turbidity is another parameter like taste which is of importance with regard to user acceptance and which is heavily affected by corrosion. Two effects of turbidity and handpump corrosion can be noted. First of all, the handpump produces red water early in the morning after it has not been used for a couple of hours at night. The water contains flakes and scales from the surfaces of rising mains and pump rods. These particles, which have been accumulated in the rising main assembly as well as in the well overnight, disappear after a few minutes of continuous pumping.

The second effect is the discoloration of water, which is free of turbidity when pumped, but changes to a red-brown color after a little while. This phenomenon is mainly due to the transformation of the dissoluble ferrous iron to non-dissoluble ferric iron and further to iron hydroxides and iron oxides when exposed to the air (oxygen).

The turbidity caused by corrosion disappears after some time due to sedimentation of the particles. The sedimentation of the corrosion products corresponds to the removal of iron from the water. Figure 2 shows the development of turbidity and iron removal through simple aeration and sedimentation of groundwater from corrosion-affected handpumps over time.

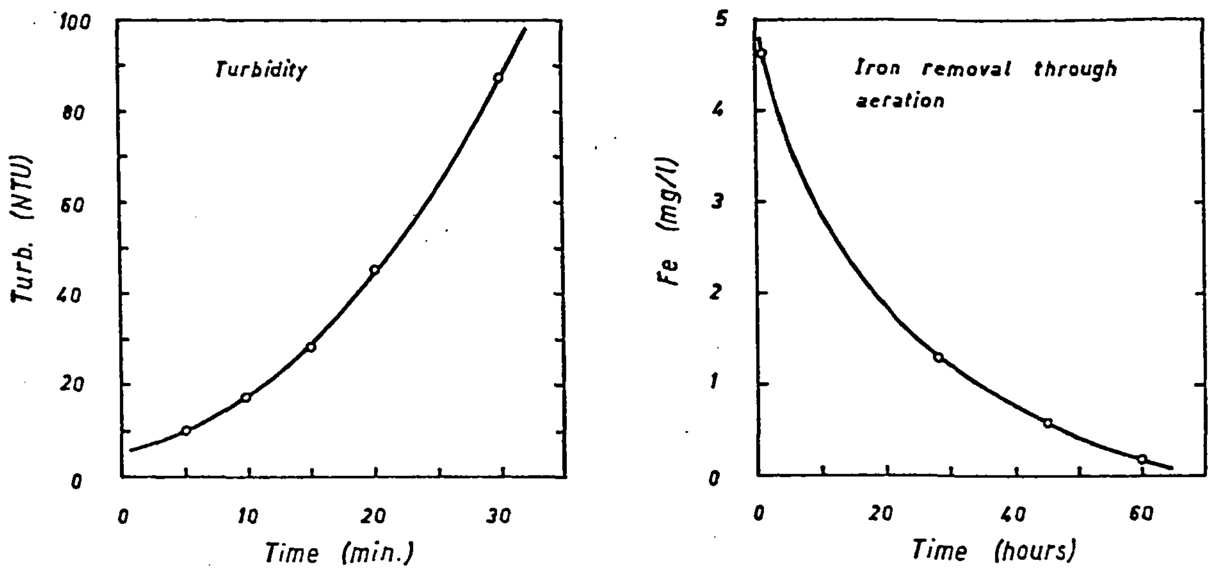

Figure 2. Development of turbidity of groundwater from a well with a corrosion-affected handpump (left) and iron removal through aeration/sedimentation in a sample bottle (right).

The most important and interesting outcome of the water quality investigations carried out within the Handpumps Project is the demonstration that corrosion is the main cause of the iron problem with handpump-equipped wells in the West African Sub-region and probably in many other parts of the World.

There are two effective methods of verifying whether corrosion is the cause of the iron problem of a well or not. The first method is to perform a pumping test, for example with the installed handpump, and to determine the iron concentration of the pumped water over time. If corrosion is the major source of iron, the iron concentration will already significantly decrease after a few minutes of pumping. The second method for determining the origin of the iron problem with handpumps is to replace non-corrosion-resistant handpumps with corrosion-resistant ones (Arlosoroff et al. 1987).

