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Demineralization of boiler feed water for the thermal power stations: Study of mineral and organic fouling of reverse osmosis membranes

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***Abstract:** The objective of the work is to diagnose the conditions of operation of the Reverse Osmosis (RO) AQUAIONIQUE the Powerhouse Kenitra by water analysis unit while comparing the physicochemical parameters of the raw water, permeate and concentrate.*

To assess the rate of water discharge, physicochemical analysis parameters hardness (TH), alkalinity (TAC), Total Dissolved Solids (TDS), Conductivity, pH, Organic matter (OM) and chloride (Cl^-) and multivariate statistical analysis were performed. It follows from this study an increase in organic matter (OM) and the chlorides in drinking water in the month of May until July. This might be explained by clogging of the membrane over time. The statistical approach to principal component analysis (PCA allowed us to observe that:- The axis is an axis F2 of pollution; it is the organic material which is the most important parameter. TH, TAC, TDS, Conductivity, pH, (OM) and Cl^- are strongly positively correlated with each other. The total information is estimated to a percentage of 97, 05%. The positive correlation between the parameters confirmed the membrane fouling. Thus, the multivariable statistical analysis served as an excellent exploratory tool in analysis and interpretation of complex data set on water quality and understanding their temporal and spatial variations

***Keywords:** reverse osmosis, organic load; multivariate analysis, PCA, Central Thermal Kenitra.*

I. INTRODUCTION

The boiler feed water is the beating heart of a thermal power plant, the power of the latter requires high purity water to protect installations against corrosion and fouling. To meet the requirement of operating demineralization and treatment of boiler feed water are essential, the latter is based on the process of Reverse Osmosis (RO).

The Reverse osmosis is a common technology used in chemical and environmental engineering separations, The suitability of RO for such applications depends on the feasibility of satisfying the following requirements: high permeate flux at moderate trans membrane pressure (TMP); good retention capability; proper mechanical strength; inertness (and bio-inertness), and chemical and thermal stability; resistance to cleaning and sanitizing agents; resistance to microbial action; high fouling protection; compliance with safety requirements; long service life; and affordable cost [1]. RO is the process that ensures the highest water quality [2], reducing high levels of dissolved salts and suspended solids, but RO encounters certain limitations when used for the removal of organic compounds [3].

In previous works [4,5], various technical aspects of the application of Reverse Osmosis for the demineralization of boiler feed water for the thermal power station were studied and optimized, In this work, the study was performed on the demineralization of boiler feed water for the thermal power stations by reverse osmosis. The major drawback of the station unit demineralized water is the fouling of reverse osmosis membranes which generates very important economic and environmental constraints.

The application of different multivariate approaches (cluster analysis (CA), principal components analysis, source apportionment by multiple regression on principal components) for the interpretation of these complex data matrices offers a better understanding of water quality and ecological status of systems and offers a valuable tool for reliable management of water resources as well as rapid solutions on pollution problems [6,7].

The objectif of this work is the characterization of deposits clogging for the reverse osmosis unit of power station and evaluate a statistical study of the production the demineralized water by reverse osmosis unit.

II. MATERIAL AND METHODS

Description of the demineralization process

The steps of the demineralization of boiler feed water.is shown in figure 1. The characteristic of well feed water is shown in table 1. The raw water is pumped to the reverse osmosis unit by intermediate of the two filters: sand filter and two activated carbon filter.

The reverse osmosis water is stored in the product water tank at the capacity 100 m^3 and then the water was pumped to the cation exchanger and the anion exchanger. The demineralized water is stored in the product water tank and then distributed to the boiler of the power plant.

