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FERRIC CLOGGING OF DRAINS
DIE EISEN-VEROCKERUNG VON DRÄNS
LE COLMATAGE FERRIQUE DES DRAINS

Typical cases of iron clogging of drains have been investigated on pyrenean border. One originated with the intermediary of an autotroph bacteria, Gallionella ferruginea, from a water bed rich in ferrous iron but poor in organic matter. The others resulted from the conjunction of mechanical (silicates) chemical (iron oxides) and biological cloggings. The later is initiated by Sphaerotilus natans or Siderococcus sp..

An application to the forecasting of iron clogging risks sketched.

INTRODUCTION

Iron clogging of wells, canalizations and drains is a phenomenon known since antiquity; the leading role of any bacterium in the process was only described 150 years ago. Early works did not make a distinction between biological iron oxidation and its chemical precipitation, consequently, ferrous bacteria were assimilated to autotrophs, taking their energy from ferrous iron oxidation.

The experiments carried out after that by MOLISCH (1892) enabling actually to differenciate two groups of bacteria : those which oxidize ferrous iron (a few species) and those which precipitate it by deteriorating the organic ligand (numerous soil and water bacteria).

Despite bacteria action in the phenomenon, purely chemical oxidation is not to be disregarded, and in the field (1,2,3) make a major contribution to the analysis of dissolved iron behaviour and to the evolution of ferruginous water.

Since we know fairly well the development process today, it is quite impossible to estimate accurately the iron clogging appearance and intensity in a given place. Research work carried out by the CEMAGREF (4,5) shows that it is not an easy problem and that any contribution to its solution will be welcome. Our own work concerns typical cases observed on the territory of CAPVERN (Hautes-Pyrénées) and LESCAR (Pyrénées Atlantiques).

1 - THE SITE OF CAPVERN DISTRICT

1.1. Clogging by Gallionella ferruginea

The drain laid along the railway line following the Pontian-Pliocene horizon (red sandy clays with shingle beds) has major ochre gel deposits in its terminal portion and in the evacuation ditch. It captures water from sloping grounds including moors, meadows and a few cultivated plots. Its flow is constant all year round and varies between 4.5 and 6 litres per minute.

Investigation on clogging risks, in direct connexion with iron compounds precipitation, was performed by means of biological and chemical analyses carried out on water samples spread out between october 1982 and june 1983.

Chemical analysis of the water

The results of the analysis are stated in Table 1. The water coming out of the drain is odourless and is not coloured but yet it con-tains ferrous iron whose average content is 15 mg/l in one year.

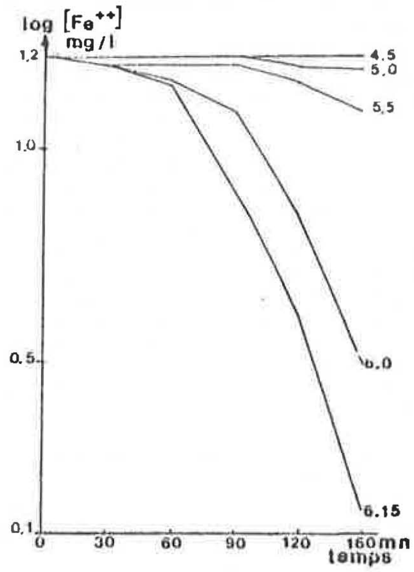

Figure 1
Evolution of the iron oxidation speed in natural water according to pH.

Table 1
Analysis of the water from the CAPVERN railway drain (from september 1982 to june 1983).
Concentrations in mg/l.

	29.9.82	24.10.82	14.11.82	11.12.82	15.1.83	19.2.83	20.3.83	24.4.83	15.5.83	12.6.83	26.6.83
T°	14,5	13,8	13,1	13,0	12,5	12,0	11,5	11,0	11,4	11,8	12,0
pH	6,20	6,30	6,10	5,90	6,20	6,10	6,15	6,30	6,15	6,30	6,20
Eh	+ 65	+ 68	+ 64	+ 65	+ 70	+ 72	+ 70	+ 68	+ 70	+ 60	+ 90
Fe^{2-}	11,0	9,60	11,70	12,0	12,20	19,60	19,20	18,60	13,60	14,60	11,40
Fe^{tot}	11,60	10,60	12,30	12,50	12,90	22,0	21,0	19,60	15,60	15,10	12,20
Mn	0,55	0,59	0,58	0,63	0,58	0,46	0,52	0,48	0,50	0,50	0,52
Ca^{++}	20,50		23,20		27,2	27	24,5	25,0	21,5	18,2	15,20
Mg^{++}	1,58		1,70		1,95	1,75	1,70	2,0	1,45	1,50	1,30
Na^{+}	4,0		5,10		6,50	4,90	4,10	4,0	3,65	3,40	3,30
K^{+}	0,52		0,50		0,72	0,36	0,34	0,38	0,50	0,34	0,54
NH_4^{+}	0,33		1,60		2,0	2,40	2,50	1,50	3,50	3,80	2,40
NO_3^{-}	0,71		0,45		0,35	0,24	0,15	0,10	0,08	0,05	0,09
HCO_3^{-}	64,40		92,50		102,60	107,60	105,5	102,5	97,57	95,35	74,74
SO_4^{-}	10,40		15,0		17,0	18,80	10,5	6,25	3,75	1,73	7,76
Cl^{-}	17,80		16,0		15,0	15,24	15,7	15,95	12,40	8,85	7,10

