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Application of Full Factorial Design for Uranium Extraction from High Strength Commercial Phosphoric Acid using Organic Solvents

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Abstract: Uranium extraction from high strength phosphoric acid, 45 % P_2O_5, has been investigated using organic solvent; D_2EHPA & TOPO mixture in kerosene under various experimental conditions in order to optimize the extraction process. Three factors (D_2EHPA & TOPO concentration, aqueous/ organic phase ratio, and reaction temperature) at two value levels were studied. The factorial design analysis was performed in order to identify the main and the interaction effects of the various factors. The obtained results shown that, at 95% confidence intervals, D_2EHPA & TOPO concentration, aqueous/ organic phase ratio, reaction temperature and D_2EHPA & TOPO concentration- aqueous/ organic phase ratio interaction are statistically significant to uranium extraction process. The optimum conditions have been determined as, 1.0 M D_2EHPA & 0.25 M TOPO mixture in kerosene, shaking time of 4 min, temperature 30 °C, and aqueous/ organic phase ratio (R aq / $_{org}$) equal 4. Under these optimum conditions, the overall uranium extraction efficiency performance is 88.3 %.

***Keywords**:* Full factorial design, uranium, Extraction, High strength, Phosphoric acid, Organic solvents.

1. INTRODUCTION

The world is facing an unprecedented energy challenge. Global energy demand is expected[1] to rise by over

50 % by 2040. The urgent need to reduce greenhouse gas emissions will require that much of this growth is supplied by low-carbon energy sources. Nuclear energy has unique qualities that make it an essential part of the low-carbon energy mix[2]. In tandem with the anticipate growth in nuclear energy, uranium requirements will also increase sharply in future[3]. This requires looking to all options available for supply of uranium – the conventional and unconventional resources. The most abundant unconventional uranium resources are seawater, and phosphate rock deposits[4].Phosphate rocks represent one the most important unconventional uranium resource in the world[5]. Uranium content of phosphate rock varies from 20 ppm to as high as 500 ppm. Several studies have reported an average uranium concentration is generally close to 100 ppm in most phosphate rocks. In April 2015, UDEPO reports 13.8 million t U of uranium estimated in phosphate rock deposits[6,7]. Phosphate deposits are classified into two main categories: igneous phosphate rocks (13%) as found in Russia, South Africa, Brazil and sedimentary phosphate rocks (87%) as found in Morocco, Algeria, Jordan, Egypt, and U.S.A[8]. The phosphate minerals in both types of ore are of the apatite group, of which the most commonly encountered variants are; Fluorapatite $Ca_{10}(PO_4)_6$, $(F, OH)_2$ and Francolite $Ca_{10}(PO_4)_{6-x}$, $(CO_3)_x$ $(F, OH)_{2+x}$.

The most commonly used process for the production of phosphoric acid is: thermal and wet-process. The thermal process produces a pure acid with huge energy consumption. The wet-process involves reaction of phosphate rock with an acid (mainly sulfuric acid). During the treatment of rock phosphate with sulfuric acid, about 80 – 90 % of the total uranium content present in the rock matrix is solubilized[9].Although several methods such as ion-exchange[10], membrane separation[11] and precipitation[12] have been investigated, solvent extraction alone has been found to be a successful process for industrial recovery of uranium from commercial di-hydrate phosphoric acid since the middle of the last century[13].It has been estimated that uranium from rock phosphate sources might cover around 20% of world demand. However, factors like the price of uranium in international markets, its content in rock phosphates, plant capacity, and its smooth running affect the process of recovery of uranium[14]. Table 1 gives an overview of plants commissioned for uranium recovery from phosphoric acid at various places during different periods [15].