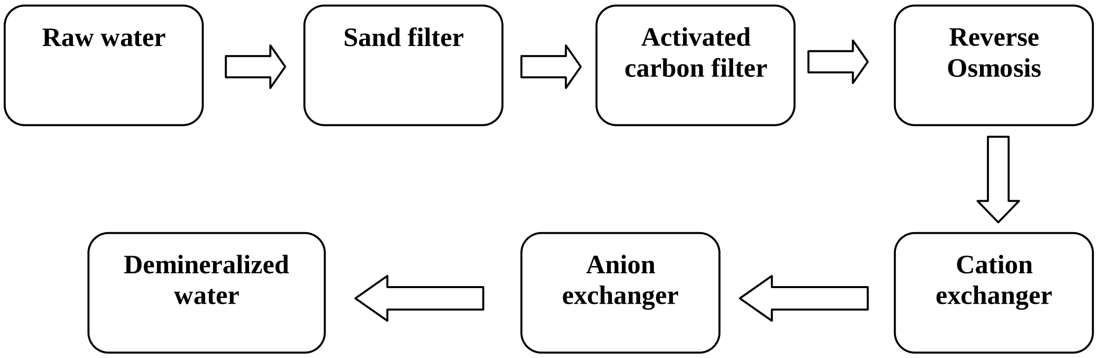

Figure 1: The steps demineralization of boiler feed water

Table 4 shows the characteristics of the feed water

Table 1: Characteristics of the feed water

Turbidité (NTU)	>2
Temperature (°C)	-5 à 35
pH	6.9 à 7.5
Conductivity (µs/cm)	600 à 2000
Na^+(mg/l)	40
Mg^{2+} (mg/l)	30
Ca^{2+} (mg/l)	250
K^+ (mg/l)	4
NH_4^+ (mg/l)	< 0,1
SO_4^{2+} (mg/l)	50
Cl^- (mg/l)	250 à 1200
HCO_3^- (mg/l)	100
SiO_2 (mg/l)	20
Langelier Index	6

Pre-treatment unit

The pre-treatment unit is composed of two filters (sand filter and activated carbon filter), the capacity of filter is of 2640l filled with sand, to retain the suspended solids and the red iron oxide that might be present. The water filtered is pumped to the activated carbon filter to remove the free chlorine and organic particles. Provided the better filtration of the remaining particles the water undergoes a filter with 0,5 µm, to remove the particles of diameters 0,5 µm to provide a final protection and to conform the pre-treated water to the reverse osmosis membranes requirements. The sequestering injected in the water to reduce alkalinity and the contamination of the molecule lime stone.

Reverse osmosis unit

The pre-treated water is pumped to the Reverse Osmosis (RO) group (figure 2) to remove the salt. The characteristic of the membrane reverse osmosis are given in table 2.

Table 2: Characteristic of the membrane reverse osmosis

Inlet pressure osmosis (bars)	9,5
Osmosis pressure output (bars)	6,0
Conductivity of the feed water (µs/cm)	600-2000
Inlet flow osmosis (m^3/m)	38-45
Permeate flow (m^3/h)	34
Flow of retentate (m^3/h)	11
Permeate Conductivity	10 – 20 (µs/cm)
Quality yield %	98,5
Quantitative yield %	79
Maximum fouling index	5

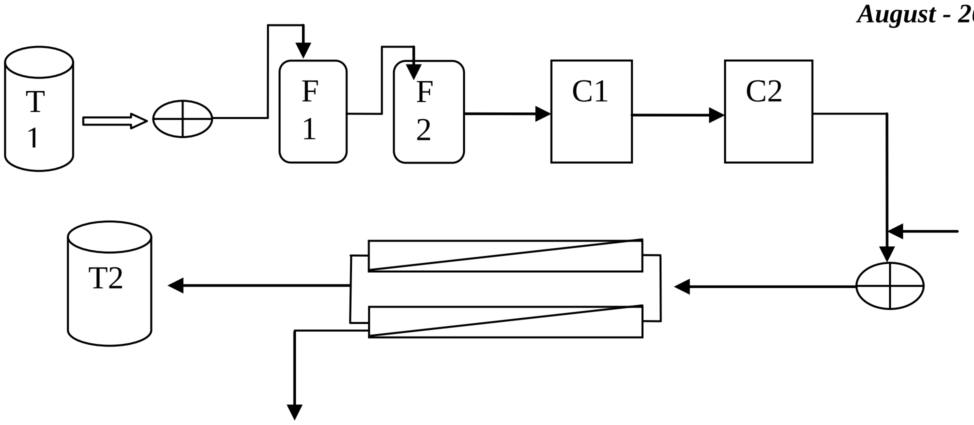

Figure 2: Design of the treatment unit by reverse osmosis

T1: Raw water tank; **T2**: Reverse osmosis water tank (100m^3), (**F1, F2**): Sand filter, (**C1, C2**): Activated carbon filter, **A1**: Sequestering, (**P1, P2**): Pump

Post treatment unit

The post-treatment unit of the RO permeate, includes demineralization using a strongly acidic cation exchanger, and strongly basic anion exchanger, suitable to remove the cations and anions, which are primarily responsible for the water hardness. Figure 3 shows the schematic diagram of the chain demineralization. After demineralization, the demineralized water was stored in the product tank (T2) and pumped to the boiler of the power plant.

