Proposition of Corrosion Expertise method for water pumping stations Application to the case of northern station of Fez city - Morocco

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Abstract - In a constant progress of a regulatory and environmental context, the diagnostic and the expertise of the corrosion, the determination of its causes and factors, and the proposed solutions to this phenomenon represent a real challenge for all stakeholders of industry. We propose in this paper to a complete study of the corrosion risk in the case of water pumping stations, based on some industrial methods of risk analysis (FMEA) and multiple laboratory tests and analysis. Finally we have proposed a masterplan (chart) as perspectives, indicating the encounter corrosion problems in the case of the northern pumping station of Fez city (as case study). The masterplan includes also the corresponding solutions, that can stop or minimize degradation of the focused equipments by the various mechanisms of corrosion. Our proposals will serve as reference during futur installation of new water equipments, or during the study and choice of appropriate materials in the Water Studies Department.

Keyword-Corrosion, FMEA analysis, metallography, physico-chemical parameters, welding process, painting techniques

I. Introduction and Context

Corrosion is considered as one of the most important causes for material degradation, especially the metallic ones and for others for which the steel is added for reinforcing the mechanical resistance of a structure.

The neglect of the material choice, in parts design or in the choice components can constitute a direct cause for corrosion starting, and by the way the beginning of the equipment degradation.

The quality standards, the new laws and control procedures in health and environment, accelerated by economical and ecological issues push more the industrials to research and develop solutions to eliminate the corrosion risks.

This paper presents a general methodology to attack any corrosion problem, especially in pumping station of water or in the case of other substances. Using at first industrial method of risk analysis as FMEA (Failure Mode Effect and Analysis), and based on a consistent historic of failures, we optimize our study to focus more on the most critical equipments of the installation.

Hence, this study presents all steps of risk analysis applied to corrosion phenomena. The same steps can be followed for similar cases.

The case of northern water pumping stations of Fez city-Morocco was studied to evaluate the consistence of our methodology.

As a first step, we had determinate the most critical equipment by FMEA Analysis, and, based on an historic of 6 years of interventions Insitu, and using a Geographic Information System (GIS), we were able to determinate a scatter (figure 8) showing us the dispersion of the defaults of pipes installation in Fez city, from 2004 to 2009.

The environment analysis, towards the corrosion defects, allows us to evaluate the quality of water into the pipes. The soil nature and its effects on the underground metallic pipes will be discussed in a next paper.

The logic that we adopted to analyze this problematic is based on cause and Effect analysis.

Each technical problem can be dispatched in accordance with the Ishikawa diagram classes: materials, machines, process parameters or methods, Environment, personal. Thus, we will try to understand the corrosion risks starting from this logic.

Material (steel and water) party will have the biggest part of the analysis due to the physico-chemical character of the subject. It will be treated in section IV and V, but also process parameters and human effects will be included, especially in section VI which discusses the effect of welding process of the pipes.

Finally we have proposed some suggestions to minimize the corrosion degradation mechanisms, by reviewing the water quality and treatments, by seeing the protection techniques (cathodic protection, painting, isolation, galvanization…), and by criticizing the installing pipes methods…

II. METHODOLOGY

As we said in the introduction, we have based our analysis on FMEA analysis, Ishikawa logical decomposition of a problem and deeper analysis by making several tests and analysis in laboratories (metal spectroscopy, rust composition, physico-chemical analysis of water…).

Figure 1 summarizes the steps toward the definition and the explanation of the corrosion forms in a pumping station, or other industrial equipments; and so finding efficient solutions against this phenomenon.

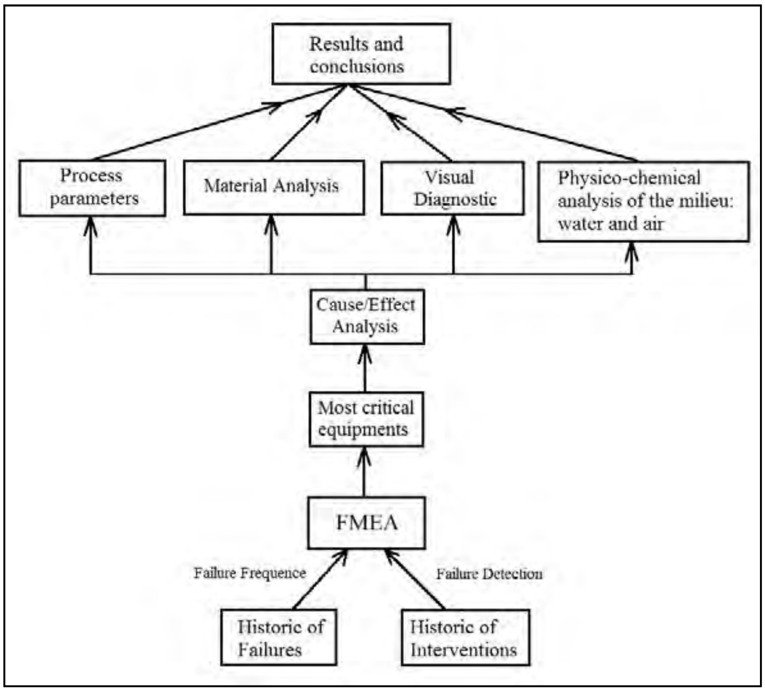


Fig. 1. The proposed steps for corrosion expertise

For example, process parameters concerns water pumping parameters and also pipes processing in workshop. Material analysis concerns the constitution of the pipes metal and the elements that are present in the rust of internal surface of the pipe…

The details of the blocks are developed in the study, applied it to the case of Northern pumping station of Fez city of Morocco.

So the schema of figure 1 constitutes the master plan for this study or for another in any industrial context.

