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Keywords: Bioremediation; RSM; Crude oil concentration; Solid waste date; Total petroleum hydrocarbons

Abbreviations: ANOVA: Analysis of Variance Average; CCD: Central Composite Design; CO: Crude Oil; HCO: Heavy Crude Oil; HEM: Hexane Extractable Material; LCO: Light Crude Oil; RSM: Response Surface Methodology; SWD: Solid Waste Date; TGY: TryptonGlcouse Yeast

Introduction

e pollution of marine environment by crude oil hydrocarbon has been regarded as an increasingly serious public concern for environmental and health reasons [1-3]. e exploitation of o shore oil resources, the use and transportation of petroleum products, wastes emission, and frequently occurring oil spill accidents have negative impacts to marine ecosystems [4]. Methods involving physical skimming and the use of chemical dispersants to solve this problem are both expensive and limited in e ectiveness [5]. us, innovative and inclusive technologies have been developed for the removal of petroleum contaminants [6].

Approaches for cleaning up an oil spill are greatly a ected by a variety of factors, such as the type of oil, the characteristics of the spill site, and, to a particular extent, political considerations [7,8]. As such, understanding the quantity and characteristics of oil spill, age of oil, weather conditions, surrounding environment, ocean behavior, and impact ovanin, sd9(r)13[(r ce t)-5(TJ -es)5.1(ce5.9(sn b)-9(e e)29)4(p)-4.9de5.9(i)3(6)9(n)(yp)-9((o)1(v). ce (h)3(a12(i)-18(v)-i)-)5(p)12(i5.1(p

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re(I)16(m empirical function of the test variables in coded units. Equations 4 and 5 provide the model for HCO and LCO removal in this research:

$$\text{HCO removal (\%)} = 92.73-0.81A+4.45B+5.27C-1.89A^2-1.95B^2-2.25C^2-1.35AB+1.32AC-1.08BC \quad (4)$$

$$\text{LCO removal (\%)} = 92.91+1.27A+0.13B+2.86C+1.68A^2+2.36B^2-2.82C^2+0.48AB-0.72AC-1.30BC \quad (5)$$

where A is CO concentration (mg/L), B is the concentration (mg/L), and C is time (day).

In this model, the two-level interaction between terms A and B and the second-order e ect of terms A and C were insigni cant, whereas the other terms were signi cant (insigni cant terms were removed in the nal equation). e coef cients with one factor show the e ect of the particular factor, whereas the coef cients with two factors and those with second-order terms demonstrate the interaction between the two factors and quadratic e ect, respectively. e positive sign in front of the terms indicates a synergistic e ect, whereas a isse e (oq 0 g5eg59(n in)4(dic)-3(a)19(t)6(es)]TJ 0 Tw T* [a (a)9(n)19(e)-6(a51(g83(o)12(
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whereas no signi cant e ects were observed for the variation of both factors on LCO removal. Figure 3b1 and 3b2 presents the e ects of initial CO concentrations and incubation time on both HCO and LCO removals at an SWD dosage of 0.28 g/L. For both COs, the removal e ciencies improved with increasing incubation time. Figure 3c1 and c2 illustrates that the cooperation e ects vary with SWD dosage and incubation time at a CO initial concentration of 1.0 g/L.

Optimization and veri cation

Optimization was carried out to determine the optimum values of HCO and LCO removal e ciency by using the Design Expert 6.0.7. Based on the so ware optimization step, the desired goal for each operational condition (initial HCO and LCO concentrations, SWD dosage, incubation time, and reaction time) was chosen “minimum” in the range. e responses (HCO and LCO removal) were de ned as the maximum to achieve the higcies ote (era)19hor end Ht5(t)-5(ra)19iat toc

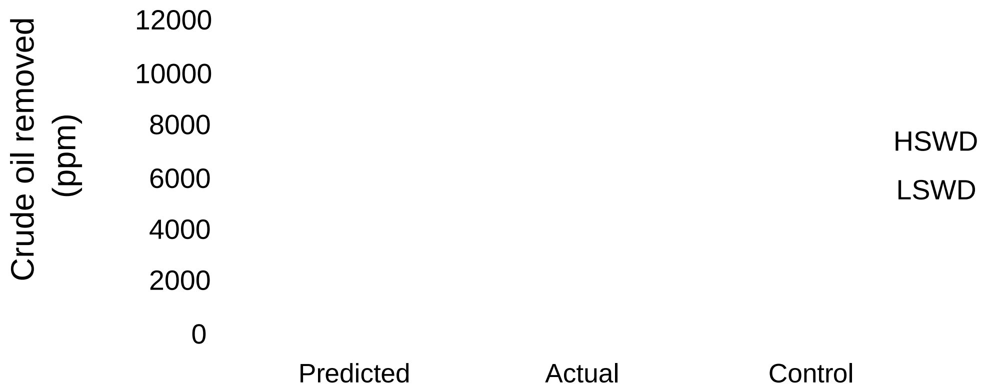

Figure 4: Comparison between actual and predicted removal on days 11 and 14 for HCOand LCO.

Figure 5: Residual curves: (a) HCO and (b) LCO removal.

e most cost-ef cient and environmental-friendly conditions for the bioremediation of crude oil would use the lowest amounts of SWD in the shortest time. Hence, a set of approximate reaction conditions based on the required criteria for maximum oil degradation and minimum nutrient consumption is predicted by the so ware via numerical optimization with the highest desirability.

e numerical optimization criteria for maximum (CO) removal were set in a range for variables. At SWD concetrations of 0.21 and 0.20 g/L in 11 and 14 d, the so ware predicted 82.01% and 95.45% removal for HCO and LCO, respectively, with desirability of 1.00, Figure 4. Con rmatory experiments at the optimum conditions were carried out, and removal rates of 79.49% and 94.15% were observed for HCO and LCO, respectively, which is in reasonable agreement with the model with removal rates of 5.5% and 14.7% for both HCO and LCO without SWD.

Residual and present between predicted and actual values error were evaluated to validate the experiments. Errors were calculated using Eq. (6):

$$\text{Error} = \frac{X_{obs} - X_{pre}}{X_{obs}} \times 100 \qquad (6)$$

Where X_{Obs} are the observed values and X_{Pre} are the predicted values.

Residual ranged between -3 and 3 (Figure 5). e residual indicates that the process optimization via CCD was reliable.

Conclusions

e e ectiveness of nutrients as SWD supplements in increasing the biodegradation rate of crude oil was investigated via RSM. A second-order polynomial mathematical model was generated with multiple regression analysis to describe heavy and light CO Bioremediation in arti cially contaminated sea water samples. e highest crude oil removal rates by natural attenuation and by unoptimized bioremediation were 5.5% and 14.7% and 97.05% and 99.10%, respectively. Numerical optimization was achieved based on desirability functions. At SWD concentrations of 0.21 and 0.20 g/L, the so ware predicted removal rates of 84.42% and 95.70%.

Removal rates of 79.49% and 94.15% were observed experimentally

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