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Removal of Black Remazol in aqueous solution with activated carbons from corncobs based on the design of experiments methodology

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ABSTRACT

This study falls not only into the theme of water depollution but also and above all into the recovery of waste (logic of the 3 R: Reduce, Reuse and Recycle). There was talk of recovering corncobs, which are considered as "agricultural waste" in developing countries such as Côte d'Ivoire. They were used as activated carbon to adsorb Black Remazol in a synthetic aqueous solution. This activated carbon obtained has a specific surface of 673.33 m²/g, a mass loss of 61.44 %, an iodine value of 168.31 mg.g^{-1} and a zero charge potential of 2.05. The design of experiments methodology was used on the one hand to detect the influential factors and on the other hand to optimize the elimination of this dye. Thus, in a first approach six factors (pH of the solution, mass of activated carbon, temperature, and concentration of the solution, stirring time and stirring speed) were used when using the Hadamard matrix. This showed that only three parameters, the mass of adsorbent, the concentration of the solution and the stirring time actually have an influence on the response. The results of the full two-level factorial design showed that the maximum removal rate of Black Remazol is 96.67 % under the conditions of stirring a solution with a concentration of 10 mg/L of this dye with a mass of adsorbent of 0.3 g for 20 minutes.

1. Introduction

Dyes are ubiquitous in everyday life, in clothing, cosmetics and food. Synthetic dyes have taken over from natural dyes and constitute a real industry and a capital of modern chemistry. Clothes are made from textile fibers colored using different dyes that give them their final color [1]. However, industrial discharges from the manufacture and use of these different products pose a major environmental problem. It is estimated that 10 to 20 % of the world production of dyes is routed through these wastes. However, most of them are recalcitrant due to their very low biodegradability and their persistence in the environment [2]. In developing countries (DCs), the situation is much more worrying due to the non-existence of effluent purification systems in small-scale dye works and the poor operating condition of wastewater collection networks. Effluents from dye works are directly discharged into surface waters, leading to their degradation, which can also have an impact on groundwater [3]. Faced with this problem, it is necessary to prevent the danger by proposing ways and methods of removal these pollutants before their discharge into the receiving environments. Thus, there are several physical, chemical and biological methods to treat and decolorize polluted effluents such as coagulation and flocculation, biodegradation, membrane filtration, chemical oxidation, ozonation, ion exchange,

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electrochemical methods etc. [4]. Adsorption technique has been used in several works to eliminate pollutants in water [5-9]. It appears to be one of the most favorable methods for the removal of dyes. It has become an analytical method of choice, very effective and simple in its application [10]. Its principle is to trap the dyes with a solid material called an adsorbent. Several solid materials (clays, zeolites, activated alumina, sludge, biomass, activated carbon, etc.) can be used in water treatment processes.

This study mainly aims at two contributions. It is first a question of recycling an agricultural waste that constitutes corn cobs by using it to make an activated carbon and then to use this carbon to carry out the removal of Black Remazol in a synthetic aqueous solution. To achieve the objective of this study, the methodology of experimental design was used to optimize the removal of this dye but also and above all to study the different interactions that exist between the parameters acting on this phenomenon. This methodology makes it possible to obtain a maximum of information in so few experiences (saving of product and time for this purpose). It makes it possible to perform a statistical analysis (ANOVA, Correlation coefficients, Deviation, Dispersion, Residuals, etc.) of the data. This methodology is therefore currently part of the methods of reliable statistical analysis of data in almost all fields.