III. PRIMARY DIAGNOSTIC: CRITICITY EVALUATING OF NORTHERN PUMPING STATION EQUIPMENTS AND SUPPLY PIPES (INTERNAL DIAMETER ≥ 300 mm)

The first step consists on the detection of the most critical and non-reliable sites (pumping station).

A first meeting, with the pumping division engineers and technicians, permits us to focus on two principal stations: northern and northwestern.

In the following analysis we focused on the northern station which presents the biggest failure ratios according to the stations division engineer. Similar studies can be made to evaluate the criticity of the other sites.

A. Visual diagnostic and inventory

Figure 2 presents some of corrosion effects on an aspiration pipe of the northern station.

The figure shows three cracking. Internal corrosion was suspected for a first time. We can observe a rubber belt tight by a sheet metal ring working as gasket to eliminate the leakage.

By analyze more, we have observed that the fissure is starting from the weld; so it can be a bad welding method, corrosion due to the thermal and mechanical effect of welding or humidity stored in flux of the welding electrode (see figure 15 of section VI).

Fig. 2. Water leakage due to cracks; internal corrosion is suspected

Figure 3 shows the internal surface of a forsaken pipe (January 2010 according to expertise period).

A preventive control by ultrasound permits the measurement of the thickness. When the thickness reaches a critical value, below which the pipe can’t support water pressure, it is advisable to eliminate this pipe.

The visual diagnostic allows us to make a first affirmation that the uniform corrosion exists also into the pipe at the internal surface, and which has as effect a uniform diminution of the thickness of the pipe, accelerated also by the water erosion.

We can also see clay deposit on the internal surface of the pipe. Quality (particles in suspension: turbidity) of the water is a key point in analysis of the degradation of these equipments by differential corrosion mechanism. Therefore, we have sent the analysis of rust deposit after triacide attack to determinate its constitution. The results of the analysis are presented in section IV.B.

Fig. 3. Forsaken pipe due to a critical value of thickness

Fig. 4. – Corrosion on the drive shaft of a pump

Fig. 5. State of the roof and walls affected by the humidity (Metal reinforcement is corroded)

We have also noted the existence of an important rate of humidity, especially in the vane chamber (figure 5 and 6), which causes great damages by uniform corrosion on the external surface of the pipes.

The humidity is caused here by a non effective aeration system, which is, in several cases not taken into consideration in architectural design of the stations. So the office has to make humidity measurement for all affected sites. Unfortunately, we had no time to make those tests, and we noticed that as suggestions and future perspectives.

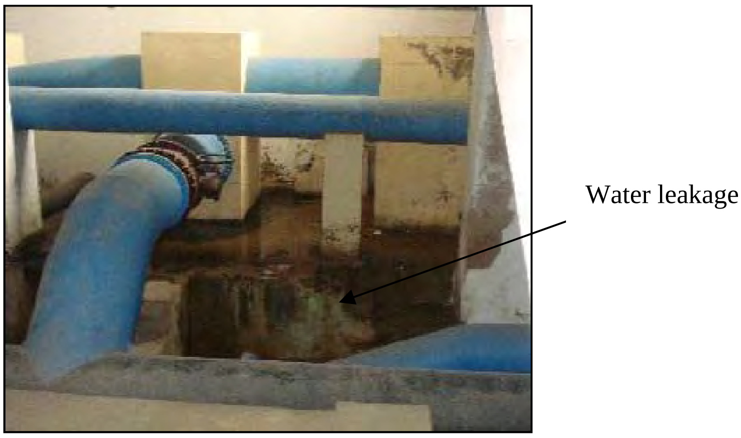


Fig. 6. Water leakage in vanes chamber

B. FMEA Analysis on Northern pumping station equipment

The FMEA (Failure Modes and Effects Analysis) is a method of industrial risk analysis which permits to detect equipments which can be deteriorated the most, based on the historic of failures, intervention, cost and security parameters.

The histogram of figure 7 – (b) summarizes the results of FMEA, and shows that the pipes are the most critical equipments of all the pumping station (figure 6-(a)). Thus, they constitute the subject of the following expertise.

The other equipments (pumps, vanes, tank, seals, manometers…) have a criticity less than 16. We based the choice the critical threshold n "*CNOMO E41.50.530.N*" standard which defines 16 as critical for mechanical components) [1].

So it is a must to modify some properties of the pipes (material dimensions, painting methods, isolation,…), according to the definition of our problematic (corrosion). For the other equipments, systematic or conditional verifications have to be instituted on the maintenance management system.

C. Determination of the most critical sections of water supply Network (metallic pipes with diameter ≥ 300mm)

Before picking any sample on the sites (soil, water or pipes material…), we analyzed the historic of interventions corresponding to explosion, great cracking of pipes, water leakage, or subsidence… which can be occurred by the effect of pipes corrosion, internal or external.