Table (1): Summary of uranium recovery from phosphoric acid[15]

Company		Process	Capacity t/y P_2O_5	Capacity lb/y U_3O_8	Start	Close
Blockson	IL	Precipitation	100000	80000	1952	1961
IMC	FL	OPPA	100000	80000	1955	1961
IMC	FL	DEPA-TOPO	1700000	1360000	1980	1992
US Phosphoric	FL	OPPA	200000	160000	1955	1961
Gardinier		Revised	450000	360000	1979	1982
URC/WR Grace	FL	OPAP	330000	264000	1976	1980
WMC/Farmland	FL	DEPA-TOPO	450000	360000	1978	1981
Freeport/Agrico	LA	DEPA-TOPO	950000	760000	1978	1998
Freeport/Agrico	LA	DEPA-TOPO	540000	432000	1980	1998
CFI	FL	DEPA-TOPO	950000	760000	1980	1992
CFI	FL	DEPA-TOPO	600000	480000	1980	1985
ESI/Western Coop	Canada	OPAP DEPA-TOPO	110000	88000	1980	1981
Chemie Rupel	Belgium	DEPA-TOPO	140000	112000	1980	1998
China Phosphate	Taiwan	DEPA-TOPO	33000	26400	1981	1985
SOM	Iraq	DEPA-TOPO	90000	72000	1984	1991

The industrially applied processes as well as most of the research works carried so far have actually been applied upon uranium extraction from dihydrate phosphoric acid (28–32 % P_2O_5). The knowledge of extracting for extraction from weak phosphoric acid does not have direct relevance on the selection of the extracting for extraction from strong acids (≈ 45 % P_2O_5)[16,17]. This made it difficult to provide extraction systems for strong phosphoric acids. In this regards, the objective of this work is to investigate the uranium extraction from high strength phosphoric acid, 45 % P_2O_5, by organic solvent; D_2EHPA & TOPO mixture in kerosene. Therefore, Design of Experiments methodology by way of fractional factorial designs (2^3) has been applied to investigate the effect of different variables on uranium extraction process.

2. EXPERIMENTAL

2.1. Raw Materials: All reagents used were of analytical reagent grade except D_2EHPA and TOPO, manufactured by Aldrich AG, were of a commercial grade and used without purification. Kerosene was obtained from Misr petrol. Ltd., Egypt. Uranium concentration was determined by ICP and titrimetric method using the Modification of Davies & Gray method[18]. Commercial phosphoric acid under study was produced from Abu Zaabal Company for Fertilizer and Chemical Materials (AZFC), its chemical composition is given in Table (2).

Table 2: Chemical analysis of commercial phosphoric acid produced from AZFC.

Component	Concentration
P_2O_5	≈ 45.0 %
Ca	0.44 %
SO_4^{--}	5.84 %
SiO_2	0.96 %
F	1.20 %
Fe	2.40 %
U	60 ppm

2.2. Pre-treatment: Prior to extraction process, the crude acid was subjected to the following treatment: first cooling down to room temperature (25 ± 1°C), then treated with clay for suspended solid particles removal, after that treating with granular activated carbon in order to remove soluble organic matter and finally oxidation[19] with hydrogen peroxide till EMF > 450 mv.

2.3. Procedure: The uranium extraction investigation was carried out by contacting the aqueous phase (45% P_2O_5 green phosphoric acid) with the organic phases (D_2EHPA-TOPO mixture in kerosene) in a separatory funnel by mechanical shaking in a thermostated water bath. After the desired extraction time, the two phases were let to separate. The concentration of uranium in the aqueous phase before and after extraction was determined also the distribution ratio D and the extraction percent E % were calculated as the following;

$$\mathbf{D} = \frac{\text{Concentration of iron in aqueous phase}}{\text{Concentration of iron in organic phase}} \ \mathbf{X} \ \frac{\text{Volume of organic phase}}{\text{Volume of aqueous phase}}$$

$$E\,\% = \frac{W - W_1}{W} \times 100$$

2.4. Design of experiments: The statistical design of experiments (DOE) method is an efficient procedure for planning experiments so that the data obtained can be analyzed to yield valid and objective conclusions. One-factor-at-a-time experimental designs are often expensive and time consuming, and do not frequently consider the interactive nature of various independent factors that would otherwise impact the results[20].

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Application of experimental design is the most effective way to identify and optimize the significant factors, and to achieve a competent result by a few experimental trials. Therefore, the experimental design can be defined as an approach to solve the problem systematically and, it is applied to collect data and to analyze data for obtaining information-rich results[21]. Optimum and valid results with a minimum effort, time and resources are the primary objectives of applying the experimental design in an analytical process[22-24].