1. Materials and methods

2-1. Preparation of activated carbon

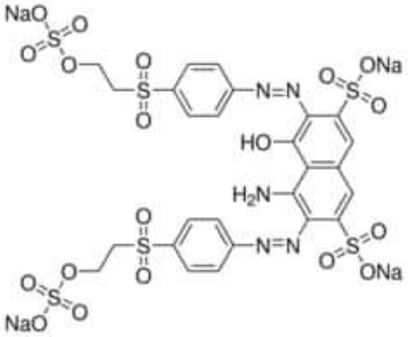
The preparation and activation of the carbon were carried out thermally and chemically from raw materials consisting essentially of corncobs. They were taken from the locality of Korhogo (a city in the Ivory Coast). The corncobs, crushed into small pieces, were washed in tap water to remove dust, then washed with distilled water and dried in a SELECTA brand oven at 105°C for 24 hours before impregnation in a 2 M solution of orthophosphoric acid. After 24 h of impregnation, the carbon is calcined at 500 °C. for 2 h in an OBERSAL brand oven. The carbons obtained are washed thoroughly, after cooling with distilled water until the pH of the rinsing water is between 6 and 7. They are dried in an oven at 105 °C for 24 hours; then crushed, sieved (size ≤ 125µm), and finally stored in an airtight bottle.

The activated carbon obtained then was characterized using different techniques in order to study its physic-chemical properties. Thus, properties such as mass loss, ash content, specific surface area, surface functions, Zero Charge Potential or pH at zero charge point (pH_{PZC}) and iodine value were determined according to methods well known in the literature. It is important to note the XRD of this carbon was carried out in this study.

2-2. Preparation of synthetic solution

Table 1 shows the characteristics of the dye.

Table 1. Characteristics of Black Remazol

Characteristics	**Black Remazol**
Structure	
Formula	$C_{26}H_{21}N_5Na_4O_{19}S_6$
Molar mass (g/mol)	991.8
λmax (nm)	696

The samples used in this study were prepared synthetically by dissolving the azo dye (Black Remazol) in distilled water. With a purity of 100 % the Black Remazol product comes from CHIMITEC Côte d'Ivoire. Thus, the concentration of this dye contained in these samples was varied.

2-3. Planning of experiments

In this study, the statistical experimental methodology used is that of experimental designs.

So, to achieve our objective, a sequential approach based on the experimental design particularly Hadamard matrix and full factorial design, were used for the study. So, to begin, a screening were be with Hadamard matrix on the pH of the solution (U_1), the mass of carbon (U_2), the temperature (U_3), the concentration of the solution (U_4), the stirring time (U_5) and the stirring speed (U_6) in order to see witch factors have more weight on the removal of Black Remazol. After screening of these factors, 3 of them were retained: the mass of carbon (U_1), the concentration of the solution (U_2) and the stirring time (U_3). Table 2 shows the coded and uncoded values of the variables taking into account in different designs were used in this study. Experiments for first set were designed to find the most influential variables, i.e., the pH of the solution (X_1), the mass of carbon (X_2), the temperature (X_3), the concentration of the solution (X_4), the stirring time (X_5) and the stirring speed (X_6). Then, the second set of experiments was carried out by considering three variables, the mass of carbon (U_1), the concentration of the solution (U_2) and the stirring time (U_3). This second design of experiments (FD) was used to optimize these three factors.

The experimental region investigated for Black Remazol removal and the coded values are shown in Table 2. The removal efficiency of Black Remazol was considered as the response (Y). The levels of different factors were selected based on the preliminary assays. The experimental values of U_i can be calculated from the coded variables X_i using the following equation (eq. 1): Table 2: Experimental field of different factors of Hadamard matrix and Full Factorial design (FD).

.**Table 2.** Experimental field of different factors of Hadamard matrix (HM) and Full Factorial design (FD)

