Wastewater Assessment and Biochemical Oxygen Demand Value Prediction from Mining Operations: A Case Study

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ABSTRACT

Wastewater is a byproduct of industrial or household waste processes, and its contamination level must be determined before treatment. Discharges of liquid effluents generated by mining operations, one of the most prevalent forms of industrial waste water, pose a risk to human health and the environment. This study evaluates the physicochemical quality of industrial liquid effluent discharges from the Boukhadra mine (Algeria). Samples were collected from the washing water to identify the level of contamination of these liquid discharges and to measure physicochemical parameters such as temperature (T), hydrogen potential (pH), Electrical Conductivity (EC), Suspended Solids (SS), Chemical Oxygen Demand (COD), Biological Oxygen Demand for 5 days (BOD5), Oils and Greases (O&G), iron (Fe^{+2}) and Kjeldahl Nitrogen (NTK). It was found that the concentration values of those effluents exceeded the maximum contamination limits specified by international industrial waste standards. A simple and reliable prediction model was developed to estimate DBO5, based on MES, COD, and O&G, by using classical regression analysis and fitting Design of Experiments (DOE) methodology. When comparing the analytical results, it was found that the quadratic model provided a better estimation, with a high correlation coefficient (R^2) of 0.9976. The parameters determined in this study will enable engineers to quickly estimate the degree of wastewater contamination and choose adequate treatment strategies.

Keywords-characterization; wastewater; BOD5; Design of Experiments (DOE); environment; ANOVA

I. INTRODUCTION

Water pollution has become a global problem that requires a sustained effort to mitigate it, as the increasing demand for agricultural and industrial products is responsible for it [1]. The increase in solid and liquid waste is directly related to the economic development of many countries, and in fact, the latter leads to detrimental impacts on the environment, the mismanagement of industrial sites, in particular, has consequences on public health and environmental problems [2]. Industry discharge wastewater containing organic matter, salts, hydrocarbons, heavy metals, biocides, micropollutants, and various chemicals, often causes permanent environmental damage [3]. The impact of these industrial effluents on the environment is a reality, and they significantly contribute to the degradation of the quality of surface and ground water, therefore, for public health reasons, these materials must be treated before being released directly into streams or lakes [4]. Numerous studies have been conducted on the characterization, evaluation, and treatment of hazardous substances in textile-related effluents [5], sludge [6], sewage sludge [7], paper waste [8], petroleum wastewater [9] and aerobic oil and grease-degrading bacteria in wastewater [10]. Additionally, studies on wastewater produced by mining operations have been conducted in cases of coal mines [11], gold mines [12], marble mines [13], and iron mines [14]. Those researchers have attempted to remove inorganic pollutants, recycle trash, segregate materials, and indirectly evaluate hazardous substances present in wastewater to treat them better. Among the industrial activities, the Algerian mining sector, which has experienced exponential economic growth, has raised many environmental issues relating to its activity [15-17]. Therefore, adopting feasible environmental assessment methods is desirable.

As a case study, the Boukhadra iron mine in Tebessa province in Algeria, is one of the largest operational iron mines in the country. The annual production of iron ore is 5 million tons, with approximately 50 thousand m^3 of wastewater generated each month by washing machinery production equipment. The mine represents a critical contamination point, as all fluid discharges are discharged into the washing plant and contain significant contaminants, and the mine does not include Wastewater Treatment Plants (WWTPs). The installation is old, as the washing pit was constructed before 1926, and since the opening of the mine, it has not been connected to the sewage network even though it is present, but in a neglected state (soak pit). These liquid ejections are directly discharged into nature and cause considerable damage. The environmental impact of these industrial effluents causes severe threats to public health. The effluents must be studied and treated before discharging.