The most widely used kind of experimental design, to estimate main effects as well as interaction effects, is the 2^p factorial design in which each variable is investigated at two levels[22]. Based on analysis results, additional runs might be required. Among "2 level" methods, the "Central Composite Design" is favored by many scientists where several runs are performed at the midlevel of all factors (variables).

3. RESULTS AND DISCUSSIONS

In regards to pre-experiments, three factors, namely, D_2EHPA & TOPO concentrations, aqueous/ organic ratio, and temperature at one constant factor (time) were chosen as controlled factors. The experimental factors are evaluated at two levels, low (denoted as −1), high (denoted as +1, and midlevel denoted as 0), as shown in Table 3. The held constant factor (time) may have some effect on the response, but was not of interest in the current study; so it was held constant at a specific level (4 minutes). The experiment order was randomly to avoid systematic errors. The results are analyzed with the Design Expert 10.0.4.0 software, and the main effects and interactions between factors were determined. The uranium extraction efficiency was taken as the measured response.

Table 3: The levels of experimental factors for the full factorial design

Factors	Coded variables	Low level (-)	High level (+)	Mid-level (0)
HD & T mixture concentration	A	0.6 M HD & 0.15 M T	1.0 M HD & 0.25 M T	0.8 M HD & 0.20 M T
Aqueous/ organic phase ratio	B	2	4	3
Temperature, ^{o}C	C	20	50	30

3.1. The significant parameters: To evaluate the influence of independent variables on the dependent variable, a factorial design experimental plan with high level and low level (–1 and +1), the levels of controlled variables[20] was used. For 2k factorial designs, it is assumed that the response is close to linear over the range of the factor levels. However, linearity assumption is often violated in practice. In this case, it is necessary to include one or more runs where all factors are set at their midpoint. The addition of center points to design allows the researcher to check whether the linearity of the effects is a reasonable assumption or whether quadratic terms should be added to the model. In this regard, the experimental plan involved running 8 tests and 3 replications of the center points in random order to determine uranium extraction efficiency from high strength phosphoric acid. The experiments matrix of this design and the low grade dissolution efficiency were performed in **Table 4**.

According to the obtained results from Table 4, it is clear that experiment number 4 shows the highest uranium extraction efficiency (88.37 %) which represents the optimal uranium extraction conditions; 1.0 M D_2EHPA & 0.25 M TOPO organic solvent mixture, aqueous/ organic phase ratio of 4 and temperature of 30 ^{o}C. Moreover, experiments number 6, 8, and 9 also represent the second highest extraction efficiency (79.07

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%). On the other hand, experiments number 1 and 2 are representing the lowest uranium extraction efficiency (65.12 %).

Table 4: Design matrix of the 2^3 full factorial design

Run #	(HD & T) Concentration, M		A/ O ratio		Temperature		%
1	-1	(0.6 & 0.15)	-1	2	-1	30	65.12
2	1	(1.0 & 0.25)	-1	2	-1	30	65.12
3	-1	(0.6 & 0.15)	1	**4**	-1	30	72.09
4	1	(1.0 & 0.25)	1	**4**	-1	30	88.37
5	-1	(0.6 & 0.15)	-1	**2**	1	50	75.56
6	1	(1.0 & 0.25)	-1	2	1	50	79.07
7	-1	(0.6 & 0.15)	1	4	1	50	72.09
8	1	(1.0 & 0.25)	1	4	1	50	79.07
9	0	(0.8 & 0.2)	0	3	0	40	79.07
10	0	(0.8 & 0.2)	0	3	0	40	76.74
11	0	(0.8 & 0.2)	0	3	0	40	74.42

The effects of the experimental factors and their interactions influence the uranium extraction from high strength phosphoric acid are summarized in Table 5. The positive values of these effects reveal that the increase of these parameters increased extraction efficiency. Conversely, negative values of the effects decreased the response (extraction efficiency %).