The impact of corrosion on the iron concentration of groundwater from handpump-equipped wells is presented in Figure 3. It shows the frequency distribution of total iron concentrations in groundwater from drilled wells with handpumps equipped with non-corrosion-resistant (galvanized) below-ground components at the time of well construction and pump installation respectively, and about two years later. This example originates from the field trial of the Handpumps Project in Southern Ghana. Field experience suggests that wells with average iron concentrations of more than 5 mg/l are usually little used.

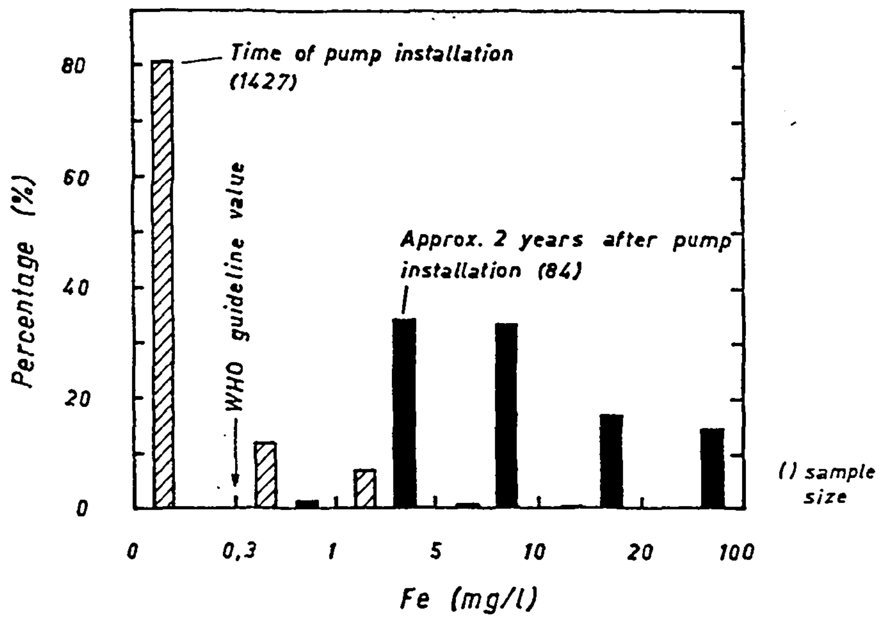

Figure 3. Frequency distribution of Iron concentrations of groundwater from wells with corrosion affected handpumps (galvanized rising mains and pump rods) at the time of installation and about two years later (field trial Ghana 1; 3000 Well Drilling Programme, GWSC/IDC).

There are several other water quality parameters which are influenced by corrosion. Ammonium (NH4) and nitrite (NO2) are two constituents which can reach high levels and which are indicators of microbiological activities (iron bacteria). The effect of corrosion on these components as well as on others, such as pH, oxygen, nitrate, total hardness, calcium, electrical conductivity, alkalinity, sulfate and silica are presented in the following chapter.

The aquifer-well-pump system

In order to describe and understand the impact of handpump corrosion on water quality, it is useful to distinguish between three different parts, namely (1) the aquifer, (2) the well, and (3) the pump (rising main-cylinder assembly) as shown in Figure 4.

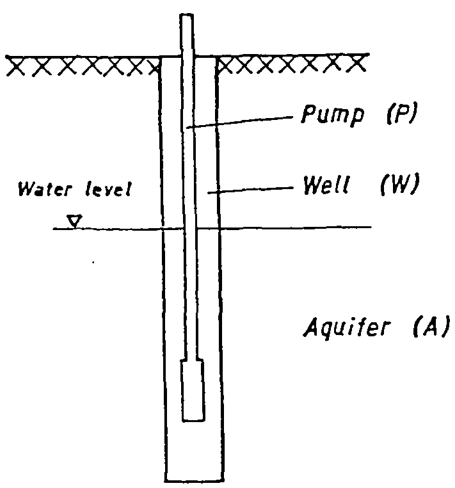

Figure 4. The aquifer-well-pump system.

