*Supplement*

**Design of a solar reactor for the removal of uranium from simulated nuclear wastewater with oil-apatite ELM system**

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**Details of solar reactor geometry**

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**Fig. S1.** Details of solar reactor geometry

**Development of regression model equation**

According to experimental results and its predicted results in **Table S1**, based on the quadratic model, for modeling of response surface Eq. (1) was proposed by CCD in the RSM.

$Y\_{1}$= +80.03 $-$2.89 $X\_{1}$ +3.60 $X\_{2}$ +13.50 $X\_{3}$ +4.40 $X\_{4}$ +12.12 $X\_{5} $ $-$0.3344 $X\_{1}X\_{2}$ $-$0.3281 $X\_{1}X\_{3}$ $-$0.4844 $X\_{1}X\_{4}$ +0.1038 $X\_{1}X\_{5}$ +0.6606 $X\_{2}X\_{3}$ +0.5631 $X\_{2}X\_{4}$ +0.0200 $X\_{2}X\_{5}$ +2.35 $X\_{3}X\_{4}$ +2.64 $X\_{3}X\_{5}$ $-$1.47 $X\_{4}X\_{5}$ $-$1.85 $X\_{1}^{2}$ $-$5.61 $X\_{2}^{2}$ $-$8.61 $X\_{3}^{2}$ $-$4.74 $X\_{4}^{2}$ $-$6.87 $X\_{5}^{2}$ (1)

Where $Y\_{1}$ is the uranium(VI) ions removal efficiency (%), $X\_{1}$, $X\_{2}$, $X\_{3}$, $X\_{4}$ and $X\_{5}$ are uranium(VI) concentration ($mg L^{-1}$), NHAP concentration ($g L^{-1}$), pH and retention time (min), respectively. A positive sign against each term of the Eq. (1) indicates a synergistic effect and the negative sign indicates a synergistic effect on the response surface ($Y\_{1}$).

The actual versus predicted responses in **Fig. S2 a** shown approximately a linear relationship with partial variation. The normal plot of residuals in **Fig. S2 b** is similar to a straight line indicating that the errors are evenly distributed and therefore support the least squares fit.

According to **Fig. S2 c-d**, the residuals versus the predicted response and the residuals versus the experimental run exhibit the residuals has been distributed above and below the x-axis with unusual structure and no obvious pattern. Also, the $R^{2}$ values for model equation was 0.926, the adjusted $R^{2}$ and predicted $R^{2}$ were 0.879 and 0.723, respectively with difference less than 0.2. The analysis of variance (ANOVA) helps to check the accuracy and validity of the proposed model. According to **Table S2**, based on ANOVA, this model was highly significant with F-value 18.88 and p-value $<$ 0.0001 also, all of the factors ($X\_{1}$, $X\_{2}$, $X\_{3}$, $X\_{4}$ and $X\_{5}$) were significant. So, the model is acceptable for the predicted results and the optimization of affecting factors on the uranium(VI) removal efficiency.