Table 5: Estimated effects and coefficients for uranium extraction

	Term	Stdized Effect	Coefficient Estimate	Sum of Squares	% Contribution
	Constant		74.56		
Model	A-Concentration	6.68	3.35	89.58	20.17
Model	B-A/O ratio	6.69	3.34	89.45	20.14
Model	C-Temperature	3.77	1.89	28.46	6.41
Model	AB	4.94	2.47	48.76	10.98
Model	AC	-1.45	-0.72	4.19	0.94
Model	BC	-8.42	-4.21	141.88	31.95
Model	ABC	-3.2	-1.6	20.51	4.62
Model	Curvature	2.28		10.39	2.34
Error	Lack of Fit			0	0
Error	Pure Error			10.81	2.43

From the obtained results it is clear that, both of D_2EHPA & TOPO concentration and aqueous/ organic phase ratio had the greatest positive effect on extraction efficiency % (6.68), followed by the D_2EHPA & TOPO concentration- aqueous/ organic ratio interaction (4.94), and temperature (3.77). This means that, the

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increase in these factors level leads to increase the uranium extraction efficiency. On the other hand, it is clear that the aqueous/ organic ratio-temperature interaction has the greatest negative effect on the extraction efficiency (-8.42) followed by D_2EHPA & TOPO concentration- aqueous/ organic ratio-temperature interaction (-3.2), and D_2EHPA & TOPO concentration-temperature interaction (-1.45), which means that these factors level should be at the lowest value. The obtained results confirm the main advantage of the 2^k factorial design compared to the One-factor-at-a-time, where it show the effects main variable and also the effect of variables interactions. The three observed recoveries at the center were 79.07 %, 76.74 %, and 74.42 % (Table 4). The average of these three center points is 76.74 %. The average of the 8 runs for base design (Table 4) is 74.56 %. Since these two averages are almost similar, it is assumed that the curvature effect is low (2.28).

The investigation of uranium extraction from high strength phosphoric acid using D_2EHPA & TOPO mixture in kerosene by One-Factor-At-a-Time methodology clear that, both of aqueous/ organic phase ratio and reaction temperature have negative effect on the extraction efficiency. However, studying the uranium extraction process using full factorial designs shows that both of aqueous/ organic phase ratio and reaction temperature have positive effect on the extraction efficiency[19-25]. In addition, the obtained results confirm the main advantage of the 2^k factorial design compared to the One-factor-at-a-time approach, where it show the effects of main variables and also the effect of variables interactions.

The normal probability plot often provides an effective way of helping with the selection[20]. In this regards, the estimates of main effects of factors, at the same time with their interaction terms, are shown on a normal probability plot of effects (Figure 1). All effects which are insignificant are normally distributed with mean zero and variance σ^2, and tend to fall along a straight line on the plot. In contrast significant effects have non-zero means and are located far away from the straight line. The greater the significant effect, the most away it is from the straight line.

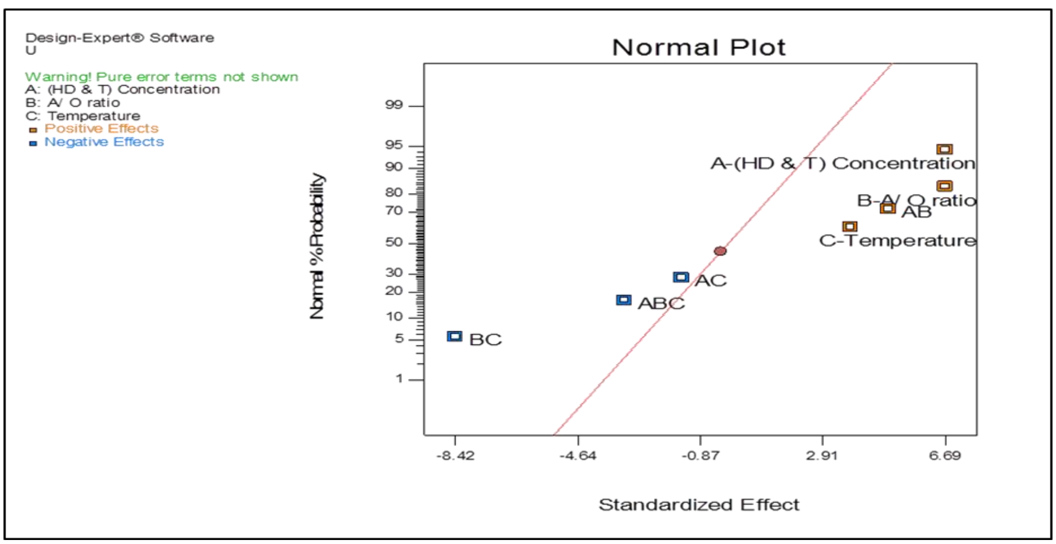

Figure 1: Normal probability plot of the standardized effects for uranium extraction