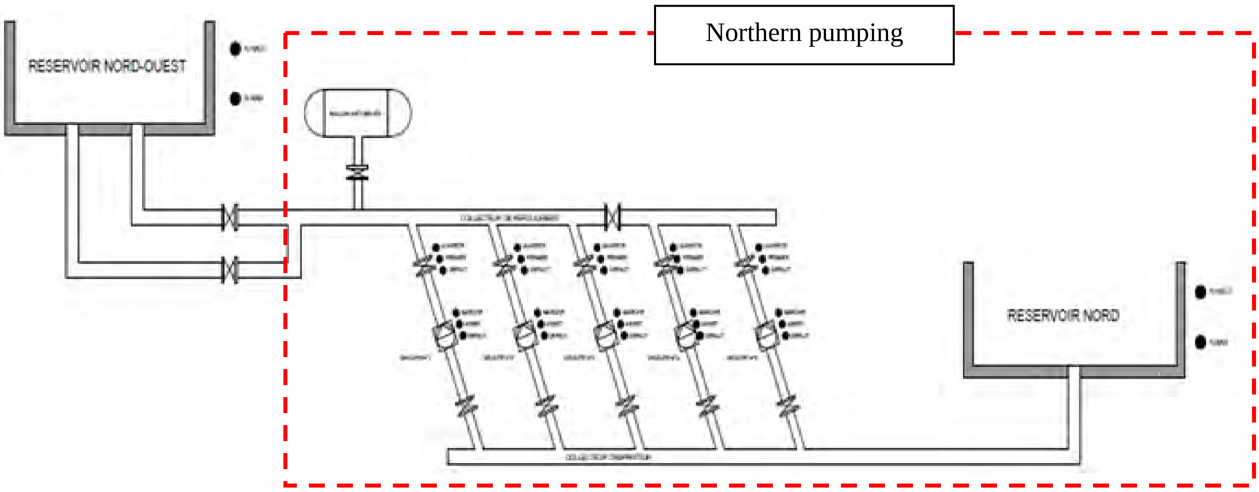
So we used a Geographical Information System (GIS) software, named '*micro-station*', to select firstly the metallic pipes (iron or steel) having diameter greater than 300mm.

We have also dispatched Fez by influence region according to pumping stations, to know exactly the history of water and their effects on pipes.

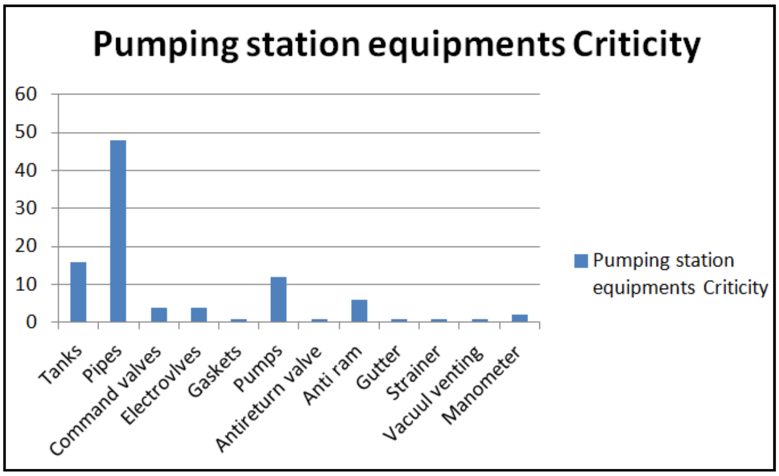
After that we put black points on the map to situate corresponding interventions and we obtained the map presented on the figure 8.

The most critical party of the water network is selected by a dotted line.

The results will be exploited in a future paper where we will try to understand and detect the principal corrosion mechanisms due to the interaction between the pipes (pumping station and underground pipes) and the external environment (air and soil), by doing several analysis: metallography and spectroscopy of the metal, soil and water physico-chemical analysis, welding methods and processing critics and pipes protection methods…



(a) Synoptic schema of northern pumping station



(b) Results of FMEA applied on the most critical equipments of Northern station

Fig. 7 – FMEA Analysis of Northern pumping station

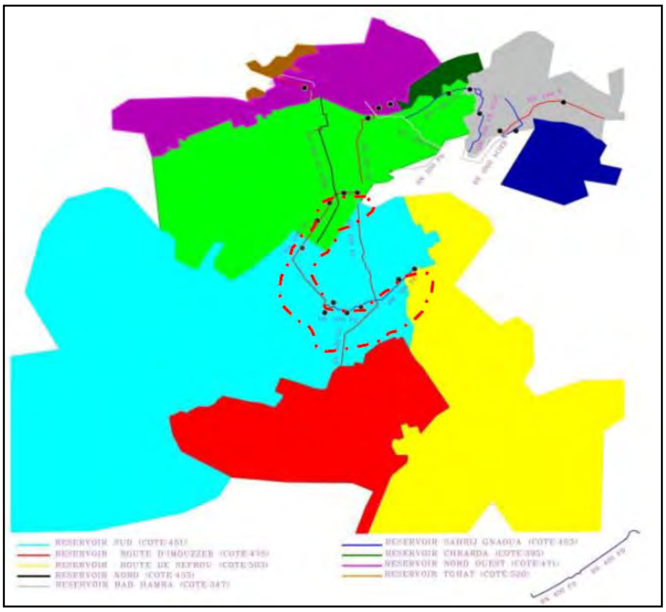


Fig. 8 - Distribution of interventions on ‘‘*Metallic pipes*’’ supply water network. (Interventions between 2004 and 2009)

IV. DIAGNOSTIC OF NORTHERN PUMPING STATION PIPES AND RELATED ANALYSIS

A. *Process parameters (Northern station) : Flow parameters in laminar regimen*

The first step is to verify the validity of pumping parameters to be sure that there is no mechanical problem due to pumping and flow variables.

- Pumps quantity : 5;
- Maximum pressure P_{max} = 0 ,4 bars;
- Minimum pressure P_{min} = 0,1 bars;
- Flow value for aspiration pipe : 500l/s;
- Interior diameter of the pipes : 600mm;
- Water temperature (mean value): 25° C.

These values correspond to the initial specification of the station, and they are correct and functional values. Otherwise mechanical stress correlated with electro-chemical effects (corrosion) that can generate *constraint corrosion*.

B. *Particles in suspension in water*

The deposit of particles in water on the internal surface of the pipes can constitute a direct cause of corrosion, due to the variation of airing between several points on the surface. The difference of airing gives difference of oxygen rate, causing a type of corrosion known as differential airing corrosion.

This kind of corrosion can be explained by a difference of electro-negativity of different point of the same material, producing by the way a corrosion cell.

Indeed, we took a corrosion deposit from the pipe presented in figure 3, and we remark a big quantity of clay mixed with corrosion steel product (rust).