Coded variables (X_1)	**Factors (U_i)**	**Experimental field**			
		Min value (-1)	**Max value (+1)**	**$U_{i,0}$**	**ΔUi**
First set of	**Experiments**				
X_1	U_1 : pH of the solution	2.000	12.000	7.000	5.000
X_2	U_2 : Mass of carbon (g)	0.050	0.300	0.175	0.125
X_3	U_3 : Temperature (^{0}C)	30.000	60.000	45.000	15.000
X_4	U_4 : Conc. of solution (mg/L)	20.000	100.000	60.000	40.000
X_5	U_5 : Agitation time (min)	15.000	60.000	37.500	22.500
X_6	U_6 : Stirring speed (rpm)	150.000	300.000	225.000	75.000
Second set of	**Experiments**				
X_1	U_1 : Mass of carbon	0.100	0.300	0.200	0.100
X_2	U_2 : Conc. of solution (mg/L)	10.000	50.000	30.000	20.000
X_3	U_3 : Agitation time (min)	20.000	60.000	40.000	20.000

Conc. of solution (mg/L): Concentration of solution (mg/L)

$$Xi = \frac{Ui - Ui,0}{\Delta Ui} \qquad \text{(eq.1)}$$

Where **$Ui_{,0}$ = (Ui,max + Ui,min)/2** represents the value of Ui at the center of the experimental field and DUi,0 =(Ui,max -Ui,min)/2 represents the step of the variation, with Ui,max and Ui,min which are the maximum and minimum values of the effective variable Ui, respectively.

The main interactions, correlation coefficients, variance analysis, residual, standard deviation were performed by using the NEMROD-W program software (design NEMROD-W, version 9901 French LPRAI-Marseille Inc, France) **[11]** . All the experiments were duplicated in order to estimate the variability of measurements.

The removal rate of Black Remazol in the case of the use of the Hadamard matrix is in the form of eq.2

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 + a_6X_6 \quad \text{(eq.2)}$$

With ai the effect of the factor Xi.

As for the second design used, which is the full factorial design, the response studied in this work has the mathematical model according to eq. 3

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_{12}X_1X_2 + a_{13}X_1X_3 + a_{23}X_2X_3 \qquad \text{(eq.3)}$$

With ai the effect of factor Xi and aij that of the interactions between factors i and j.

It is so important to note that the Hadamard matrix only makes it possible to separate the factors into several classes according to their weight on the phenomenon studied. A distinction will therefore be made between significant, average and negligible factors [12]. As for the full factorial design. It makes it possible to calculate the average effect, the main effects of the factors and their interactions 2 to 2, 3 to 3, etc. [12].

3-3. Calculation of removal rate

The removal rate (T) in Black Remazol is calculated from eq. 4:

$$T(\%) = \frac{C_i - C_f}{C_i} \, x\, 100 \qquad \text{(eq.4)}$$

Where Ci is the content of the ion in the raw water and Cf that in the treated water.

(eq.2)

3. Results and discussion

3-1. Characteristics of the activated carbon prepares

The characteristics of the carbon activated by H_3PO_4 obtained in this study are recorded in Table 3. The value of the specific surface obtained is equal to 673.80 m²/g (Table 3). This value is three times higher than that found by Aboua in 2013 [13] for activated carbon based on Tieghmelia heckelii known as Makoré. It indeed obtained a specific surface of 229.51 m²/g [13]. It is twice lower than that found (1179 m^2/g) by Kouakou et al. in 2017 [7]. However, the values of the specific surface (673.80 m^2/g) and the ash rate (5.87 %) obtained in these works are practically similar to those of Abo et al. in 2021 [9]. Indeed, the work of the latter gave 674.506 m^2/g and 6 % respectively for a specific surface and for the ash content of activated carbon based on corncobs. They are also similar to those obtained (674.00 m^2/g and 6 %) in the work of Kambiré et al. in 2021 [8] in the elimination of rhodamine B in aqueous solution from activated carbon made from corncobs. Concerning the surface functions, the presence of both acidic and basic groups on the surface of the activated carbon gives it a double efficiency vis-à-vis the chemical nature of the pollutant to be treated. These results are similar to those obtained by Atheba et al. in 2015 [14]. These deniers obtained a total acidity of 3.99 meq/g and a total basicity of 1.075 meq/g from an activated carbon prepared from coconut shell of Ivorian origin [14]. The value of the surface functions 2.05 obtained (Table 3) shows that the activated carbon that we used has a marked acid character. The value of the zero charge potential of the prepared activated carbon value is comparable to that obtained in the context of the determination of the isoelectric point of an activated carbon prepared from peanut shell and activated with orthophosphoric acid by Kafack in 2012 [15]. The latter obtained a value of 2.18 [15]. The iodine value result obtained is 168.31 mg.g-1 (Table 3). This value is low compared to that obtained by Afrane and Achaw in 2008 [16]. Indeed, the latter obtained iodine number values ranging from 250 mg/g to 640 mg/g from activated carbons prepared with the coconut shell [16]. This value is also lower than that of the work of Abo et al. in 2021 [9] and Kambiré et al. in 2021 [8] where they found 674.506 $mg.g^{-1}$ and 674.00 $mg.g^{-1}$ respectively.