Recent investigations have focused on the development of numerical models using machine learning techniques for estimating the Biological Oxygen Demand for 5 days (BOD5) of wastewater [18, 19], but those models are complicated and difficult to use. However, none of the previous studies have used the Design of Experiments (DOE) technique to produce an adequate model for predicting the parameters of wastewater. The advantage of DOE technique is that it allows the variation of different factors simultaneously to screen the reaction space for optimum values. In this study, the physicochemical quality of industrial liquid effluents was evaluated to detect the level of contamination. Classical Regression Analysis (CRA) and (DAO) techniques with linear, 2FI, and quadratic models were employed to quickly estimate BOD5 and to reveal its experiential relationship with liquid effluent discharge parameters. The experiential relationship of BOD5 with wastewater parameters was identified and the performance of the resulting model was assessed.

II. GENERAL SETTING AND AVAILABLE DATA

The study area is located in the eastern part of Tebessa city, Algeria (Figure 1). The iron mine is located between longitudes 8°01'30" to 8°03'18" and latitudes 35°45'54" to 35°44'42", covering an approximate area of $3.7km^2$. The mine was discovered in 1903 and produces iron ore since 1926, with exploitable reserves exceeding 50 million tons. The Boukhadra iron deposit consists mainly of hematite and is one of the largest in the Algerian-Tunisia border region. [20]. There is a washing station which is used to wash equipment and drain oil from construction machinery. The waste wastewater from this wash station exceeds 10 thousand m^3 daily. The liquid discharge contains significant polluting substances, and the mine does not include WWTPs. Also, it is not connected to the sewage, and the liquid ejections are directly discharged to the nature causing considerable environmental damage. The environmental impact of these industrial effluents causes serious threats to the quality of surface water, groundwater, and public health, while the Boukhadra town is located at the vicinity of the mine.

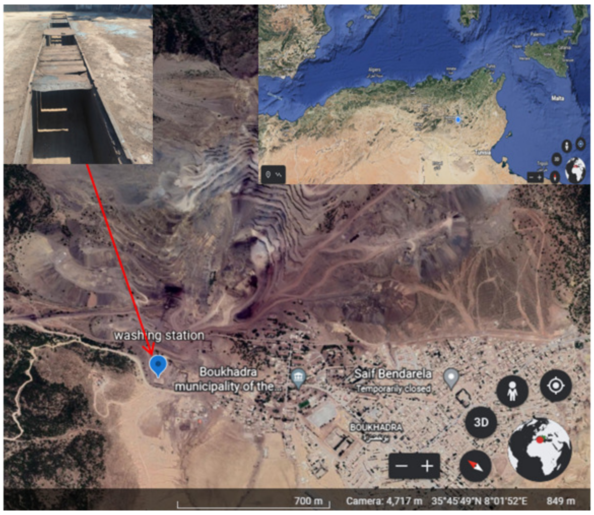


Fig. 1. Location of the study area. © Google Earth, GEBCO Landsat, Copernicus IBCAO.

III. MATERIALS AND METHODS

To evaluate the physicochemical quality of liquid discharges, samples were collected from the washing pit located in Boukhadra mine. Temperature (T), pH, Electrical Conductivity (EC), Suspended Solids (SS), Chemical Oxygen Demand (COD), BOD5, Oils and Greases (O&G), iron (Fe^{+2}), and Kjeldahl Nitrogen (NTK) were measured to determine the level of contamination. Twenty five samples were collected from 2016 to 2021, 1 every 3 months. The samples were taken from the equipment and production machinery washing station (final discharge) with a stainless steel bucket of 1.5L, attached to large polyethylene terephthalate (PET) bottles. Bottles were filled after 2 to 3 rinses with the same sample. To ensure the traceability of the sample, a tag was associated with each sample (date, location, and GPS coordinates), and the samples were hermetically sealed and conserved [21]. The samples were transported to the laboratory in an icebox at 4°C and were stored for 48h before being analyzed. The statistical analysis results of the physical and chemical parameters of the industrial wastewater discharge from Boukhadra mine are shown in Table I, where, the mean value (x_{mean}), standard deviation (σ), variance (σ^2), maximum value (x_{max}), and minimum value (x_{min}) are presented. The statistical variation intervals are performed for each parameter, checking for measurement errors and values outside logical bounds.