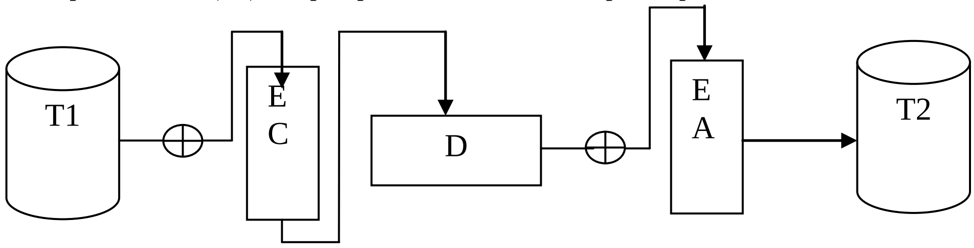

Figure 3: Schematic diagram of the chain demineralization

T1: Reverse osmosis tank (100m^3), **T2**: demineralized water tank (500m^3), **EC**: Cation exchanger, **EA**: Anion exchanger, **D**: Degasser, (**P1, P2**): Pump.

Monitored parameters and analytical methods

All physico-chemical methods were determined using standard methods Rodier (2009) [8], such as pH, TH, TAC, Cl^{-}, conductivity and organic matter (OM).

Principal components analysis

The processing of data and multivariate statistical method of all quantitative analyzes of the boiler feed water was treated by multivariate statistical study by logiciel XSLAT to study the evolution of the quality of wastewater for 3 months. PCA is a useful statistical tools to summarize all the information encoded by the physico-chemical parameters indicating the quality of the water [6,7].The experimental matrix is composed of (9 ×7) by a principal component analysis (PCA) based on logitiel XSLAT (Table1).

III. Results and discussion

Descriptive Statistics

Table 3 shows the different values of the parameters obtained by the physico-chemical analyzes for three months May, June and July.

Table 3: physico-chemical analyzes of May, June and July.

Paramètres	**pH**	**Cond**	**TDS**	**Cl^{-}**	**TH**	**TAC**	**MO**
M5-inp	7,01	722	388	166	205	105	0,285
M6-inp	6,98	750	392	180	225	120	0,25
M7- inp	7,08	792	401	155	237	145	0,455
M5-Perm	5,8	51	29	12,5	9,5	25	0,104
M6-Perm	5,95	57	32	15	10	29	0,184
M7- Perm	5,77	60	33	13	14,5	30	0,204
M5-Conc	7,84	2750	1450	640	680	355	0,95
M6-Conc	7,77	2680	1394	700	780	408	0,85
M7- Conc	7,6	2330	3770	580	894	485	1,15

M5-T.R(%)	0,929	0,925	0,925	0,954	0,762	0,635
M6-T. R (%)	0,924	0,918	0,916	0,954	0,758	0,264
M7-TR %	0,924	0,918	0,916	0,939	0,793	0,5516

***M5**: May; **M6**: June; **M7**: July;* **TDS**: *Total Dissolved Solids*
***Conc**: Concentrate; **Perm**: Permeate; **Inp**: Input; **TR**; Rejection rates*

Table 4 shows the descriptive analysis of physico-chemical parameters

Table 4: Descriptive analysis of physico-chemical parameters

Parameters	**Observations**	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
pH	9	5,770	7,840	6,867	0,834
Cond	9	51,000	2750,000	1132,444	1137,565
TDS	9	29,000	3770,000	876,556	1215,085
Cl–	9	12,500	700,000	273,500	284,454
TH	9	9,500	894,000	339,444	350,402
TAC	9	25,000	485,000	189,111	178,418
OM	9	0,104	1,150	0,492	0,388

Discussions

All settings tend to evolve from May to July, according to Figure 4. Conductivity information on the overall mineralization and salinity varies from 51 to 1132.444 (microseconds / cm).

The hardness and chlorides respectively changed from 9.5 to 894 ° F and 12.5 to 700 mg / L, and the organic matter evolves from 0.1 to 1.150 mg / L.

This development may be explained by the presence of algae plant to the power plant that causes the increase in MO and the chlorides in drinking water.

The water pretreatment system used in demineralized water station is that of Activated Carbon Filter (ACF), which contains coal grain, coal type changes according to the contact time and temperature.

Moreover, the organic material occupies the macropores (50 nm or more in diameter) of coal because of their large size.

This position leads to reduction in the number of adsorptions accessible to smaller molecules websites (micro). The organic matrix has the effect of decreasing the surface area of coal.

So over time the treatment of the month May to July, the charcoal filter has retained many organic compounds and eventually saturate by forming a film that has clogged the adsorption sites and reduced the adsorption efficiency.

As a result FCA can therefore eliminate most all of the chlorine and organic matter. So the input of the reverse osmosis unit no longer meets the requirements of the water.