The pH, Eh and the O_2 content are the three elements which affect mostly iron solubility; with the latter relatively low (0.5 mg/l), it is difficult to assess the pH or Eh action by using the theoretical curve calculated by (1). In order to value the pH action on iron resis--tance when dissolved, we acidified various water samples; then, we observed the iron oxidation (the water was aerated by means of magnetic agitation). Figure 1 shows the results of this experiment (the pH ground average is 4.9).

For a pH of 5.5, the oxidation is low during the first hours, and becomes even nil for a pH of 4.5. For a pH close to neutrality, a difference of 0.1 pH unit leads to very different oxidation speeds. In the experienced system, the pH is mainly controlled by the CO_2 HCO_3 equilibrium; so, it is easy to see the microorganism action (which produces CO_2 by breathing) or the water rippling causing a CO_2 release. However, the physico-chemical factor and mineral compounds are not the only ones which act upon iron solubility. Organic compounds also have a direct (complexing) and indirect action (bacterial development) leading to the rise or limitation of iron solubility.

The investigation on water oxidability ($KMnO_4$) and carbon dosage (2.4 mg/l) showed in water a relatively poor organic matter. However, organic compounds can be qualitatively interes-ting. The analyses which are carried out in various steps concern four groups of compounds : sugar, amino acids and phenolic compounds :
- Sugar is not detected in samples, which indi-cates that it is quickly assimilated at ground level.

The amino acid analysis shows, at drain's outlet, a quantitatively and qualitatively depleted mixture compared with the draining water from soil A-horizon.

As far as organic acids are concerned, the only detected compound has a phenolic characteristic and corresponds to gallic acid, which is not surprising as this last one originates from lignins decomposition.

The analysis of draining water organic com-pounds reveals mainly as follows :
- the organic matter which can be used to feed heterotrophic microorganisms is chiefly composed of amino acids;
- if we take into account the quantity, this organic matter cannot play a major role in the transport of iron in solution.

However, if we consider the nature of compounds which have been observed (sulphurous amino acids, gallic acids), we may think that those solutions can participate to the iron reduc-tion.

Chemical analysis of ochre

The sediments which were taken from the drain's final part (Table 2) have a low silica content and a very high iron one, which is due to the presence of Gallionella (6). This value is close to the maximal ones stated by different authors, that is 65.9 % (7). On the other hand we note the absence of Calcium and Magnesium.

Finally, the low C/N confirms the idea in which the medium is poor in compounds resulting from the plants deterioration (high C/N) this relation is close to that of bacterial cells composition.

Table 2

Chemical analysis of CAPVERN drain deposit

SiO_2	16,5 %	K_2O	0,5 %
Fe_2O_3	59,6 %	Na_2O	0,2 %
Al_2O_3	3,4 %	OH_2	15 %
FeO	-	C	1,98%
TiO_2	0,2 %	N	0,17%
CaO	-	C/N	11,6
MgO	-		

Microbiological analysis of ochre

* Heterotrophic bacteria

They were isolated from sediments of drain's final part. Two mediums were used for their culture :
- an ammoniacal iron citrate medium (8);
- a peptone glucose medium used during the culture of Sphaerotilus natans.

Among the investigated microbial population, we note a high number of negative-gram chromogenic bacteria and the absence of positive-gram sporulated bacteria.