Figure 9 shows corrosion deposit from the pipe of figure 3.

Explanation

The office does not use any filtration system, but only a strainer to eliminate big particles. The installing of an additional filtration system can cause a depression and will damage the normal functioning of the units.

Proposition

They can install nanofilters but they have to redesign the pumps and other parts of the circuits to search the functioning points of the pumps.

Fig. 9 – Rust deposit from a forsaken pipe

TABLE I
ICP test analysis result of the corrosion deposit (unit: mg/l)

Element	Al	As	Ca	Cd	Co	Cr	Cu	Fe
Percentage	15	<0.01	2	<0.01	<0.01	0,26	0,02	1342
Element	**K**	**Mg**	**Mn**	**Na**	**Ni**	**Pb**	**Ti**	**Zn**
Percentage	2	0,5	5,7	10	0,04	2,4	1,8	3,34

Table 1 shows the results of the ICP analysis, which permits to determinate the percentage of solid constitution elements of the corrosion deposit (rust).

We can see that Iron is the most important element of the sample. So it is clear that there is a great corrosion deposit in this pipe.

Since this step, we cannot estimate with precision the aggressively of the water; so we have to make other tests, as presented in the following sections.

C. Material analysis

Figure 10 presents a portion of sheet metal used in the processing of water pipeline.

Table 2 regroups the principal alloys constituting the pipes material.

Fig. 10 – Sample of sheet metal used for pipes

TABLE 2
Spectrometry results of pipe material (Material laboratory of ENSAM-Meknes)

Samples	%C	%Si	%Mn	%P	%S	%Cu	%Cr	%Mo	%Ni	%Fe
1	0,140	0,054	0,232	0,001	0,002	0,058	0,019	0,001	0,053	99,33
2	0,139	0,053	0,238	0,001	0,007	0,059	0,019	0,001	0,054	99,32
3	0,132	0,049	0,230	0,001	0,003	0,056	0,020	0,001	0,052	99,37
Average	0,137	0,052	0,233	0,001	0,004	0,058	0,019	0,001	0,053	99,34

These results prove that the steel used in fabrication of pipes for northern station is a Carbone steel with low values of alloys.

Remark: It is necessary to use special steel, galvanized one, or efficient protection with standard steel, if not the material can be corroded easily; that is the situation in this pumping station.

D. Exterior protection of the pipes

In perfect conditions, a good application of anti-rust, an appropriate painting method or surface treatment can give efficient protection for external surface against air humidity effect. If not we will remark uniform corrosion affecting the corresponding surface.

For example, figure 11 shows the result of a simple painting of pipe of northern station which can't protect the pipe from external air corrosion.

Normally, painting methods must be reviewed in the office, for home made pipe and also for the purchased ones as explained in [2].

Fig. 11 – Corrosion under the paint frame

V. ANALYSIS OF THE WATER OF NORTHERN STATION AND AGGRESSIVENESS ESTIMATION

A. General view:

In the previous analysis, we have seen that the more critical equipments in the north station, in a point of view of corrosion risk analysis, are the pipes. These pipes are attacked by several types of corrosion: uniform corrosion, internal and external, differential airing corrosion caused by clay or other particles deposit on internal surface, corrosion and crack starting from the weld, under the paint frame…

All these types of corrosion generate cracks starting, and because of the internal pressure of water, these cracks propagate by the mechanical effect of hydraulic pressure.

When the crack appears, it generates water leakage which will cause a great increasing of the relative humidity of air, and in the same direction increasing the risk of humid corrosion for external surface of all the equipments.

In this section we will present water physico-chemical analysis to evaluate water quality related to the corrosion risk against the northern pumping station equipments.

The analyses were made in both the office water laboratory and geo-resources and environment laboratory of FST-Fez (Faculté des Sciences et Techniques):

- Analysis in the office water laboratory: This part concerns a time analysis in a restricted region concerning only what we called influence region of the water of northern pumping station.
- Analysis in Laboratory of Geosciences and Environment of FST-Fez: space analysis in several locations of the city. It will be exploited when discussing the environment effect (soil and water) in a future article.

B. *Office water laboratory Analysis*

In this section, we will present the tests in the office laboratory.

We have done physico-chemical tests, bacteriological tests and we have estimated the corrosiveness of the water after picking of several samples in different places of the city. We have also taken into consideration the effect of time by repeating the same analysis for a period of two months (from 27/01/2010 to 24/03/2010).

1) *Bacteriological ratios measurement:* Table 3 presents results of bacteriological ratios according to different points of picking, corresponding, all of them, to the water distributed from northern station, studied below.

Remark: these results present the average of values measured daily on the week of 29th March 2010.

Interpretations:

- The Null values of bacteria indicators are explained by the existence of residual chlorine in water; and it is functional to obtain a not null residual chlorine quantity to be sure that the bacteria are eliminated.

TABLE 3
Results of bacteriological analysis

Picking point / Test designation	Northern reservoir station	ATALIS coffee (train station)	Commercial Avenue Mly Abdellah	Commercial Avenue Mly Abdellah	Planet coffee HADIKA avenue
Residual chlorine mg/l	0,6	0,4	0,4	0,5	0,5
Califormes totaux/100ml 37°C	0	0	0	0	0
Califormes fécaux/100ml 44°C	0	0	0	0	0
Streptocoques fécaux/100ml 37°C	0	0	0	0	0
Germes totaux/ml 37°C	0	0	0	0	0
Germes totaux/ml 37°C	0	0	0	0	0
Clostriduls perfringens/ml 46°C	-	-	-	-	-
Salmonelles et shigelles/100ml	-	-	-	-	-

Remark and relation with corrosion risk:

- WHO (World Health Organization) proposes a maximum value of residual chlorine in water of 0,1 mg/l.
- In our measurements, we found a minimum value of 0,4mg/l and a maximum of 0,6 mg/l, which represent high values. The reactivity of chlorine with other substances, especially in high temperature, can generate pipes corrosion and degradations [2].
- The chlorination policy of the office is to inject chlorine continuously in the water network without taking into consideration the temperature and water constitution effects, and also the time variable that can be understood from: a top consumption of water (11h30 to 14h30, and 17h00 to 22h00), and a stagnation time/period in supply pipes in the case of low consumption periods.