The water quality of these three elements can be characterized as follows:

<u>Aquifer</u> (A): The water quality is determined by the environment (hydrogeology, climate, anthropogenic factors) and is, apart from minimal seasonal variations, of a constant composition.

<u>Well</u> (W): There are a number of variables which can have an effect on the water quality, for example corrosion of well screens, well casings, and pump parts, degassing through pressure release, aeration, pump operating conditions, and daily discharge rates. As for corrosion, the specific <u>external</u> surface area of rising mains per water volume in a drilled well in typical handpump applications is in the range of <u>10 to 60 cm^2/l</u>.

<u>Pump</u> (P): The same applies as to the well. However, the specific <u>internal</u> surface area of rising mains, including the surface area of the pump rods, per water volume is about <u>2000 cm^2/l</u>.

Field observations have indicated that there are differences between the various parts of the A - W - P system in terms of water quality. The results of a pumping test performed on a well with a non-corrosion-resistant handpump are presented in Figure 5. It shows the typical water quality variations in the A-W-P system of a corrosion-affected well over a full day (24 hours). The composition of the pumped water in the evening after the handpump had been intensively used is presented on the left margin of the shadowed areas of the diagrams in Figure 5. At that point the water was not or only very slightly affected by corrosion. The shadowed areas indicate the night, when the handpump was locked for 13.5 hours. During this pause, the water in the pump (P) and in the well (W) were heavily affected by corrosion which is illustrated by the values of the presented water quality parameters at the right hand margin of the shadowed zones in Figure 5. For example, the iron concentration in the pump increased from 1.9 to 105 mg/l, the electrical conductivity went up from 260 to 360 µS/cm, the turbidity changed from 5 to 180 NTU, and the total hardness decreased from 59 to 49 mg/l (as $CaCO_3$). The changes in water quality are much higher in the pump (P) than in the well (W) mainly because of the difference between their specific metal surface areas per water volume. The diagrams in Figure 5 indicate that, in the presented case, most of the constituents reach values which are close to those of the groundwater in the aquifer (A) after continuous pumping of about 100 liters.