By observing the isolated elements, we attempted to assess the influence they might have on the iron deposit. (In the drain, they only play a minor role if we take into account their concentration and the fact that the iron circulates in the ionic form). For this, the iron oxidizing process was observed by comparison with an element having no bacterium; when bacteria are present, it has been noted that the oxidizing process rate is low (the endogenic respiration consumes oxygen), but at the end of the experiment, that is four hours later, the iron precipitation was more complete. The supernatant solution is clear, which means that there is coprecipitation of iron and bacteria. It has also been observed that there is no difference between the tested bacterial germs. This may cause an indirect action : Gallionella develops more easily when Pseudomonas is present (9).

* Autotrophic bacteria

If we consider the physico-chemical characteristics of the medium, we may say that the precipitated and oxidized iron comes greatly from the iron's autotrophic bacteria. The evidence of these bacteria was obtained by comparing a sample of normal water and a sample of water added with Thiomersal with a concentration of 0.01 %. Results are specified in Figure 2. Then, we searched for the three main species : Thiobacillus ferroxidans, Metallogenium symbioticum and Gallionella ferruginea.

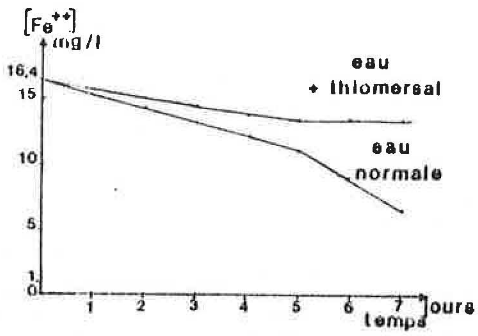

Figure 2
Evidence of iron's biological oxidation in natural water.

The first two bacteria were not detected in the drain water. On the contrary, the presence of Gallionella was directly observed by microscopic examination; actually, the twisted filaments are sufficiently typical to enable the identification of the bacterium in the deposits (Photo 1).

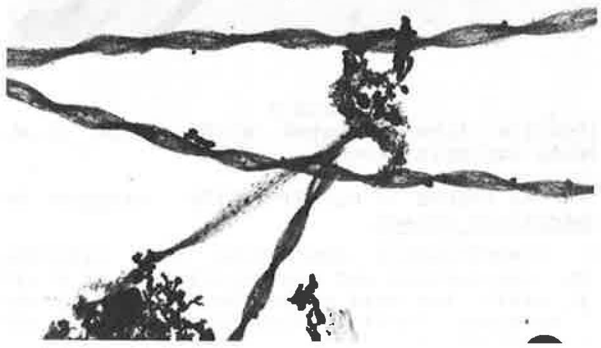

Photo 1
Gallionella ferruginea : typical twisted aspect (X 2400 optical microscopy).

We also obtained the growth of the bacterium on the medium proposed by (10); the isolated microorganism corresponds to the Gallionella ferruginea one. We enumerate the bacterium by extinction, using its property to reduce nitrates to nitrites (11) by means of dilution and seeding in the KUCERA and WOLFE (10) medium + nitrates (50 mg/l). The number of 4.5 . 10^4 germs/ml is important, especially considering the fact that there is a fixed bacterium.

1.2. Iron clogging of a geotextile by Siderococcus.

This is about a clogging observed on a temporary drain carried out in geotextile configuration alongside a motorway construction. The dissolution of the ochre which is deposited on fibers by oxalic acid enabled us to observe heterotrophic bacteria belonging to the Siderococcus species (Photo 2). These bacteria do not directly precipitate iron on their cells : the group becomes impregnated with ferric oxides, then with clay and calcite (lime treatment) which forms a sleeve around the fiber whose diameter doubles or triples. We have to note that the investigated drain portion was located in the open air. Average manganese and iron concentrations of water reaching the drain were respectively 1.22 mg/l and 0.20 mg/l.

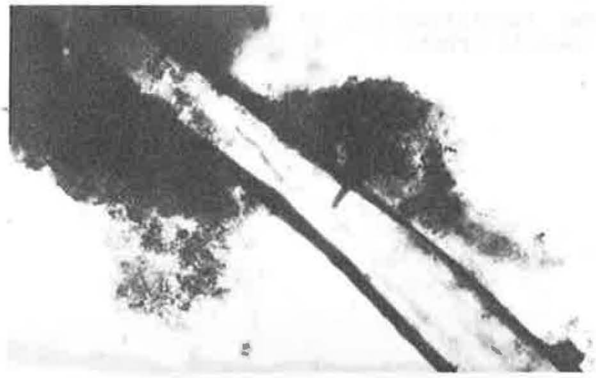

Photo 2
Geotextile fiber treated with oxalic acid, showing bacterial sheath.

2 - THE LESCAR 'S DISTRICT SITE : Clogging by Sphaerotilus natans.