TABLE I. BASIC STATISTICS OF BOUKHADRA MINES WASTEWATER

	x_{mean}	σ	σ^2	x_{max}	x_{min}
T (°C)	19.852	3.980	15.842	26	9.1
pH	8.051	0.359	0.129	8.67	7.31
CE (µS/cm)	2580.92	2172.42	4719414	7830	840
COD (mg/l)	134.36	18.609	346.323	163	95
SS (mg/l)	106.52	18.888	356.76	136	67
NTK (mg/l)	0.884	0.550	0.303	2.1	0.4
Fe^{+2} (mg/l)	1.812	0.502	0.252	2.6	0.4
O&G (mg/l)	98.88	21.044	442.86	133	60
BOD_5 (mg/l)	45.64	18.843	355.073	74	5
COD/BOD_5 (mg/l)	3.930	3.40	11.599	19	2.202

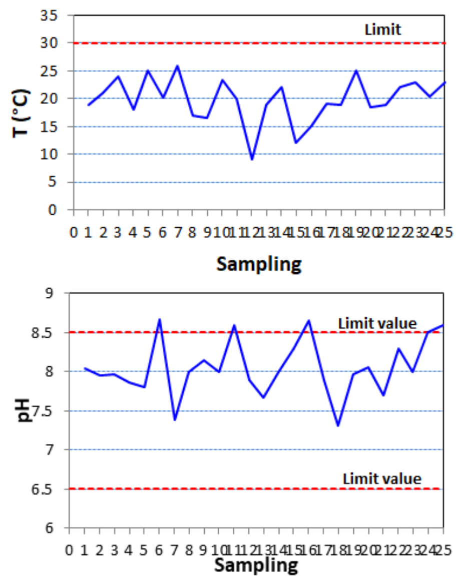
IV. RESULTS AND DISCUSSION

A. Wastewater Assessment

Most of the measured values do not meet the international discharge of industrial wastewater standards. Temperature is an essential factor in biological activity. Referring to the standard limits, it can be noted that the measured temperatures were below 30°C (Figure 2(a)), which is considered the standard for Algerian industrial waste [22]. The pH is also one of the most significant parameters affecting the biological activity of the microorganisms in the water, whose majority grows in the range of 4.5-8 [23]. The average pH values of the wastewater ranged between 7.31 and 8.67, slightly exceeding the standard value (Figure 2(b)). High COD [24] values were found, as indicated in Figure 2(c). Most values were above the standard limit of 120mg/L [25] for industrial waste. They ranged from 95 to 163mg/L, indicating the presence of biodegradable load [26]. These values would be related to the presence of large amounts of machine oil and SS due to the washing of mine equipment. The calculated results of SS show that it exceeds the threshold of acceptable values (20mg/L), with the highest value found in the wash station (136mg/L) due to the presence of heavy oils of large molecular mass (Figure 2(d)). NTK and Fe^{+2} comply with the standards (Figure 2(e)-(f)), while the average concentration of O&G (98.88mg/l) is very high and exceeds the limit value of 20mg/l (Figure 2(g)). This high quantity could lead to severe environmental pollution. The BOD5 values (mg/L) at 20°C in the dark were between 5 and 74mg/L, with the most values exceeding the allowable standard industrial waste limit of 35mg/L. Those values could be explained by the fact that the wastewater is highly loaded with oils, which create inhibited microbial activity similar to that found in anaerobic conditions. The COD/BOD5 ratio gives a first estimate of the biodegradability of the organic matter of an effluent. An increase in this ratio indicates a rise in non-biodegradable organic materials [27]. The test results showed that the COD/BOD ratio ranged from 2.20 to 19, with an average value of 3.93.