**Table S1.** Experimental design matrix and results.

|  |  |  |
| --- | --- | --- |
|  | **Actual level of factors** | **Responses** |
| **Run** | $X\_{1}$($mg L^{-1}$) | $X\_{2}$($g L^{-1}$) | $$X\_{3}$$ | $X\_{4}$ ($ml$) | $X\_{5}$($min$) | **Actual** | **Predicted** | **Residual** |
| 1 | 260 | 10.13 | 7.5 | 35 | 32.5 | 78.15 | 80.03 | -1.88 |
| 2 | 140 | 15.06 | 9.75 | 47.5 | 46.25 | 52.23 | 55.72 | -3.49 |
| 3 | 380 | 5.19 | 9.75 | 47.5 | 46.25 | 47.81 | 42.78 | 5.03 |
| 4 | 140 | 15.06 | 9.75 | 47.5 | 18.75 | 33.45 | 39.87 | -6.42 |
| 5 | 380 | 15.06 | 9.75 | 47.5 | 18.75 | 29.65 | 32.90 | -3.25 |
| 6 | 140 | 5.19 | 9.75 | 47.5 | 46.25 | 51.25 | 48.01 | 3.24 |
| 7 | 260 | 10.13 | 7.5 | 35 | 60 | 80.52 | 76.81 | 3.71 |
| 8 | 380 | 5.19 | 9.75 | 22.5 | 46.25 | 44.07 | 43.72 | 0.3537 |
| 9 | 140 | 5.19 | 5.25 | 47.5 | 46.25 | 81.34 | 84.31 | -2.97 |
| 10 | 260 | 10.13 | 7.5 | 35 | 32.5 | 70.05 | 80.03 | -9.98 |
| 11 | 260 | 10.13 | 7.5 | 35 | 32.5 | 86.63 | 80.03 | 6.60 |
| 12 | 380 | 15.06 | 9.75 | 47.5 | 46.25 | 48.45 | 49.16 | -0.7088 |
| 13 | 260 | 20.00 | 7.5 | 35 | 32.5 | 87.52 | 64.78 | 22.74 |
| 14 | 260 | 0.25 | 7.5 | 35 | 32.5 | 35.16 | 50.38 | -15.22 |
| 15 | 500 | 10.13 | 7.5 | 35 | 32.5 | 65.32 | 66.84 | -1.52 |
| 16 | 380 | 15.06 | 5.25 | 47.5 | 46.25 | 80.36 | 86.79 | -6.43 |
| 17 | 260 | 10.13 | 12 | 35 | 32.5 | 14.25 | 18.59 | -4.34 |
| 18 | 140 | 5.19 | 5.25 | 47.5 | 18.75 | 57.45 | 57.98 | -0.5341 |
| 19 | 380 | 5.19 | 9.75 | 22.5 | 18.75 | 25.35 | 21.64 | 3.71 |
| 20 | 140 | 15.06 | 5.25 | 47.5 | 46.25 | 89.25 | 94.67 | -5.42 |
| 21 | 140 | 15.06 | 9.75 | 22.5 | 18.75 | 30.36 | 30.72 | -0.3583 |
| 22 | 140 | 5.19 | 5.25 | 22.5 | 46.25 | 75.14 | 73.92 | 1.22 |
| 23 | 380 | 5.19 | 5.25 | 47.5 | 18.75 | 52.87 | 51.03 | 1.84 |
| 24 | 260 | 10.13 | 7.5 | 35 | 32.5 | 75.25 | 80.03 | -4.78 |
| 25 | 260 | 10.13 | 7.5 | 35 | 32.5 | 80.85 | 80.03 | 0.8183 |
| 26 | 140 | 15.06 | 5.25 | 22.5 | 46.25 | 78.5 | 82.03 | -3.53 |
| 27 | 260 | 10.13 | 7.5 | 60 | 32.5 | 78.25 | 69.89 | 8.36 |
| 28 | 260 | 10.13 | 3 | 35 | 32.5 | 84.45 | 72.59 | 11.86 |
| 29 | 260 | 10.13 | 7.5 | 35 | 5 | 32.14 | 28.33 | 3.81 |
| 30 | 380 | 5.19 | 5.25 | 47.5 | 46.25 | 76.46 | 77.78 | -1.32 |
| 31 | 260 | 10.13 | 7.5 | 35 | 32.5 | 76.45 | 80.03 | -3.58 |
| 32 | 380 | 15.06 | 9.75 | 22.5 | 46.25 | 45.85 | 47.84 | -1.99 |
| 33 | 140 | 15.06 | 5.25 | 47.5 | 18.75 | 66.52 | 68.26 | -1.74 |
| 34 | 380 | 15.06 | 5.25 | 22.5 | 18.75 | 38.75 | 43.37 | -4.62 |
| 35 | 20 | 10.13 | 7.5 | 35 | 32.5 | 87.45 | 78.41 | 9.04 |
| 36 | 140 | 5.19 | 9.75 | 22.5 | 18.75 | 29.54 | 25.34 | 4.20 |
| 37 | 380 | 5.19 | 5.25 | 22.5 | 46.25 | 73.84 | 69.33 | 4.51 |
| 38 | 380 | 5.19 | 9.75 | 47.5 | 18.75 | 28.25 | 26.60 | 1.65 |
| 39 | 380 | 15.06 | 5.25 | 22.5 | 46.25 | 74.45 | 76.09 | -1.64 |
| 40 | 380 | 5.19 | 5.25 | 22.5 | 18.75 | 37.65 | 36.69 | 0.9624 |
| 41 | 140 | 5.19 | 5.25 | 22.5 | 18.75 | 41.35 | 41.70 | -0.3508 |
| 42 | 140 | 5.19 | 9.75 | 47.5 | 18.75 | 32.17 | 32.24 | -0.0698 |
| 43 | 380 | 15.06 | 9.75 | 22.5 | 18.75 | 26.74 | 25.68 | 1.06 |
| 44 | 380 | 15.06 | 5.25 | 47.5 | 18.75 | 56.32 | 59.97 | -3.65 |
| 45 | 260 | 10.13 | 7.5 | 35 | 32.5 | 80.57 | 80.03 | 0.5383 |
| 46 | 140 | 15.06 | 9.75 | 22.5 | 46.25 | 49.21 | 52.46 | -3.25 |
| 47 | 140 | 5.19 | 9.75 | 22.5 | 46.25 | 48.45 | 47.00 | 1.45 |
| 48 | 260 | 10.13 | 7.5 | 10 | 32.5 | 51.45 | 52.29 | -0.8362 |
| 49 | 140 | 15.06 | 5.25 | 22.5 | 18.75 | 42.14 | 49.72 | -7.58 |
| 50 | 260 | 10.13 | 7.5 | 35 | 32.5 | 84.78 | 80.03 | 4.75 |

