# Optimization of the Coagulation Process Used in a Water Treatment Plant Using the Response Surface Methodology (RSM)

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**Abstract**

***Coagulation is one of the most important processes in surface water treatment. The main difficulty encountered during the operation of this process is to determine the optimum quantity of coagulant to be added in order to achieve the objectives targeted by this treatment step. This dosage can be correlated non-linearly with the characteristics of the raw water to be treated. There is currently no knowledge model for expressing the physical and chemical phenomena involved. Solution for the establishment of this model is to use behavioral modeling.***

***This modeling is based on the experimental design methodology, using the Minitab software.***

***Three parameters influencing the coagulant dose were considered, namely turbidity, pH and temperature. A first degree polynomial model gave a coagulant dose value of 34.37 mg/l different from 40 mg/l obtained experimentally. This encouraged the test of a second degree model which in fact led to a better value of 39.72 mg/l, considered very close to the experimental one.***

***Key words:*** *Aluminum sulphate, modeling, Minitab, turbidity, pH, temperature.*

## I. Introduction

Coagulation is one of the most important processes in surface water treatment **[1].** However the main difficulty encountered in this process is the determination of the optimum quantity of coagulant to be added in order to achieve the assigned objectives for this treatment step, particularly regarding the non linear nature of the characteristics of the raw water to be treated [1-5]**.** Currently there is no model for the expression of the physical and chemical phenomena involved. The only solution is to base on the experimental design methodology, using Minitab's software.

## II. Experimental procedure

In order to collect data, coagulation experimental runs were carried whenever the raw water characteristics of Oued El Athmania water treatment plant changed. Each run was subject to physico-chemical analyses. The used coagulant reagent was the aluminum sulphate ($Al_2(SO_4)_3.18H_2O$) obtained from a local supplier.

### A. *Operating parameters*

From the literature it is shown that several operating parameters such as turbidity, pH, temperature, conductivity, organic matter and total alkalinity, do have an influence on coagulation process using particularly the aluminum [2, 3, 6, 7].

**Table 1:** Statistical distribution of the experimental data

| Variables | Turbidity (NTU) | PH / | Temperature °C | Aluminium Sulfate Dose (mg/l) |
|---|---|---|---|---|
| **Minimum** | 4 | 7.7 | 6.4 | 20 |
| **maximum** | 24 | 8.55 | 22 | 45 |
| **Center** | 14 | 8.13 | 14.2 | 32.5 |
| **Means** | 10.6 | 8.15 | 12.8 | 27.5 |
| **Standard deviation** | 4.07 | 0.22 | 4.96 | 4.59 |
| **Variation Coefficient** | 0.8 | 0.03 | 0.39 | 0.17 |

A statistical analysis of the data of the raw water characteristics of Oued El Athmania station for a period of one year showed that turbidity, pH and temperature were the most varying parameters. Table 1 shows the statistical distribution of the considered experimental data.

## III. Results and Discussion

### A. *Complete factorial plan*

**-** Construction of the complete plan: for a complete factorial design involving 3 factors the number of trials is N = 8 ($2^k$, k=3) [8].

For this purpose, a cause-effect diagram was established to estimate the influence of parameters such as turbidity, pH and temperature on the coagulant dose.

Beginning with a classical factor plane of the first degree, the construction of a complete plan with 3 factors is carried out according to the following model:

$$y = a_0 + \sum_{i=1}^{3} a_i * x_i + \sum_{\substack{i=1 \\ j=2 \\ i\neq j}}^{3} a_{ij} * x_i * x_j \quad (1)$$

with y the model response, $a_i$ the model coefficients and $x_i$ the model variables.

The variables $x_i$ are reduced and of small amplitude (they vary between -1 and +1). This choice of coding makes it possible to compare directly the influence of the descriptors on the response.

The transformation of a real variable $U_i$ into a coded variable $x_i$ is obtained from the following relation:

$$x_i = (U_i - U_{i0})/\Delta U \quad (2)$$

If $U_{sup}$ and $U_{inf}$ represent the upper and lower variation limits of a descriptor, respectively, then:

$$U_{i0} = (U_{sup} + U_{inf})/2 \quad (3)$$

$$\Delta U = (U_{sup} - U_{inf})/2 \quad (4)$$

with $U_{i0}$ the real variable at the center of the experimental domain and ΔU, the maximum deviation.