(a)

(b)



(c)

(d)

(e)

(f)

(g)

(i)

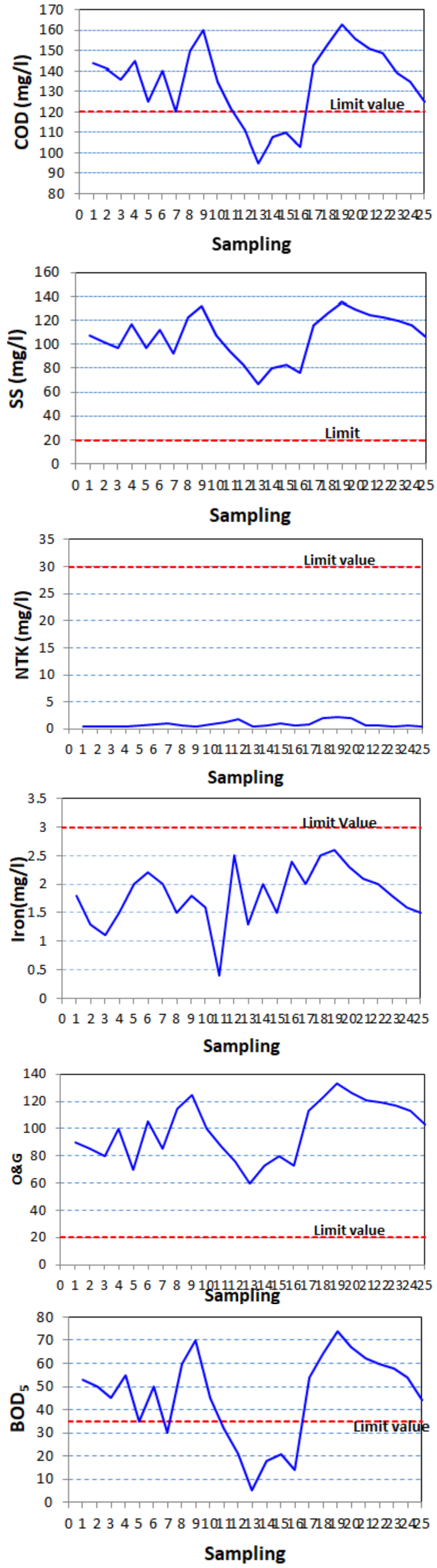


Fig. 2. Evaluation of physicochemical parameters of effluent discharges.

B. ANOVA Study

The developed model was performed using DOE, Design-Expert version 10. The input data were the values of COD, SS, and O&G. The statistical analysis included the analysis of variance (ANOVA), which is used to obtain suitable models and suitability studies. The ANOVA table of the effluent discharges, with linear, 2FI, and quadratic models, was employed to ensure the most appropriate model. The comparison between the influence of the main factors and their interactions can be carried out using the F-value of each factor. The presented results for the quadratic model confirm that the COD and SS and OG are significant at ≤5% (probability level), but this is not true for linear and 2FI models. Table II shows that the F-values of COD, SS, and OG are 3779.12, 3327.85, and 1656.90, respectively. Therefore, it is clear that in the proposed model, the influence of COD is more considerable than the weight fraction. Therefore, it can be said that the quadratic model is the most expressive and the changes in BOD5 can be accurately estimated using the proposed model. The proposed quadratic model for estimating BOD5 related to COD, SS, and O&G is defined as:

$$BOD5 = -47.41946 - 1.20218 \times COD + 1.29202 \times SS + 0.917706 \times OG - 0.023951 \times COD \times SS - 0.027619 \times COD \times OG + 0.025533 \times COD^2 + 0.001488 \times SS^2 + 0.002399 \times OG^2 \quad (1)$$

The model incorporates all the necessary main factors and their interactions.

TABLE II. ANOVA RESULTS FOR WASTEWATER WITH THE QUADRATIC MODEL

Source	Sum of squares	Mean Square (MS)	F-value	p-value
Model	8521.74	946.86	8.654E+05	< 0.0001
A-COD	4.14	4.14	3779.12	< 0.0001
B-SS	3.64	3.64	3327.85	< 0.0001
C-OG	1.81	1.81	1656.90	< 0.0001
AB	1.81	1.81	1654.43	< 0.0001
AC	11.43	11.43	10450.61	< 0.0001
BC	3.93	3.93	3591.32	< 0.0001
A^2	5.36	5.36	4901.37	< 0.0001
B^2	0.6547	0.6547	598.38	< 0.0001
C^2	0.1202	0.1202	109.82	< 0.0001
Residual	0.0164	0.0011		
Total	8521.76			

It can be seen from Figure 3 that the Residual Sum of Squares (RSS) for the quadratic model is very small (0.0164). It was also observed, that the Coefficient of Variation (CV) had a small value (0.0725), indicating that the proposed model provides the best reliable measurement. CV is less than 5% is deemed acceptable [28]. Therefore, it is clear that in the proposed model, the influence of the COD is more considerable than the weight fraction.