Proposition

- So the office has to make a strong scientific study to choose optimal parameters of chlorination, function of space, time, temperature and reservoir/pumping stations influence regions.
- A first study can be obtained by making a design of experiments [3] on the different process inputs having as output the quantity of residual chlorine. By this way, we can obtain mathematical/statistical model which could explain the variation of residual chlorine into water network.

2) *Physico-chemical analysis:*

Note: the protocols used in this study are based on Rodier book [4].

Table 4 summarizes the results of water analysis coming from the northern station, which were picked from different points of the city, on Tuesday 30/03/2010.

Scientifically, it is desirable to make several essays to have good interpretations of results [3].

Therefore we've consulted the measurement data base of the laboratory to collect sufficient information to be as reliable as possible, and we have plotted the following parameters evolutions: temperature, acidity, turbidity, residual chlorine quantity, chlorides quantity...

The information period started from 27/01/2010 to 30/03/2010.

Thus, the resulting analysis will make us able to estimate the water conformity towards pipes metal of northern pumping station.

TABLE 4
Physico-chemical analysis results of water from Northern pumping station

Picking point / Test designation	Northern reservoir station	ATALIS coffee (train station)	Commercial Avenue Mly Abdellah	Commercial Avenue Mly Abdellah	Planet coffee HADIKA avenue
Temperature (°C)	25	24	22	22	23
Turbidity FTU	0,31	0,31	0,28	0,31	0,31
Conductivity μ s/cm at 20°C	1008	1042	1130	1008	1029
pH	7,6	7,47	7,39	7,6	7,52
Complete alkalinity titration TAC	25,2	26,4	26	25,2	26
Noncarbonated hardness	9,2	16,4	14,4	13,2	11,2

- Temperature Evolution

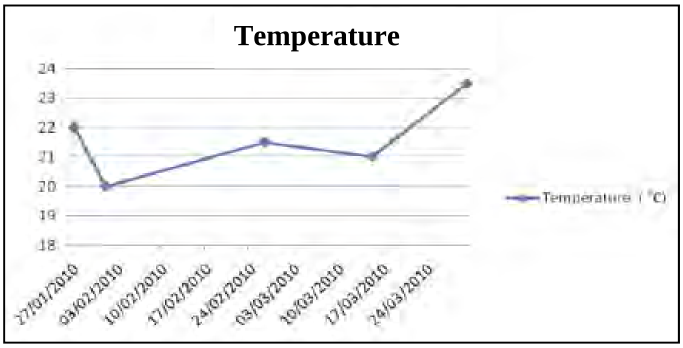


Fig. 12. Temperature evolution

Figure 12 presents the evolution of the temperature according to sampling days.

We remark the trend of the temperature is in increasing between the end of January and March; this is a normal trend corresponding to normal evolution of seasons. This temperature, when increasing, will affect the reactivity of residual chlorine and also chlorides especially when reaching higher temperature in summer.

- Water Acidity (pH evolution)

Figure 13 present an *average* evolution of the acidity between 27/10/2010 and 27/03/2010.

The values of pH are greater than the neutral value of 7, so the water of the northern station is basic, but it is important to push the study by measuring the electronegativity of the material.

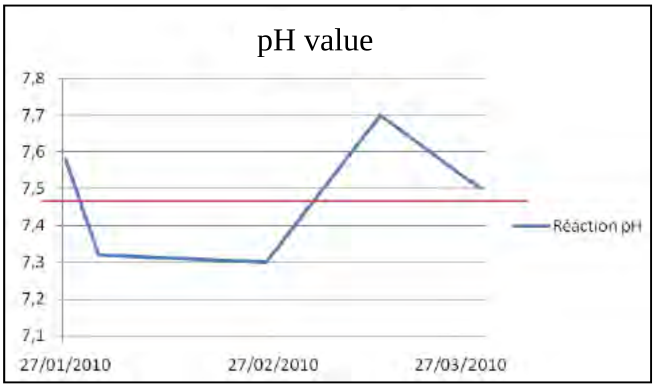


Fig. 13. pH Evolution

Remark and suggestion

For a first seeing, we can judge that the value of acidity is not too aggressive, but in reality we have to see both parameters: acidity level and electronegativity of the metal.

These two variables will inform us about the aggressiveness level of water (H_3O^+ ions) depending on the quantity of free electrons (electronegativity) of the steel to estimate corrosion risk.

- Turbidity

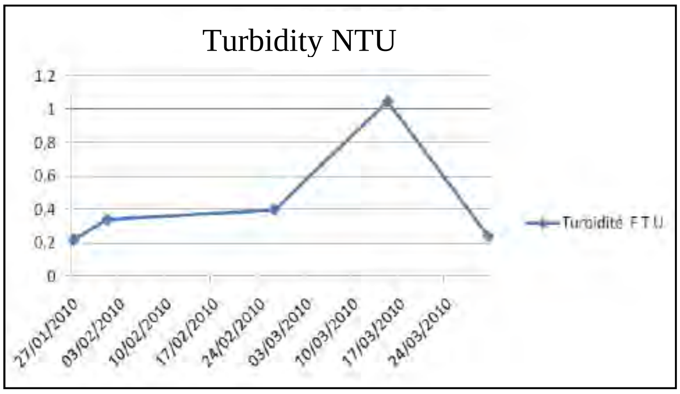


Fig. 14. Turbidity Evolution

The turbidity is an indicator that informs about the cloudiness of a liquid (water in this case), which is caused by fine solid particles in general invisible with naked eyes.