Table 3. Characteristics of prepared activated carbon

Physical quantities	**Values**
Mass loss (%)	61.440
Ash content (%)	5.870
Specific surface m^2/g	673.80
Zero charge potential (pH_{PZC})	2.050
Iodine number (mg/g)	168.210
Acidity (méqg/g)	3.950
Basicity (méqg/g)	1.070

Moreover, the XRD and the SEM of this carbon were carried out in this work.

As regards the XRD, the result of the prepared carbon is presented in FIG. 1. The diffractogram does not show any peak. This shows that this type of carbon does not present microcrystalline fragments and therefore entirely amorphous. This carbon would therefore be able to adsorb organic and mineral pollutants including dyes in accordance with the literature **[17].**

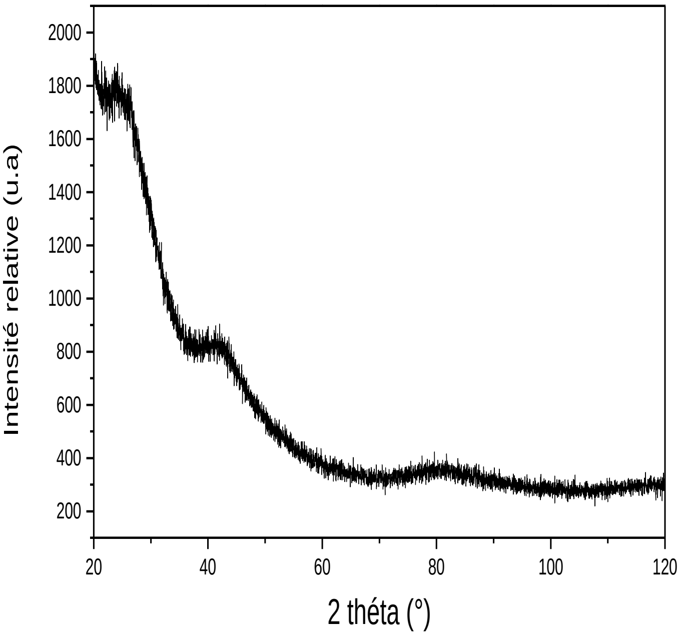


Figure 1. X-ray diffractogram of prepared carbon

As for SEM (Scanning Electron Spectroscopy), Figure 2 depicts H_3PO_4 activated carbon in this study. It is found that the coal surface is heterogeneous with a variety of randomly distributed sizes. The presence of unevenly distributed micropores is visible on the carbon indicating a more or less porous surface. This porosity justifies the high value of the iodine number.