Figure 1 show that the main variables of A (D_2EHPA & TOPO concentration), B (aqueous/ organic phase ratio) and C (temperature), and the AB (D_2EHPA & TOPO concentration- aqueous/ organic phase ratio) interaction are statistically significant for uranium extraction efficiency. On the other hand, the effect lines attained for the other interactions- AC, BC, and ABC- reveal their insignificant effect on uranium extraction efficiency. The results obtained from the normal probability plot of effects (Figure 1) are confirmed with a Pareto chart as shown in Figure 2. The purpose of the Pareto chart is to highlight the most important among a set of factors. The horizontal line in the Pareto chart indicates the minimum statistically significant effect magnitude for 5 % significance level, while the vertical column lengths are proportional to the degree of significance for each effect. Any effect or interaction that exceeds the horizontal line (Bonferroni limit) is considered significant.

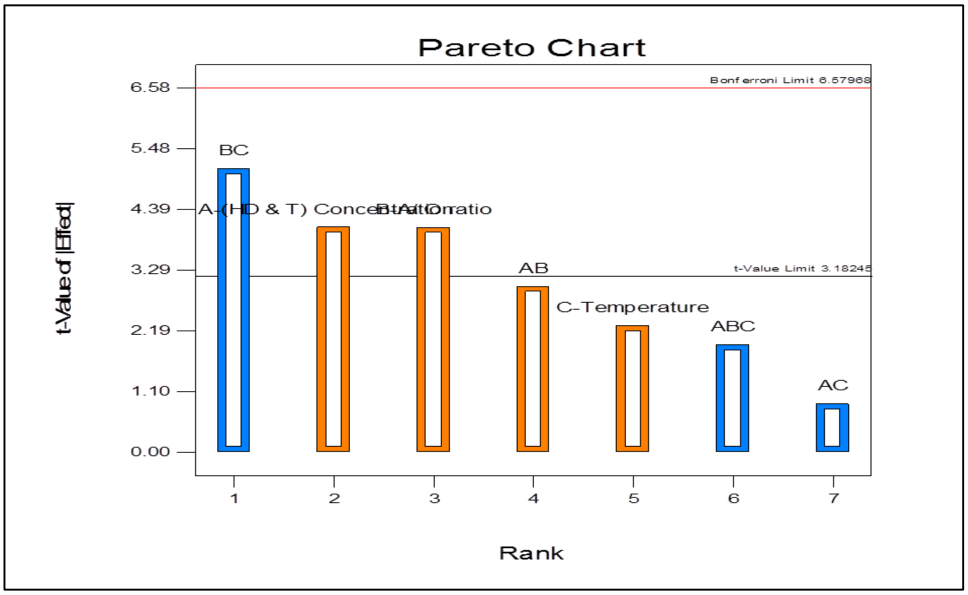

Figure 2: Pareto Chart of the Standardized Effects.

From the Figure it is clear that, the sequence of the significant main and interaction effects with respect to decreasing influence on uranium extraction efficiency was in agreement with that obtained from the normal probability plot of standardized effects, that is B C > A > B . Analysis of the individual factors on the Pareto chart showed that HD & T concentration, and A/O phase ratio were statistically significant since they overshot the critical value line. In regards to the obtained results, a normal first order polynomial model (fitted model) between significant factors and the response was developed to illustrate the dependence of the response on the significant factors for uranium extraction investigation. The model is expressed below as:

$$Y = b_o + b_1A + b_2B + b_3C + b_{12}AB + b_{13}AC + b_{23}BC + b_{123}ABC \quad (1)$$

Where Y = the leaching percentage; b = model coefficients of all corresponding main and interaction factors; and A, B, and C = dimensionless coded factors for D_2EHPA & TOPO concentration, aqueous/ organic ratio, and temperature respectively. The coefficients of equation (1) are presented in **Table 5**.