The calculation led to the following model (expressed in reduced variables):

$$y = 34.375 + 6.875\,TU + 1.875\,pH - 3.125\,T - 0.625\,TU\,pH + 1.875\,TU\,T - 0.625\,pH\,T - 0.625\,TU\,pH * T \quad (5)$$

Figure 1 shows the effects of Turbidity, pH and temperature on the coagulant dose.

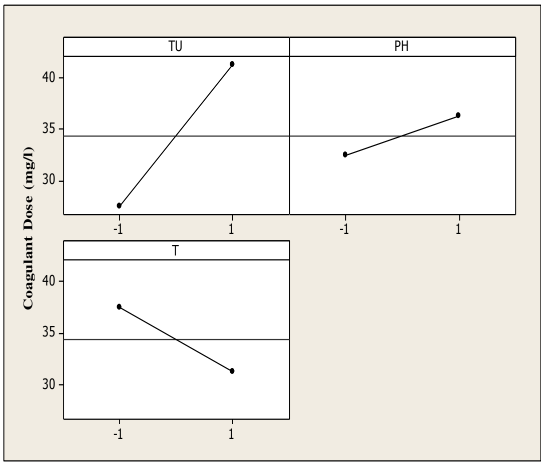


**Figure 1**: Main effects plots

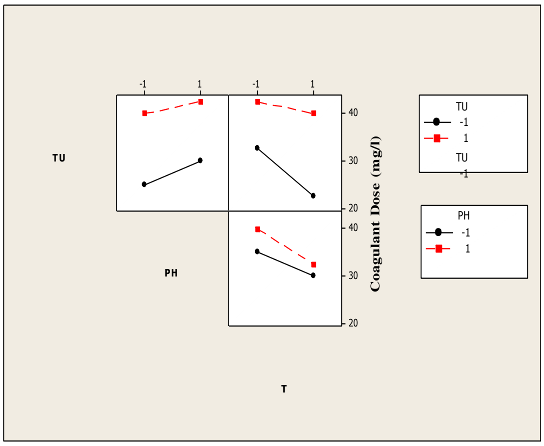


**Figure 2**: Interactions plots

Figure 1 clearly shows that all the considered parameters: the turbidity, the pH and the temperature had an influence on the coagulation process. The increase of the turbidity and even the pH increased the coagulant dose, whereas the coagulant dose decreased by the increase of the temperature;

Figure 2 shows the interactions diagram for the coagulant dose were the parallel plots indicate no interaction, contrary to cases where they might intersect, reflecting strong binary parameters interactions: turbidity- pH, pH- temperature and turbidity- temperature.

At the central point which may represent the optimum, the factors values were 14 NTU, 14.2°C and 8.125 for turbidity, temperature and pH, respectively and the corresponding coagulant dose was $y_{calc}$ =34.375 mg/l, a value quite different from the experimental one which was equal to 40 mg/l, hence an important deviation of 5.225 mg/l.

Therefore the first order polynomial model can be regarded as not accurate enough encouraging the test of the second order polynomial model which however requires more experimental data points.

## B. Response Surface Plan

- *Response Surface Plan Construction*

For this the response surface methodology (RSM) was used and the response was expressed by a second order polynomial function in terms of the considered variables as follows [9]:

$$y = a_0 + \sum_{i=1}^{k} a_i x_i + \sum_{i=1}^{k} a_{ii} x_i^2 + \sum_{\substack{i=1 \\ j=2 \\ i\neq j}}^{k} a_{ij} x_i x_j \quad (6)$$

with y the model response, $a_i$ coefficients, $x_i$ the model variables and K the factor number (K = 3).

The usual approach adopted when shifting from the first order to the second order polynomial model is

still to retain the previous carried out tests and then complete by the estimation tests using higher order model.
Therefore, the central composite plane was necessary to carry out a total of 20 experiments including the 8 previous experiments in order to evaluate the experimental error.
The quality of the prediction would be assessed according to three criteria:

- the standard deviation of the estimate on the response (σ),
- the square-adjusted multiple regression coefficient ($R^2$),
- The residue curves to visualize the difference between the experimental and the proposed model calculated and this for each of the samples.