The turbidity are around an average value of 0,3 NTU except in the week corresponding to 17/03/2010, which correspond to the highest value for the tests period (greater than 1). This big value of cloudiness of water is caused by the rain on this week.

Figure 14 shows that the rain, of the week of 17/03/2010, produced a great concentration of clay in water, which is coming from '*Sebou*' river, and that can't be filtered with classical filters used in the office.

The Moroccan Standard NM 03.7.001 gives a middle value of 1 NTU for the samples and a maximum admissible equal to 5 NTU for *human consumption*. So the turbidity values are always in the accepted tolerances according to [5].

Canadian Quebec standards propose several thresholds according to the multiples stages of water production [6].

Turbidity and corrosion risk

A high value of turbidity can affect the internal surface of pipes by having some solid particles stacked on, and so that will cause a different in aeration between several points of the surface, causing by the way corrosion by differential airing.

Suggestions

The office has to make other turbidity analysis especially in rainy weather in winter, to have more information about the turbidity, to estimate the effect and the aggressiveness of the environment around the water (hydrology).

- Chlorides Concentrations

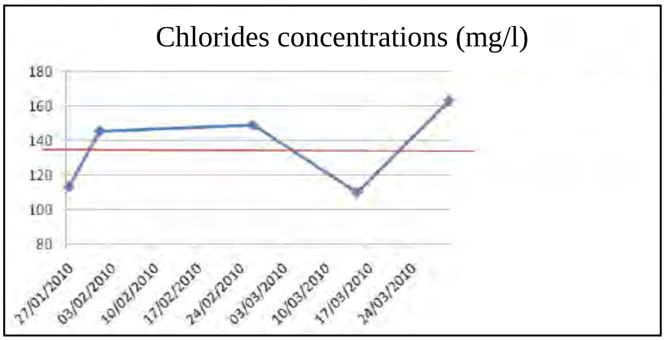


Fig. 15. Evolution of the concentration of chlorides

Figure 15 shows that the chlorides concentrations are around 135mg/l.
We will see in next sections the effect of chlorides concentrations on corrosion risk.

- Residual Chlorine

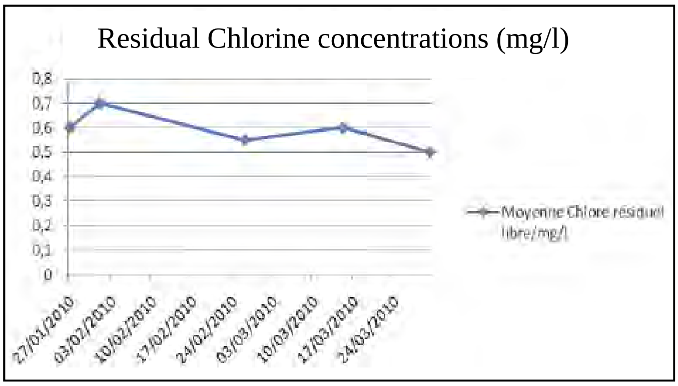


Fig. 16. Residual chlorine evolution in water

Figure 16 proves that the residual chlorides concentrations present not null values; and as we said below, a not null residual chlorine in water are correct with the prescriptions of the WHO which prescripts that it is important to have a percentage higher than 0,5 mg/l to be sure that the disinfection is done but not higher than 5 mg/l [7].

Moroccan standard NM 03.7.001 gives as prescript values between 0,1 mg/m and 1 mg/l for distribution and between 0,1 mg/l and 0,5 mg/l in the step of production [5]; but in the case of a great rate of chlorine, it can generate chemical reactions increasing the acidity of the milieu and the corrosion risk for pipe material.

We can refer for more detail to the potential-pH diagram of chlorine/water.

3) Marble test (aggressiveness test of water) and comparison with other water sources

When the water reaches its equilibrium, it can be incrusting or aggressive if it constitutes a deposit (protective layer) on the internal surface of the pipes or not.

Marble test allows us to estimate the aggressive behavior of water. If it does not present any of these behaviors, we say that the water is in equilibrium.

In the office laboratory, we made this test for several samples from all pumping station of Fez city.

Indeed, the water coming from the northern station and other related stations (Bab Hamra station, and Northwestern station) are the most aggressive of the city (see table 5).

<u>*Remark*</u>

The details of measurements procedures are described in details in [4].

Results

TABLE 5
Marble test per pumping station water

Test / Pumping station or reservoir	pH_0	CAT_0	pH_S	CAT_S
Bab Hamra station	7,58	9,3	7,89	9,9
Southern station	7,51	11,6	7,92	12,3
Ain chkaf reservoir	7,20	12,5	7,39	13,8
Sefrou road reservoir	7,58	15,00	7,47	12,7
Immouzer road reservoir	7,65	14,9	7,31	12,5
Northern station	7,78	12,2	7,51	10,8

Water is considered aggressive if $CAT_S < CAT_0$. The results show that the northern station, *'Immouzer road'* reservoir and *'Sefrou road'* reservoir.

CAT defines the Complete Alkalymetric Title.

Remark

The aggressiveness of water is an intrinsic property depending of the history of the water, its source, its path…, so it is an obligation to take these points into consideration to limit the effect of water on equipments (material choice, adding corrosion inhibitors, filtration techniques…).

Thus, a hydrology study must be done if the office wants to estimate water constitution, and the effect on the pipe health, especially for the most critical sections of the water supply network.