The investigation concerning this clogging which was carried out posteriorly, as we could only visit the site after the draining system was restored (installation of a new drain and lime treatment of soils). However, as the old drain remained in position, the following observations were made possible :

The drained grounds correspond to a peaty bog area; development was favoured by a trough-shaped topographic site.

The drain's feed water runs in the MINDEL's alluvial deposits when it picks up iron; at the peaty area level, as it becomes acid,the water solubilizes organic matter, stimulating in that way the microorganisms proliferation.

The drain (in ringed plastic, 100 mm diameter, laid at a depth of between 80 to 100 cm) is clogged (it was inoperative one month after being laid). Outside, it has no ferric deposit; inside, it is covered by a whitish bacterial gel. In its final part, the gel becomes rusty on the surface (under the rusty layer, a whitish one remains) (photo 3). The drain

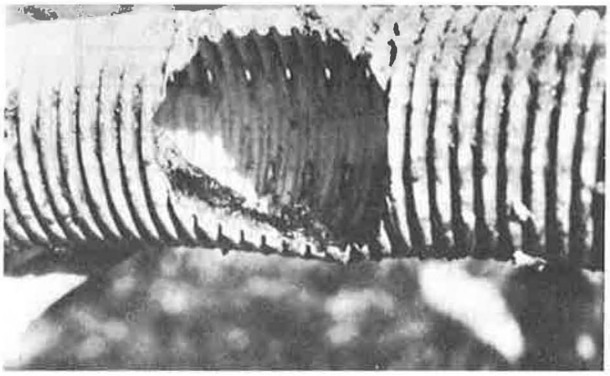

Photo 3
Opened portion in the LESCAR's drain showing different kind of deposits.

pores reveal small ferric oxide protuberances (these protuberances surrounded pores but did not block them). The drain final part and and the discharge ditch have major ochre deposits. As the drain is almost no longer flowing only a partial water analysis was carried out; it concerned its pH : 6.05;its Redox potential : + 70 mv, and its Fe2 + content is 6.2 mg/l. In the adjacent grounds, in order to reach the bed, a bore enabled us to measure its ferrous iron content, which is 18 mg/l. Some parts of water-logged beds have pools where we can see a high development of rusty bacterial gels composed of fibrous bacteria.

The analysis of the deposit which was taken from the inner part of the clogged drain (table 3) shows the importance of silica (50 % compared with the 16.5 % in the CAPVERN site). The C/N relation (21.5 compared with the 11.4 in CAPVERN) is high; a major part of the organic matter comes, at this point, from peat.

Table 3
Chemical analysis of LESCAR's drain deposit

SiO_2	50 %	K_2O	1,0 %
Fe_2O_3	19,2%	NO_2O	0,6 %
Al_2O_3	8,8%	OH_2	10,4 %
FeO	-	C	4,73%
TiO_2	0,6%	N	0,22%
CaO	0,6%	C/N	21,5 %
MgO	0,3%		

In this case, three types of clogging are observed : a biological clogging (bacterial gels), a mechanical clogging (silica) and a chemical one (iron oxides).

As to the role of microorganisms, in this area rich in organic matter, the heterotrophs, which act indirectly, must be incriminated : they deteriorate the organic matter, which releases the linked iron; the latter becomes chemically oxidized and precipitates on bacterial gels. The microbiological analysis showed the existence of several bacteria such as the Pseudomonas ones and especially wrapped bacteria (photo 4) which is part of the Sphaerotilus type (these ones are responsible for the whitish gels inside the drain).

If we consider these analyses, the following clogging sequence can be stated: the development of fibrous bacteria wrapped in their case forms the bacterial gel; the deteriorated organic matter and microorganisms release chelated iron; this one becomes chemically oxidized and precipitates on gel surface. In addition, drifted mineral particles get trapped in the bacterial matrix. Within the deposits, we consequently reach an oxidized surface layer (rusty) and at a greater depth (in contact with the drain) a thin whitish layer, rich in mineral particles.

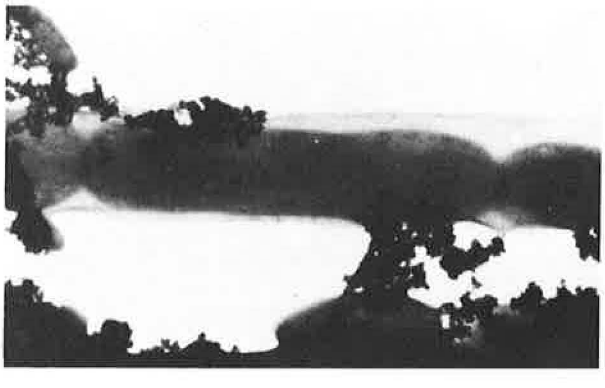

Photo 4
Sphaerotilus natans : sheathed fibrous bacteria (X 5550 electron microscopy).