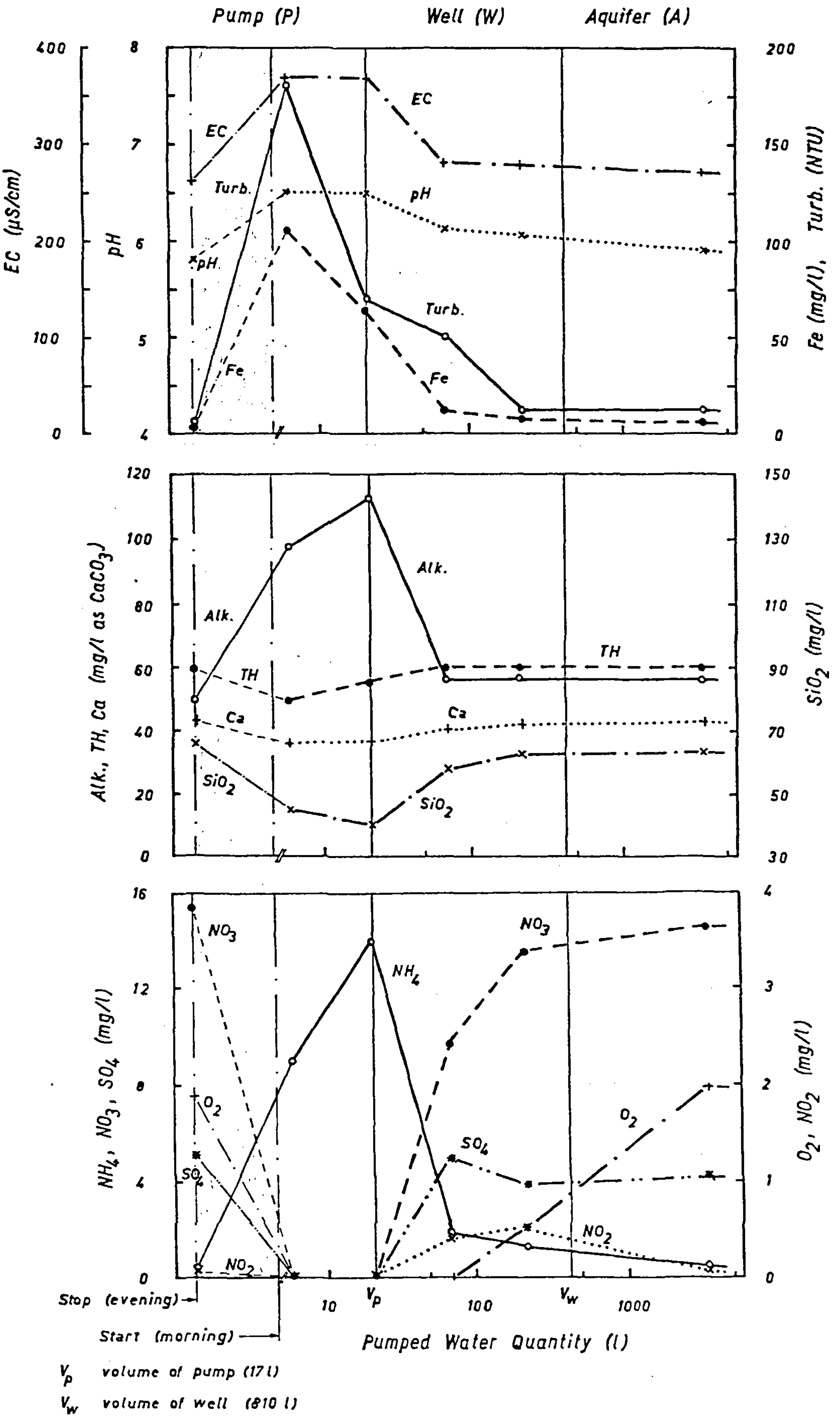

Figure 5. Variations of the water quality from a well affected by handpump corrosion as a function of operating conditions (Divo).

The hourly increase of iron in corrosion-affected rising main-cylinder assemblies (P) of handpumps in the Divo field trial versus the pH is shown in Figure 6. This diagram also suggests that the pH is a useful indicator of corrosion.

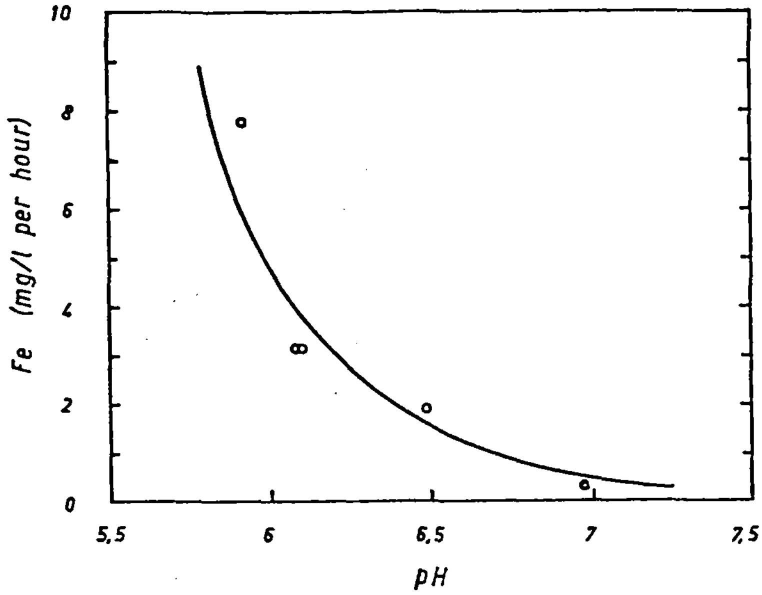

Figure 6. Hourly increase of iron versus pH in rising main-cylinder assemblies (P) of corrosion affected handpumps (Divo).