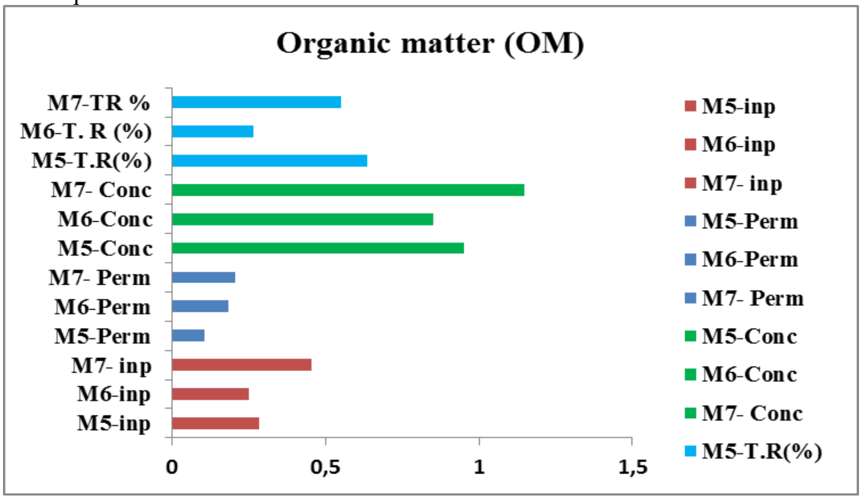

Figure 4: Physico-chemical analyzes of May, June and July.

***M5**: May; **M6**: June; **M7**: July; **TDS**: Total Dissolved Solids; **Conc**: Concentrate;*
***Perm**: Permeate; **Inp**: Input;**TR**; Rejection rates.*

Principal Component Analysis

Projection on the plan 1×2

The first three principal axes are sufficient to describe the information provided by the data matrix. Indeed, the percentages of variance are 11,59% and 85,37% for the axes F1 and F2 respectively. The total information is estimated to a percentage of 96, 97%. The principal component analysis (PCA) [9] was conducted to identify the link between the different variables.

- According to this factorial representation we notice a distribution according to four groups illustrated in Figure 5.

– A first group was representative of the input and the output water quality. It was contributed by the input and output parameters.

M-Input, M-permeate, M-concentrate and M- TR%

- The axis is an axis F2 of pollution; it is the organic material which is the most important parameter. TH, TAC, TDS, Cond, pH, OM and Cl^- are strongly positively correlated with each other.

-These correlations can be explained by a common transport policy of organic and inorganic pollutant load along the chain diagram of demineralization.

-These correlations can be explained by a common transmission diagram of a pollutant demineralization load chain organic and inorganic

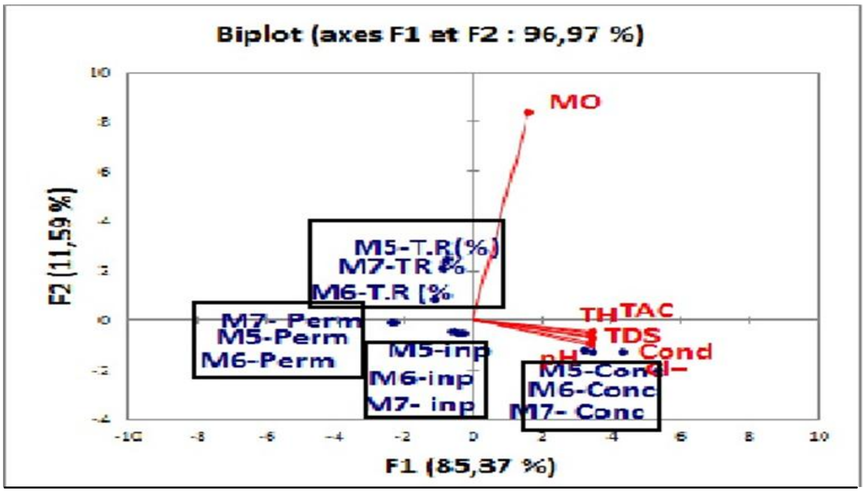

Figure 5: Cartesian diagram shows the analysis of projections by F1XF2

***M5**: May; **M6**: June; **M7**: July**; TDS:** Total Dissolved Solids **; Conc**: Concentrate;*
***Perm**: Permeate; **Inp**: Input.**TR**; Rejection rates*

Projection on the plan 1 × 3 without considering the group (TR: Rejection rates)

The first three principal axes are sufficient to describe the information provided by the data matrix. Indeed, the percentages of variance are 1,74% and 93,44% for the axes F1 and F3 respectively. The total information is estimated to a percentage of 95,18%.