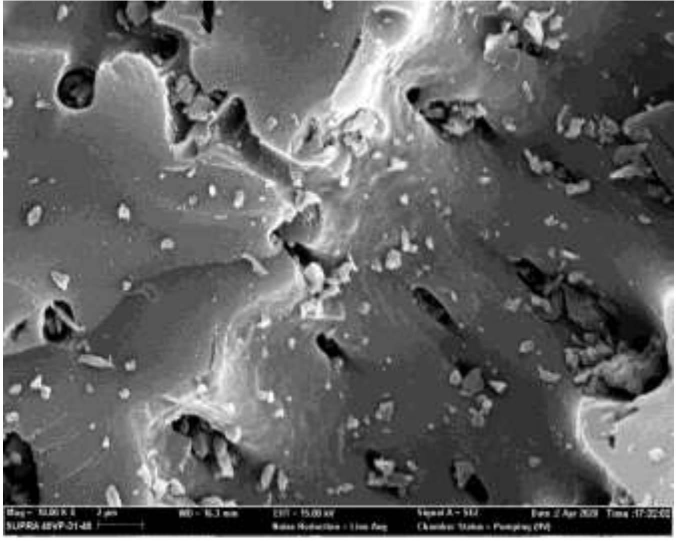


Figure 2. SEM photograph of the prepared activated carbon

3-2. Screening of factors on removal of Black Remazol from Hadamard matrix

The results of the experiments related to the Hadamard matrix provided the removal rates summarized in Table 4. The results vary from 0.15 to 70.80 % (Table 4). The high rate is obtained with experiment 5 consisting of the treatment of 25 mL of a solution of Black Remazol with a concentration of 20 mg/L at pH = 2 in contact with 0.3 g of activated carbon and stirred at room temperature (30 °C) at 300 rpm for 60 minutes.

The estimates and statistics of the coefficients are presented in Table 5. Thus, the average removal rate is expressed by a_0 and is equal to 26.872 %. The analysis of the different coefficients therefore shows that the reduction rate decreases by 24.974 % ($2xa_1$ or 2x12.487) and by 24.67 % ($2xa_4$ or 2x12.335) respectively when the pH increases from 2 to 12 and when the concentration of the solution increases from 20 to 100 mg/L. However, this reduction rate increases by 32.9 % ($2xa_2$ or 2x16.45), 0.02 % ($2xa_3$ or 2x0.01) and 12.794 % ($2xa_5$ or 2x6.397) respectively, when the absorbent mass increases from 0.05 to 0.3 g; when the temperature increases from 30 to 60 °C and the stirring time increases from 15 to 60 min. Furthermore, a coefficient is considered to be statistically significant if its absolute value is greater than twice the standard deviation [18]. The experimental error (standard deviation) obtained is 6.567. Thus, the significant factor is the main effect a_2 (the mass of carbon). However, the three factors X_1, X_4 and X_5 have medium effects on removal of Black Remazol and X_6 has a inconsiderable effect. The importance of the factors is also highlighted on the removal of Black Remazol, using eq. 5. Indeed, it is possible to give information that is more significant by calculating the contribution of each factor on the response (removal of Black Remazol).

$$\mathbf{P_i = \left(\frac{b_i^2}{\sum b_i^2}\right)*100 \qquad (i\neq 0) \qquad (eq.\ 5)}$$

Where bi represents the different estimates the main effect of the factors.

The Pareto chart in Figure 1 shows the contributions of solution pH (X_1), carbon mass (X_2), temperature (X_3), solution concentration (X_4), stirring time (X_5) and the speed of agitation (X_6) on removal of Black Remazol which are respectively, 24.85 %, 43.11 %, 0.000016 %, 24.24 %, 6.52 % and 1.28 % (figure 3). The Pareto diagram confirms the analysis made previously on the various factors. These results are valid only in the experimental field considered.