C. Adequacy of the Proposed Model

One practical and efficient way to test the adequacy of the proposed model is the normal distribution of errors. Examining the normal probability of the studentized residuals can confirm the normal distribution of errors [29]. One interesting feature of a proper model is the agreement between the experimental and the predicted values. Figure 4 shows the correlation between the actual values obtained during the experiments and the predicted values of the proposed BOD5 model. The graph shows that there is a good agreement between the actual and the predicted values. Therefore, the proposed model can predict the DBO5 activity in effluents under the experimental conditions.

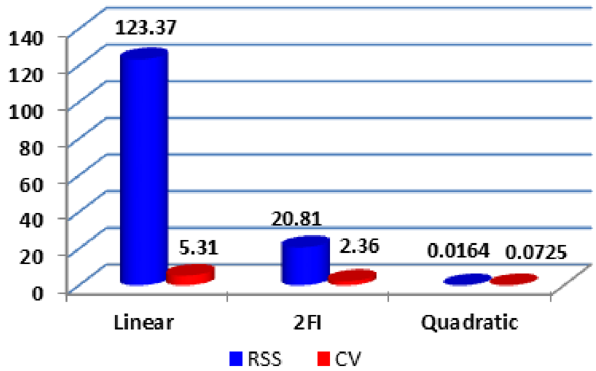


Fig. 3. Verification results for the responses on BOD5.

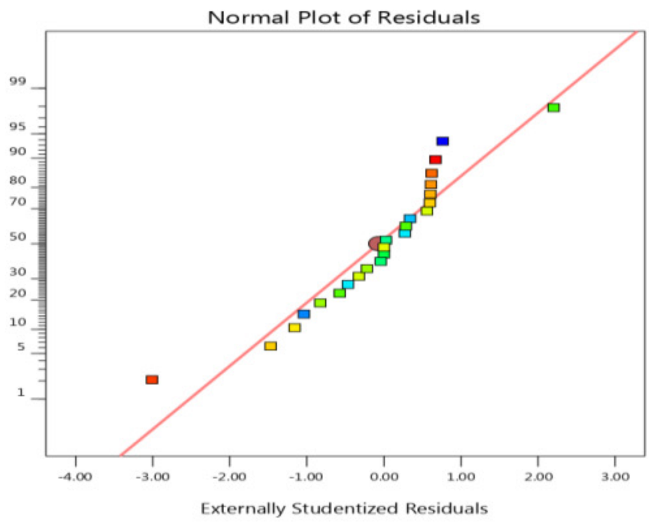


Fig. 4. Comparison between the predicted and the actual values of DBO5.

V. CONCLUSIONS

In this research work, physicochemical characterization of industrial liquid effluent discharges, collected from the washing water from the Boukhadra mine (Algeria) was conducted. The samples were evaluated, to identify their level of contamination. The analysis showed that the values of COD, SS, BOD5, and O&G are very high. Their presence indicates strong and unbalanced biological pollution, which could be dangerous to the environment. To control and quick estimate the main effluent parameter, classical regression analysis without measuring BOD5 value was conducted by the DOE methodology to fit the appropriate model. After simulation, and by the combination of SS, COD, and O&G parameters, the quadratic model was adopted. To control errors and resemblances according to the experimental values, the MS, RSS, and P-values were used to compare the performance of the model with the actual results. The quadratic model provided a high correlation coefficient (R^2) of 0.9976. Based on the ANOVA results, is clear that the effect of COD is more than that of the weight fraction and the interaction between the other parameters. Also, the statistical parameters of the proposed model revealed that this model could predict the DBO5 activity of the samples strictly, by giving close responses to the instantaneous variations.

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