Corrosion products

Rising main and pump rod surfaces which are attacked by corrosion are typically covered with soft reddish-brown mud (biofilm). Such material is also found on the bottom of the wells. The corrosion products from rods and pipes consist usually of about 40 to 60% iron.

Some results of dried corrosion product (biofilm) analyses are presented in Table 1. They suggest a notable difference between the chemical composition of the external and internal corrosion products, which corresponds to the differences in the water quality shown in Figure 5, and which mainly results from intermittent pump operations. In other words, field observations indicate that the internal conditions of rising mains in terms of water quality are more favourable to forming protecting layers than the external ones. These observations are supported by corrosion rate measurements.

Table 1: Composition of dried biofilm taken from corrosion-affected galvanized rising mains (mean values of 2 samples from Kumasi).

	Constituents			
Sample	Fe (%)	Ca (ppm)	Mg (ppm)	Al (ppm)
External surface	54.2	79	19	196
Internal surface	46.0	248	630	1330

Effect of microbiology on corrosion

In order to obtain some idea about the development of biofilms and their impact on corrosion, a laboratory test was carried out with mild steel pump rod specimens, which were exposed to groundwater of different origins. The test was performed in 1.5 plastic bottles, which were kept in the dark at temperatures of 27 °C and 10 °C (refrigerated), respectively. The mild steel specimens had a diameter of 14 mm and were of 10 cm length, which is equal to a specific metal surface area of 40 cm^2 per liter of water, and which corresponds to the situation in the well (W). The results shown in Figure 7 originate from a test performed with water from the same well referred to in Figure 5.