VI. Process Parameters for Welding Techniques

A. Pipes Welding process : Manual Metal Arc Welding

To estimate the risk of the degradation of a mechanical part, it is very important to know with exactitude its historic, from material processing, passing by forming, manufacturing, heat treatment, assembly process…

This paragraph discusses the effect of the arc welding parameters on the corrosion risk of the pipes in the step of manufacturing and sites assembly.

Figure 17 shows water leakage due to a crack starting near the pipe welding. It could be from the Heat Affected Zone.

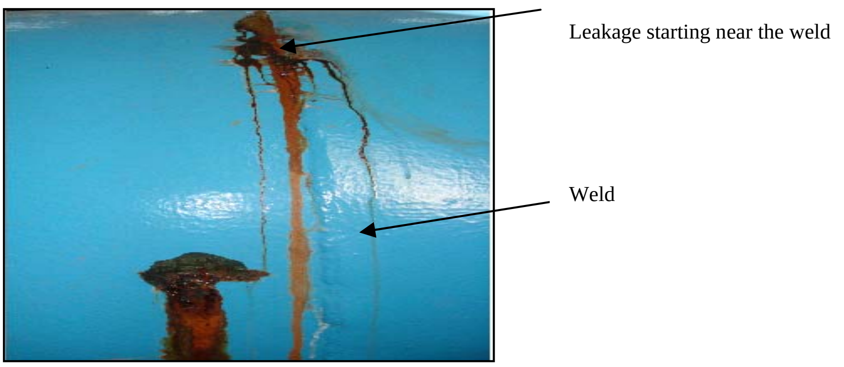


Fig. 17. Crack and water leakage starting from the weld zone

We distinguish several zones in a weld according to the figure 18:

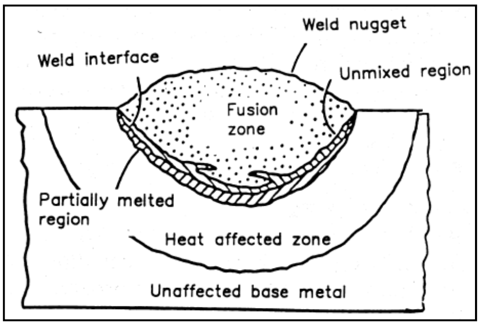


Fig. 18. Weld zones [8]

Each zone includes its own physical phenomena which can include corrosion risk potentials.

B. Forms of Weld Corrosion

1) *Galvanic corrosion in **Fusion Zone** [8]:* The fusion zone is the result of melting which fuses the base metal and filler metal to produce a zone with a composition that is most often different from that of the base metal.

This compositional difference produces a galvanic couple, which can influence the corrosion process in the vicinity of the weld. This dissimilar-metal couple can produce macroscopic galvanic corrosion.

The fusion zone itself offers a microscopic galvanic effect due to microstructural segregation resulting from solidification.

2) *Intergranular corrosion (especially for stainless steel) in **Heat-Affected Zone:*** The HAZ is the portion of the weld joint which has experienced peak temperatures high enough to produce solid-state microstructural changes but too low to cause any melting. Every position in the HAZ relative to the fusion line experiences a unique thermal experience during welding, in terms of both maximum temperature and cooling rate. Thus, each position has its own microstructural features and corrosion susceptibility [8].

We say that even if we use stainless steel to protect the surfaces (internal and external) of the pipes, we have to pay attention on the welding processes. High temperature can contribute to the formation of *chromium carbides* or other carbides according to the steel constitution causing by this manner local galvanic corrosion (macroscopic, microscopic/intergranular). It can be due to local variation of the metal constitution, and by the way the variation of electronegativity of some neighbor regions, causing galvanic corrosion.

3) *Effect of the humidity of electrode coating (**Elimination of hydrogen source):*** We have noticed in the office workshop, when using MMA (Manual Metal Arc), that the welding electrodes are not stored in good conditions. The electrodes are simply put in the workshop and they are exposed to the air without taking into consideration its humidity.

This quantity of relative water (H_2O) in air will generate rapid corrosion reaction with iron because of the high velocity of reaction on highest temperatures, both in the fusion and Heat-Affected Zone (HAZ).

VII. CONCLUSION AND PERSPECTIVES

In this first part of the expertise, we have realized several tests in order to estimate and verify the relation of water characteristics with corrosion risk of metallic equipments, especially the pipes of northern pumping station.

Figure 16 gives the principal forms of corrosion found on the equipments of the station and the principal corresponding causes. It constitutes a global view of the work reported in this paper.