Table 4: Experimental field of coded and real variables of the Hadamard design factors

	Factors												
	Coded Variables						Real Variables						Black Remazol
No Exp	X_1	X_2	X_3	X_4	X_5	X_6	pH of solution	Mass of carbon (g)	T (^{0}C)	Conc. Sol. (mg/L)	Ag. Time (min)	Stir. Sp. (rpm)	Removal rate (%)
1	+1	+1	+1	-1	+1	-1	12.00	0.30	60.00	20.00	60.00	150.00	53.31
2	-1	+1	+1	+1	-1	+1	2.00	0.30	60.00	100.00	15.00	300.00	46.49
3	-1	-1	+1	+1	+1	-1	2.00	0.05	60.00	100.00	60.00	150.00	7.58
4	+1	-1	-1	+1	+1	+1	12.00	0.05	30.00	100.00	60.00	300.00	1.39
5	-1	+1	-1	-1	+1	+1	2.00	0.30	30.00	20.00	60.00	300.00	70.80
6	+1	-1	+1	-1	-1	+1	12.00	0.30	60.00	20.00	15.00	300.00	0.15
7	+1	+1	-1	+1	-1	-1	12.00	0.05	30.00	100.00	15.00	150.00	2.69
8	-1	-1	-1	-1	-1	-1	2.00	0.05	30.00	20.00	15.00	150.00	32.57

Ag. time : Agitation time (min) Stir. Sp.: Stirring speed (rpm) Conc. of sol. Concentration of solution

Table 5. Estimates and statistics of the coefficients of response Y (Hadamard matrix)

Name	a_0	a_1	a_2	a_3	a_4	a_5	a_6
Coefficients	26.872	12.487	16.450	0.010	12.335	6.397	2.835
Standard deviation	6.670	6.670	6.670	6.670	6.670	6.670	6.670

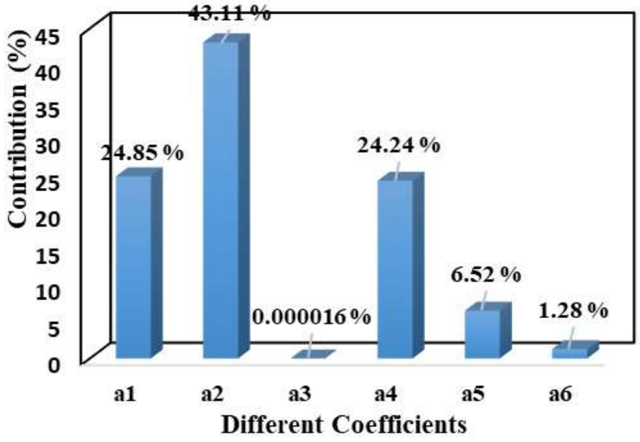


Figure 3. Analysis of the weight of the different factors from the Pareto chart

Thus, in order to optimize the removal of Black Remazol, another experimental field was defined by retaining the factors whose contribution is greater than 5.00 %. Four factors therefore appear to be important. On the other hand, the pH of the solution (X_1) will be set at 2 because the work has shown that the reduction rate is maximum at acid pH [9]. The factors selected for the rest of this study are; the factor X_2 (the mass of the carbon), X_4 (the concentration of the solution) and X_5 (the stirring time) by varying the experimental field. The other factors will be fixed at their value allowing having a good removal rate. The work will be done at room temperature (30 °C) and the stirring speed will be set at 150 rpm. Hadamard matrix does not optimize the removal of Black Remazol. Therefore, the use of the full factorial design will optimize the three factors retained in this study.

3-3. Optimization of removal of Black Remazol from Full Factorial Design (FD)

3-3-1. Analysis of data from FD

The implementation of the full factorial design with three factors made it possible to obtain the reduction rates presented in Table 6. The results vary from 18.05 % to 96.67 %. The high reduction rate is obtained during experiment 2, when 25 ml of a solution of Black Remazol with a concentration of 10 mg/L was stirred for 20 minutes in contact with 0.3 g of activated carbon. The experiment took place at room temperature and the pH of the solution was set at 2.

In view of the coefficients linked to the various factors contained in Table 7, it can be seen that factors such as the mass of the carbon (X_1) and the concentration of the solution (X_2) really have a considerable impact on removal of Black Remazol. As for the effects of interactions, only the interaction between the mass of carbon (X_1) and the stirring time (X_3) is insignificant on this phenomenon.