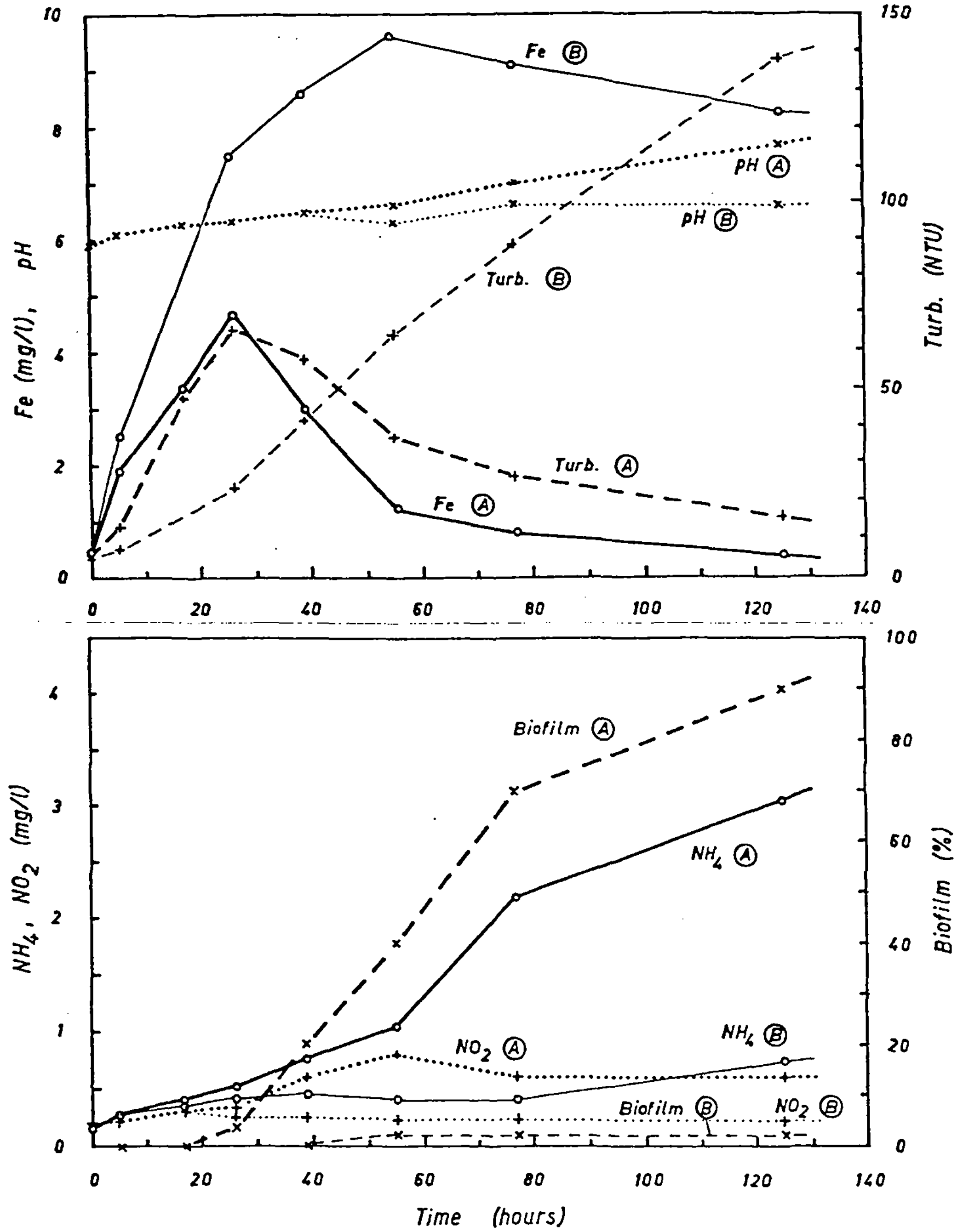

Figure 7. Biofilm development on a mild steel pump rod specimen under corrosive conditions and its impact on various water quality parameters.

The presented results indicate that:

- A biofilm developed on the mild steel specimen at 27 °C within about 30 to 40 hours (sample A). No biofilm or only little traces of a biofilm was observed on the specimen at 10 °C (sample B). The development of the biofilm on sample A was about proportional to the increase of ammonium (NH_4). The occurrence of NH_4 in sample B was negligible in comparison to that of sample A.

- The dissolution of iron through corrosion measured as iron-increase (Fe total concentration), was indirectly proportional to the formation of the biofilm and the NH_4 concentration in sample A. The iron-increase was higher and relatively constant with that of sample B. This behaviour indicated a decrease of the corrosion rate in sample A primarily due to the biofilm.

CONCLUSIONS

(i) Under the prevailing groundwater conditions in the investigated areas, galvanization does not protect mild steel from corrosion. Protecting zinc layers (galvanization) were removed from rising mains and pump rods in three to six months time.

(ii) The iron surfaces are, in general, covered by a biofilm. The composition and thickness of the biofilms vary with the water quality. Biofilms from the interior of rising main assemblies showed higher concentrations of calcium than those from external pipe surfaces. This observation suggests that the internal parts of rising main assemblies show a higher tendency to form protecting layers and, thus, are less susceptible to corrosion than the exterior of pipes.

(iii) The dissolution of iron through corrosion is a function of the aggressivity of groundwater and the composition of the biofilm. The iron-increase rate in rising main assemblies of non-corrosion-resistant handpumps was, under non-operating conditions, in the range of 0,5 to 5 mg/l Fe total per hour. This observation explains the red water problem early in the morning and makes it clear that the less a pump is operated, the more corrosion products (iron compounds including biofilm debris) are formed and accumulated in the rising main assembly and in the well. In other words, wells which are little used are more susceptible to the iron problem than intensively used ones.

(iv) Water sampling from corrosion-affected wells has to be done with care if reliable results are to be obtained. As a rule of thumb, at least double the well volume should be pumped immediately before any sample is taken.

(v) Handpump corrosion should be avoided by all means. Therefore, where groundwater is likely to be aggressive, only corrosion resistant handpumps should be considered (Langenegger, 1987).

REFERENCES

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