The model is characterized still by 3 variables but with 20 experiments and 10 coefficients.

- *Interpretation*

The calculation led to the following model (expressed in reduced variables):

$$y = 39.7273 + 7 * TU + 2pH - 3T - 1{,}8182TU^2 - 1.8182\ pH^2 - 1.8182T^2 - 0.6250TU\ pH + 1.8750TU\ T - 0.625\ pH\ T \quad (7)$$

The standard deviation σ and the coefficient of regression $R^2$ values were equal to 0.808337 and 0.9915, respectively, showing the reliability of the second order model. This was confirmed by the residue curves as shown in Figures 3 and 4.

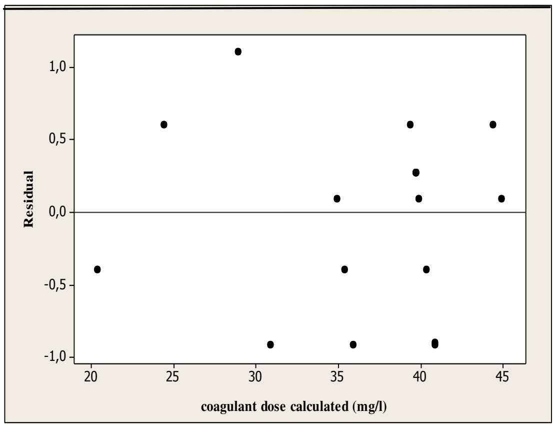


**Figure 3 :** Distribution of residues as a function of the calculated coagulant dose

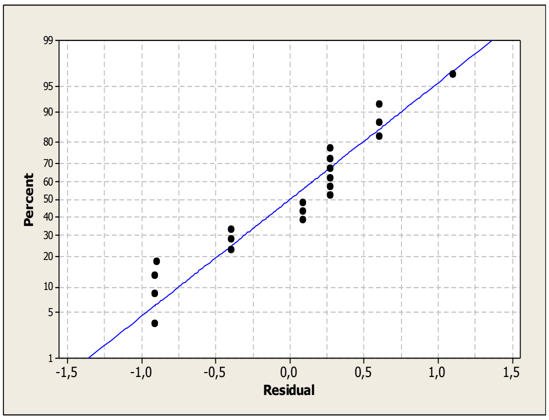


**Figure 4:** Distribution of residues on the Henry line

Figure 3 shows a distribution of the residues reasonably close to the zero axis.
The largest adjustment error was in the order of 1.10227 for an observed response of 28.8977;

Figure 4 shows that the set of residuals were well aligned with the Henry line;
The graphical study of the two figures indicates that the set of residues follows a normal distribution;
In these specific cases, the coagulant dose increased with turbidity and pH, and decreased with temperature.

In the present case, the influence of a factor can be interpreted as easily, since it intervenes not only in a linear and / or quadratic way but also by its non-interaction with one or more other factors.

The complexity of the coagulation is clearly represented if the representation by iso-response curves (Figure 5-7) is used. These curves represent in fact the optimum rate of treatment in the plane:

- Turbidity, pH, fixing the temperature (Figure 5).
- Temperature, pH, fixing the turbidity (Figure. 6).
- Turbidity, temperature, fixing the pH (Figure 7).