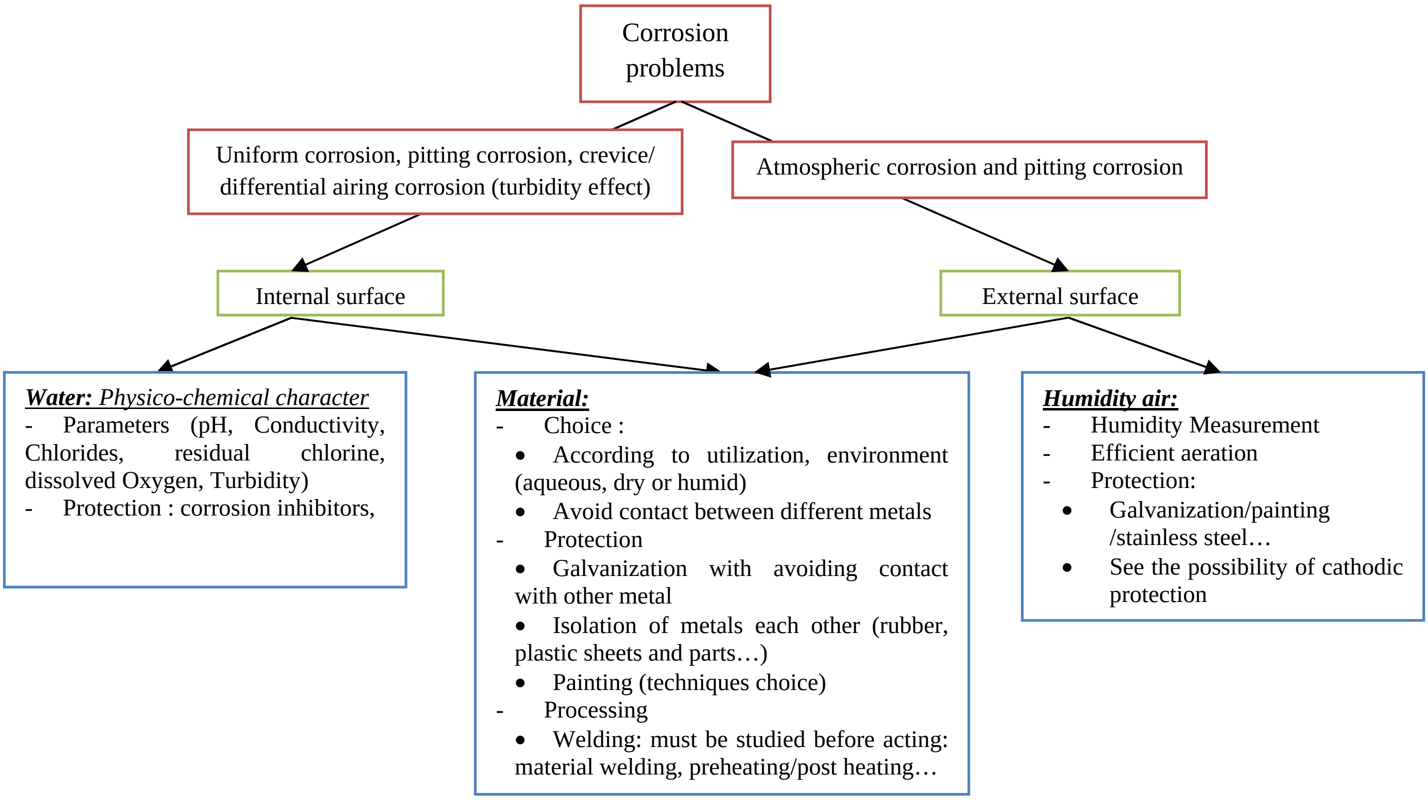


Fig. 19. Corrosion types according to analysis variables

A. Principal conclusions

- Cause/effect of residual chlorine and chlorides: important rates of these two elements on high temperatures can cause undesirable effects. The quantities of these two substances, especially the residual chlorine, are affected directly by the chlorination process, which has to be controlled to optimize chlorine quantity in distribution network. Chlorides are the results of liquid industrial waste.
- The responsible of water treatment in the office informed us that the chlorination metering pump work continuously without taking into consideration the variables space and time as explained in *Bacteriological ratios measurement and analysis* (section V.B.1).
- There are no filtration systems for little solid particles in the input of all pumping stations, which can affect turbidity of water, in the case of violent rain on winter.
- Important humidity rate in some parts of pumping station. Without measuring, we were able to smell a strong odor of moisture in the air. It can cause bacterial and uniform (humid) corrosion of external surface of equipments.

B. Propositions and perspectives

1) Modeling and optimization of chlorination: is a step that has to be done to optimize the functioning of metering pumps. Simple and rapid modeling can be done by design of experiments methods.
2) Water aggressiveness of northern station: the water of this station is coming from *'Sebou'* river, which is known, in a near past, as one of the most polluted rivers in the region due to the industrial pollution.

In spite of the pretreatment done by the water supplier of the office, this water is still aggressive with middle to high level of turbidity in winter. So we propose some suggestions to improve this situation:

- Study the integration of special filters in the input of the station which can eliminate more particles (decreasing the turbidity). In this case, all process parameters of the water circuits must be reviewed and redesigned, because of the decrease in the circuit pressure when integration a new element (loss of pressure). The new functioning points have to be recalculated for more efficiency of the installation.
- Making an appropriate material choice for equipments, especially for the pipes with more efficient protection techniques. The material choice has to include the interaction between the material and its environment, included also interaction between metallic materials it selves to avoid galvanic corrosion risks;

- Add some corrosion inhibitors (physical or chemical agents) in water, especially in stagnation period of a day (period of low consumption).
- Study the feasibility of cathodic protection in aqueous milieu for internal and external surface of pipes and for all equipments of the northern station and too for the other stations.

3) Air humidity in the pumping stations: is one of the most important causes of uniform corrosion of external surface of the pipes. In the case of bad painting process, corrosion will exist under the paint frame and don't appear until discovering water leakage due to pipe cracking caused by corrosion.
We propose three principal suggestions:

- Measuring the humidity rate periodically to estimate its natural evolution, according to the seasons.
- Study the airing techniques of all parts of pumping stations: pumps rooms and vanes chambers.
- Making efficient gutters or other water evacuating systems to evacuate water if a leakage remains for a long time (before maintenance). Figure 5 shows the effect of water leakage in vanes chamber without any water evacuating system. So leakage water, remaining in this location, increases the humidity rate in the air. This effect is forced more and more by the absence of aeration system!
- Study the possibility of cathodic protection for the most delicate equipments even in air milieu.

4) Reviewing welding process parameters:

- Quick and practical solution: The humidity of electrode coating (flux) must be eliminated by drying into an oven or, while welding, by enforcing an electric current on the electrode (closed circuit with the electrode) to make a heating by Joule effect. By this way the electrode will heat and the humidity will disappear from the coating.
- Reviewing the storage method of the electrodes, using an appropriate oven dedicated especially for this.
- Through proper selection of welding consumables (that is, low-hydrogen shielded metal arc welding electrodes), and welding clean surfaces, the hydrogen pickup can be drastically reduced [8].

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