3 - CONTRIBUTION OF OUR INVESTIGATION TO IRON CLOGGING DIAGNOSIS.

Before laying properly a drainage system, various investigations and analyses, aiming at determining whether there is any risk of iron clogging, are recommended Initially, a geologic map examination enables us to learn the formation process of soils. The parent rock is a factor which, in many cases, may supplant the role played by soil and vegetation. So, close to the CAPVERN site, in contact between the Pontian-Pliocene formation (sandy clay alluvial deposits) and LANNEMEZAN upper formation (quaternary alluvial deposits rich in clay), the disappearance of dissolved ferrous iron in the water of Pontian-Pliocene formation was assessed. We note that the difference existing in water composition is not due either to soils (brown acid soils in both cases), vegetation(which is an acidophilic one), topography (slope does not change when we switch from a formation to another) or to pHs (which are inferior to 6 in both cases).

However, vegetation and soil influence in iron clogging should not be minimized (autochthonous iron), consequently and secondly, a classical pedologic analysis will provide interesting information as to soil clay wealth, its acidity, its hydromorphy and its iron and organic matter content.

Natural vegetation is also of interest if we consider the role played by organic compounds in iron transport and reduction, and by aliphatic organic acids (citric acid) in heterotrophic nutrition; in addition, its examination enables us to know immediatly the soil hydromorphy degree (typical vegetation of hydromorphic mediums).

The first data can be optimized by examinations aiming at determining in ditches or pools rusty products with a gelatinous aspect and intensive irisations due to bacterial veils, which is a sign of important activity (12). Finally, the analyses of the bed water (Fe^{2+}, organic matter, pH, Eh content)enables, using previous results, to set up a diagnosis on the iron clogging risk.

Following the study carried out at CAPVERN and LESCAR, we may say that, actually, there are three main situations :

- calcareous areas where water is free from any ferrous iron and where clogging risks are extremely low. However, all risks are not eliminated if we consider the possible heterogeneity of organic matter formation which may form a superficial reducing horizon (autochthonous iron);
- Non calcareous areas where water contains ferrous iron but little organic matter. There may be a clogging risk but it depends on the development of the autotrophic bacteria as the Gallionella one (i.e. the drain of CAPVERN. In this case, we may state the following clogging sequence :

When water penetrates into the drain, ferrous iron is partly chemically oxidized by atmospheric oxygen and biologically oxidized by autotrophic bacteria. Consequently, there is a formation of a ferric hydroxide soil, and with other ions and bacterial substances, and precipitation. As the ferric hydroxide has an important exchange capacity (13), it will combine with various water cations and anions. The formed gel traps, then, organic and mineral particles and, as a consequence, becomes a substrate favourable to the development of the heterotrophic bacteria; finally it will result in ochre : a rusty sediment with a gelatinous aspect. In this typical case, it is interesting to know the water iron content and the number of bacterium oxidizing ferrous iron in order to evaluate the iron clogging amplitude and rate of incrustation.

- The non calcareous areas both rich in ferrous iron and organic matter (LESCAR), favour a direct development of heterotrophic bacteria (Sphaerotilus), as their adhesion is stimulated more by the ringed-shape drain.

Clogging is very rapid there, and in this case, we may wonder whether this type of drain should not be abandoned. The lime treatment of the ditch revealed that it was immediatly efficient, but duration of the effect is to be observed (in the long run). As for us, we noted on CAPVERN's motorway site that the use of lime did not prevent the growth of Siderococcus bacteria, which is responsible for clogging of part of geotextile filter surrounding the drain.

CONCLUSION

The two cases of iron clogging investigated have only the ferrous iron resource of drained water in common. This is a factor of the utmost importance as the allochthonous iron cannot be definitely eliminated by punctual methods, such as lime treament. The absence of energetic organic matter does not prevent clogging due to possibilities of rising settlement of the Gallionella ferruginea autotrophic bacterium. In addition, this one paves the way to heterotrophic biological or mechanical clogging. The latter has a higher scope and rate (the LESCAR drain no longer ran after a month). Simultaneous and abundant organic matter and ferrous iron in water, undoubtedly outlines the example when the building of drainage systems may be questioned (4).

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