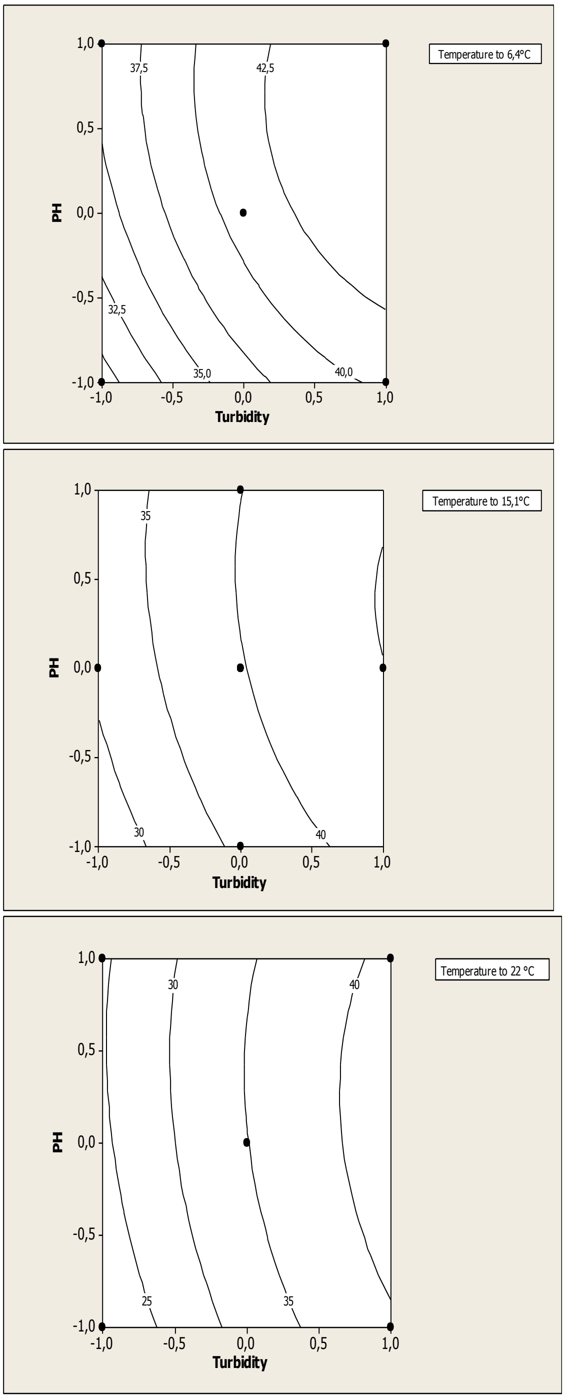


**Figure 5 :** Iso-response curves: at fixed temperature

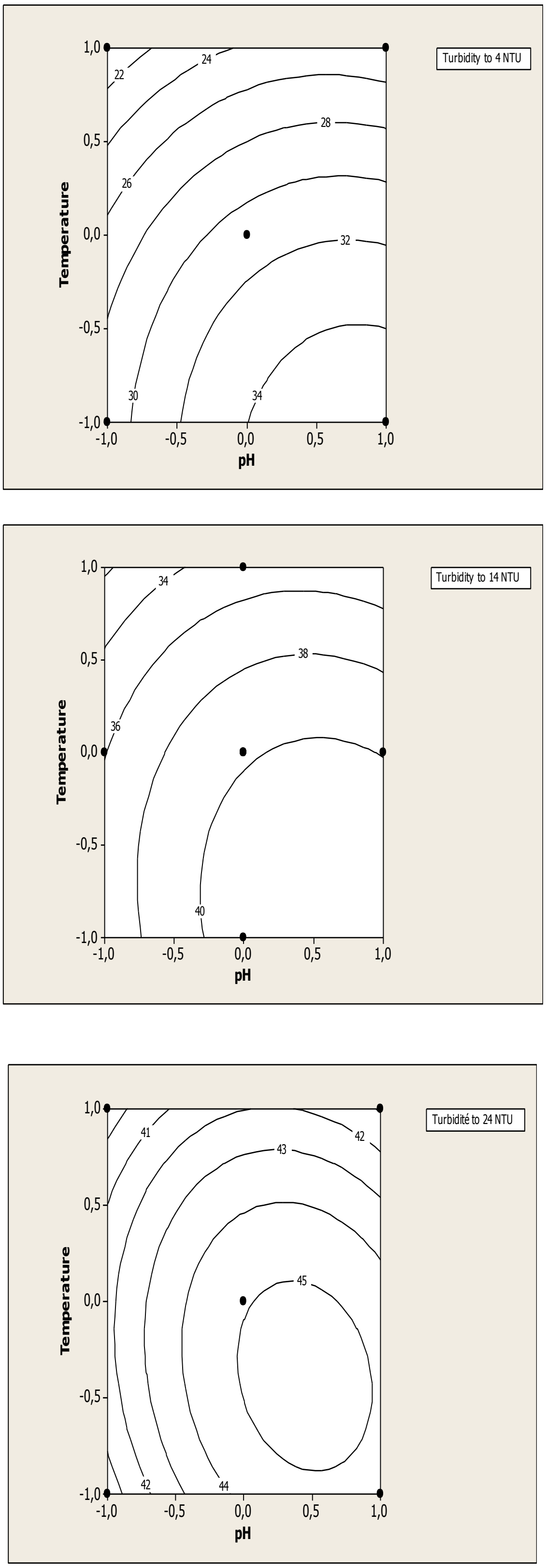


**Figure 6:** Iso-response curves: with fixed turbidity

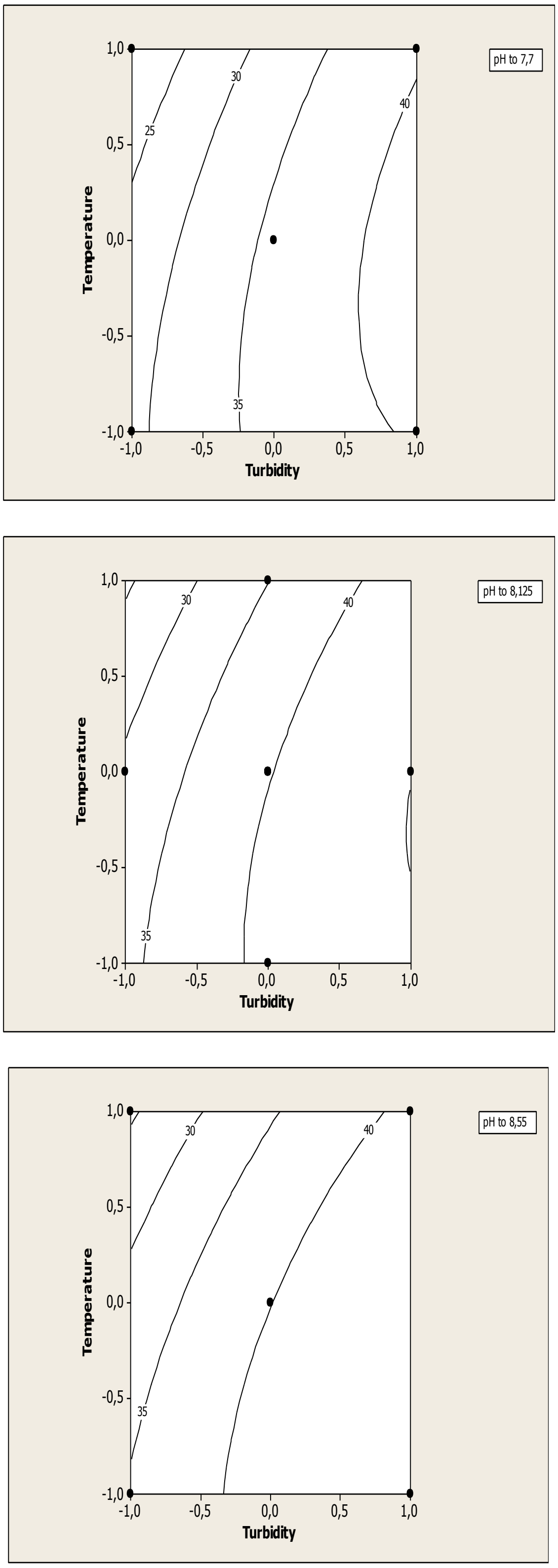


**Figure 7:** Iso-response curves: at fixed pH

It can be seen that at constant temperature the coagulant dose increased with pH and turbidity (Figure. 5);

At medium and low turbidity (Figure. 6) the aluminum sulphate dose increased with pH and decreased with temperature, but for a turbidity of 24 NTU the rate could remain practically constant whatever the temperature and pH values;

It can be seen from figure 7 that the coagulant dose increased with turbidity and decreased with temperature for a fixed pH value.

The results show that turbidity was the most influential parameter on the optimum rate of aluminum sulphate.

## IV. Conclusions

This study showed that the second order polynomial model was much reliable than that of first order and led to reasonable results compared to the experimental values. Therefore its use on waters with characteristics similar to those of Oued El Athmania could be considered. It can be improved further by inserting certain modifications to take account of the invariability of certain parameters.

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