The Cartesian diagram (Figure 6) shows the analysis of projections by F1XF3 plan is (95, 18%) of the total variance quality parameters.

It emerges this projection (Fig. 6) M-Concentrate group is strongly correlated with all parameters. He could probably show the effect of the seasonal pollutant on the ecology of the plant.

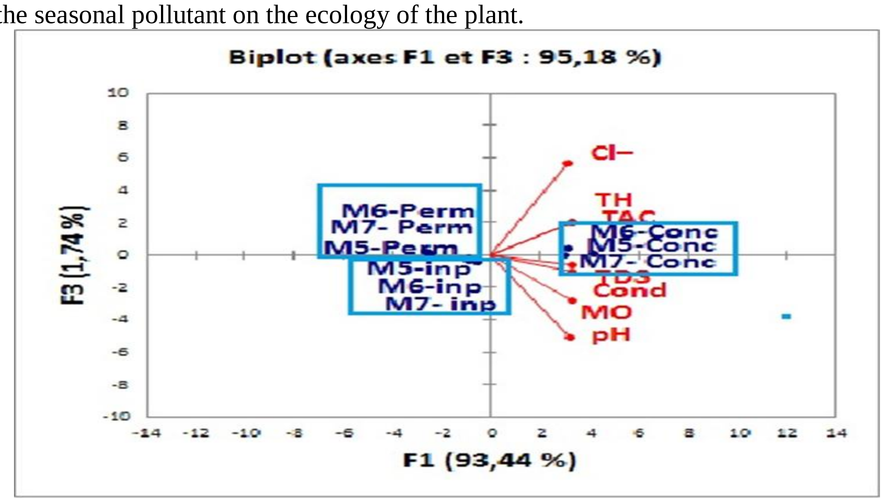

Figure 6: Cartesian diagram shows the analysis of projections by F1XF3

M5: May; **M6:** June; **M7**: July; **Conc**: Concentrate; **Perm**: Permeate; **Inp**: Input.

Projection on the plan 1 × 2 without considering the group (TR; Rejection rates)

The first three principal axes are sufficient to describe the information provided by the data matrix. Indeed, the percentages of variance are 3,61% and 93,44% for the axes F1 and F2 respectively. The total information is estimated to a percentage of 97,05%.

The positive correlation between the parameters has confirmed membrane fouling since the organic matter is highly correlated with MO (Concentrat-M7) in which there is clogging of the membrane (Figure 7).

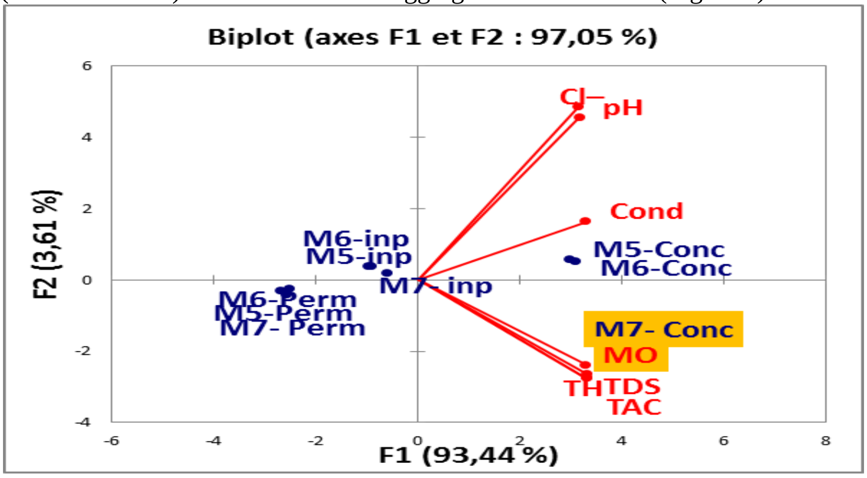

Figure 7: Cartesian diagram shows the analysis of projections by F1XF2

IV. CONCLUSION

Treatment of the month May to July, the charcoal filter has retained many organic compounds and eventually saturate as adsorption sites have reduced the adsorption efficiency of the Activated Carbon Filter (ACF).

Water-quality monitoring programs generate complex multidimensional data that need multivariate statistical treatment for their analysis and interpretation of the underlying information. An experimental 9×7 matrix and 6x7 matrix was found and analysed by multivariate statistical procedures. The inspection of the correlation matrix of seven variables showed the existence of strong correlations between variables.

Thus, the multivariable statistical analysis served as an excellent exploratory tool in analysis and interpretation of complex data set on water quality and understanding their temporal and spatial variations.

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