The coefficient a_0 = 55.171 represents the average of the responses from the 8 trials (Table 6). The average coefficient a_0 = 55.171 implies that the Black Remazol is removed up to 55.171 % in this experimental field. Furthermore, the mass of activated carbon produces a positive effect on the response (a_1 is positive). Its increase leads to an increase in the reduction rate of 29.212 %. However the concentration of the colored solution has a negative effect on the response, (a_2 is negative). Its increase causes a significant decrease in the rate of degradation of Black Remazol by 44.608 %. Therefore, for too high concentrations of the dye, the reduction rate will be low. Hence the need to work with low concentrations. Changing the stirring time from 20 minutes to 60 minutes has no significant effect on the phenomenon in the study area. Thus, in order to reduce the energy involved, the stirring time will be maintained at 20 minutes.

Table 6. Experimental field of coded and real variables of the factors of the Full Factorial design

No. Exp.	Factors Coded Variables X_1	X_2	X_3	Real Variables Mass of carbon (g)	Concentration of the Solution (mg/L)	Agitation time (min)	Black Remazol Removal rate (%)
1	-1	-1	-1	0.10	10.00	20.00	**59.56**
2	+1	-1	-1	0.30	10.00	20.00	**96.67**
3	-1	+1	-1	0.10	50.00	20.00	**18.05**
4	+1	+1	-1	0.30	50.00	20.00	**41.39**
5	-1	-1	+1	0.10	10.00	60.00	**60.89**
6	+1	-1	+1	0.30	10.00	60.00	**92.78**
7	-1	+1	+1	0.10	50.00	60.00	**23.76**
8	+1	+1	+1	0.30	50.00	60.00	**48.27**

Table 7. Estimates and statistics of coefficients (FD)

Name	a_0	a_1	a_2	a_3	a_{12}	a_{13}	a_{23}
Coefficients	55.171	14.606	-22.304	1.254	-2.644	-0.506	1.894
Standart deviation	0.799	0.799	0.799	0.799	0.799	0.799	0.799

3-3-2. Effects of factors on the removal of Black Remazol

Through the Hadamard matrix, we noticed that the pH has an average effect on the studied phenomenon. But absorption occurs best at acidic pH, i.e. at pH 2. This is in agreement with the work of Aboua in 2013 [13] and Abo et al. in 2021 [9] on the absorption of methylene blue [13]. The high reduction rate at acidic pH could be explained by the fact that Black Ramazol is a cationic dye. The high reduction rate at acidic pH could be explained by the fact that Black Ramazol is a cationic dye. The temperature has no significant influence on the phenomenon studied. Its influence depends on the experimental field, at a high level, on the mass of carbon used and to a lesser extent on the concentration of the Black Remazol solution. Time has a medium effect on the reduction rate of Black Remazol according to the Hadamard matrix. Whatever the stirring time, we have a relatively acceptable reduction rate. It should be noted that the kinetics of dye fixation can be linked to the physicochemical characteristics of the material, and more precisely to the nature of the sites on the surface and to the porosity of the material [19-20]. The concentration of the dye has a significant influence on the phenomenon studied. Indeed, the reduction rate is linked to the concentration of the dye. The mass of carbon also has a significant influence on the removal of Black Remazol. Indeed, work on removal of organic pollutants on activated carbons has enabled their authors to reach similar results [21-23]. The reduction rate increases with the mass of activated carbon. This could be explained by the increase in the exchange surface of the adsorbent and the (increasing) availability of more adsorption sites.