**Table S2.** ANOVA for response surface quadratic model for uranium(VI) removal efficiency.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Sum of Squares** | **Degree of freedom** | **Mean Square** | **F-value** | **p-value** |  |
| Model | 21018.50 | 20 | 1050.93 | 18.27 | < 0.0001 | significant |
| $$X\_{1}$$ | 334.89 | 1 | 334.89 | 5.82 | 0.0224 | significant |
| $$X\_{2}$$ | 518.11 | 1 | 518.11 | 9.01 | 0.0055 | significant |
| $$X\_{3}$$ | 7288.92 | 1 | 7288.92 | 126.73 | < 0.0001 | significant |
| $$X\_{4}$$ | 774.75 | 1 | 774.75 | 13.47 | 0.0010 | significant |
| $$X\_{5}$$ | 5877.23 | 1 | 5877.23 | 102.19 | < 0.0001 | significant |
| $$X\_{1}X\_{2}$$ | 3.58 | 1 | 3.58 | 0.0622 | 0.8048 | not significant |
| $$X\_{1}X\_{3}$$ | 3.45 | 1 | 3.45 | 0.0599 | 0.8084 | not significant |
| $$X\_{1}X\_{4}$$ | 7.51 | 1 | 7.51 | 0.1305 | 0.7205 | not significant |
| $$X\_{1}X\_{5}$$ | 0.3444 | 1 | 0.3444 | 0.0060 | 0.9388 | not significant |
| $$X\_{2}X\_{3}$$ | 13.97 | 1 | 13.97 | 0.2428 | 0.6259 | not significant |
| $$X\_{2}X\_{4}$$ | 10.15 | 1 | 10.15 | 0.1764 | 0.6775 | not significant |
| $$X\_{2}X\_{5}$$ | 0.0128 | 1 | 0.0128 | 0.0002 | 0.9882 | not significant |
| $$X\_{3}X\_{4}$$ | 176.06 | 1 | 176.06 | 3.06 | 0.0908 | not significant |
| $$X\_{3}X\_{5}$$ | 223.03 | 1 | 223.03 | 3.88 | 0.0585 | not significant |
| $$X\_{4}X\_{5}$$ | 69.50 | 1 | 69.50 | 1.21 | 0.2807 | not significant |
| $$X\_{1}^{2}$$ | 109.77 | 1 | 109.77 | 1.91 | 0.1777 | not significant |
| $$X\_{2}^{2}$$ | 1008.32 | 1 | 1008.32 | 17.53 | 0.0002 | significant |
| $$X\_{3}^{2}$$ | 2372.71 | 1 | 2372.71 | 41.26 | < 0.0001 | significant |
| $$X\_{4}^{2}$$ | 717.71 | 1 | 717.71 | 12.48 | 0.0014 | significant |
| $$X\_{5}^{2}$$ | 1508.49 | 1 | 1508.49 | 26.23 | < 0.0001 | significant |
| Residual | 1667.88 | 29 | 57.51 |  |  |  |
| Lack of Fit | 1469.04 | 22 | 66.77 | 2.35 | 0.1241 | not significant |
| Pure Error | 198.84 | 7 | 28.41 |  |  |  |
| Cor Total | 22686.38 | 49 |  |  |  |  |

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**Fig. S2.** Comparison of experimental and predicted response $Y\_{1}$ (%) (a), Diagnostics and model graphs for pulp yield: normal plot of residuals (b), residuals versus predicted (c), residuals versus run numbers (d).

Contact me if you have any questions.