3-3-3. Determination of optimal conditions for the studied response

Full factorial designs describe first-order mathematical models in general. The statistical analysis of this model leads initially to the analysis of variance table (Table 8). It mainly indicates that the model used is well adjusted since the sum of squares due to the error (5.10) is very small compared to the total sum of squares ($5.79.10^3$). This good adjustment is confirmed by the finer analysis given by the value of the multiple linear correlation coefficient (R^2 = 0.999 or 99.90 %; given by the statistical software design NEMROD-W). This value is close to 1. This indicates that the model explains 99.99 % of the phenomenon studied. The adjustment made is therefore satisfactory. Analysis of the residuals also makes it possible to judge the quality of the adjustment made by comparing the values of the measured responses (Yexp.) with those of the responses predicted by the model (Ycalc). The differences (dU) (Table 9) between Yexp and Ycalc are identical in absolute value and are not greater than 5.00 % [12]. This also shows a very good correlation between the experimental responses and the calculated responses. All these findings validate the postulated linear model and confirm not only the linearity of the phenomenon studied but also and above all the use of a first degree model to account for a good adjustment of the model. The main coefficients and the interactions between factors (Table 7) therefore make it possible to establish this model (eq. 6.). The mathematical model described by this phenomenon is in the form of:

Table 8. ANOVA results for full factorial design (FD)

Source of variation	**Sum of squares**	**Degrees of freedom**	**Mean square**	**Report**	**Signif**
Regression	$5.78.10^3$	6	$9.64.10^2$	188.92	5.6
Residue	5.10	1	5.10		
Total	$5.79.10^3$	7			

Table 9. Comparison of actual values (Yexp.) and calculated (Ycalc.) for FD

N°Exp	Yexp.	Ycalc.	Relative deviation
1	59.560	60.359	0.875
2	96.670	95.871	0.875
3	18.050	17.251	0.875
4	41.390	42.189	0.875
5	60.890	60.091	0.875
6	92.780	93.579	0.875
7	23.760	24.559	0.875
8	48.270	47.471	0.875

In this part, we will call optimal output response: Y = 100, which amounts to eliminating all the dye (100 %, ideal condition) in the effluent after its treatment with activated carbon. Thus, finding the conditions to satisfy this output amounts to solving the eq. 6:

$$55.171 + 14.606\ X_1 - 22.304\ X_2 - 2.644\ X_1X_2 + 1.894\ X_2X_3 = 100$$

Using the Excel Solver utility, we get the following results:

$Y = 100.000055$ pour $X_1 = 1$ et $X_2 = -1$

The optimal retention conditions for Black Remazol would be:

$X_1 = 0.3$ g
$X_2 = 10$ mg/l
$X_3 = 20$ min since the weather has very little influence on the phenomenon.

Under these conditions, the Black Remazol in synthetic aqueous solution is removed up to 96.67 %.

The removal rate of this dye in synthetic aqueous solution obtained in this study is similar to those of Abo [9]. However, it is better than that obtained by Ahmad et al. in 2014 [5] in the removal in aqueous solution of the brilliant Remazol. The removal rate of this dye is higher than those obtained in the work of Basava Rao et al., in 2009 [24], Asadzadeh et al., in 2022 [25], and Sajad et al., in 2020 [26], and Asadzadeh et al., in 2020 [27], who had obtained 67.00 %, 62.00 % and 90.00 % as their respective rates.

4. Conclusion

The main objective of this study was to optimize the removal of Black Remazol in synthetic aqueous solution from activated carbon using experimental designs. Derived from corncobs, activated carbon prepared and activated by the chemical process with orthophosphoric acid as an activating agent has been shown to be effective in the removal of Black Remazol from an aqueous solution. This activated carbon has a strong acid character with a non-negligible basicity. The exploitation of data from two experimental designs (the Hadamard matrix and the full factorial design) showed that under the conditions of the study, an increase in the mass of activated carbon leads to an increase in the removal rate of Black Remazol while increasing the concentration of the colored solution produces the opposite effect. The agitation time, on the other hand, has a very insignificant effect and the acid pH is favorable to the treatment. The optimization of the process has shown that for a mass of activated carbon equal to 0.3 g, a concentration of the colored solution of 10 mg/L at pH = 2, a removal rate of Black Remazol of 96.67 % is reached after 20 minutes of stirring in a synthetic aqueous solution.

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