$$Y = 75.16 + 3.35 * A + 3.34 * B + 1.89 * C + 2.47 * AB - 0.72 * AC - 4.21 * BC - 1.60 * \mathrm{ABC} \quad (2)$$

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. In equation 2, the positive sign of coefficients for main effects A, B, C, and the interaction AB indicate their synergistic effects on uranium extraction percent while the negative sign of coefficient for AC, BC, and ABC interactions denotes an antagonistic effect. The size of regression coefficients in equation 2 denotes the degree of significance of each independent variable which, in the order of decreasing significance with respect to the influence on extraction %, is A≈B> AB > C. In addition, the negative signs in the variables of the prediction model equation indicate that in order to maximize uranium extraction, these factors must be kept at low levels. The positive signs mean that the factors must be kept at high levels. The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. Equation (3) in terms of actual factors:

$$Y = 75.16 + 3.35 * \text{HD \& T concentration} + 3.34 * \text{A/O ratio} + 1.89 * \text{temperature} + 2.47 * \text{HD \& T concentration} * \text{A/O ratio} - 0.72 * \text{HD \& T concentration} * \text{temperature} - 4.21 * \text{A/O ratio} * \text{temperature} - 1.60 * \text{HD \& T concentration} * \text{A/O ratio} * \text{temperature} \quad (3)$$

The Statistical Analysis for the Proposed Model: Analysis of variance (ANOVA) for the experimental data of uranium extraction for 2^3 full factorial design has been performed to measure the adequacy of the fitted model, as shown in Table 6. The null hypothesis stating that the main effects, interactions, and the curvature equal to zero was tested by using and *F-test*. The small *P* values (<0.05) mean that not all the main effects and interactions are zero at the 5 % significance level. Curvature term with *P* value lower than 0.05 indicates that there is curvature in the fitted data, and the response at the center point will be either higher or lower than the fitted value of the factorial (corner) points. The obtained results show that, According to ANOVA results, the main effects of all factors (A, B and C), their two-way (AB, BC and CA) and three-way (ABC) interaction effects are statistically significant: $P < 0.05$.

Table 6: Analysis of variance for uranium extraction

ANOVA for selected factorial model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	422.83	7	60.4	8.55	0.0427	significant
A-(HD & T) Concentration	*89.58*	*1*	*89.58*	*12.68*	*0.0378*	
B-A/ O ratio	*89.45*	*1*	*89.45*	*12.66*	*0.0379*	
C-Temperature	*28.46*	*1*	*28.46*	*4.03*	*0.1384*	
AB	*48.76*	*1*	*48.76*	*6.9*	*0.0785*	
AC	*4.19*	*1*	*4.19*	*0.59*	*0.4973*	
BC	*141.88*	*1*	*141.88*	*20.08*	*0.0207*	
ABC	*20.51*	*1*	*20.51*	*2.9*	*0.187*	
Residual	21.2	3	7.07			
Lack of Fit	*10.39*	*1*	*10.39*	*1.92*	*0.3*	*not significant*
Pure Error	*10.81*	*2*	*5.41*			
Cor Total	444.03	10				

S = 2.66, Mean = 75.16, Precision (Adeq) = 10.25, R-Sq = 95.23

***3.3. Influence of main factors on uranium extraction process*:**

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3.3.1. Effect of organic solvent concentration: Figure 3 illustrates the effect of D_2EHPA & TOPO concentration on uranium extraction from phosphoric acid, 45 %, P_2O_5. From the Figure it is clear that the increase in D_2EHPA & TOPO concentrations from 0.6 M D_2EHPA & 0.15 M TOPO to 1.0 M D_2EHPA & 0.25 M TOPO increase the uranium extraction efficiency. This behavior is result from the increase in the organic solvent concentration that will furnish the necessary molecules to form the complex to reach the equilibrium state. These results are similar to the results obtained form (OFAT) method, where at (OFAT) the organic solvent concentration was enhancing the uranium extraction process up to 0.8 M HD & 0.2 M T mixture and further increase in the organic solvent has slightly effect on the extraction process[19-25].

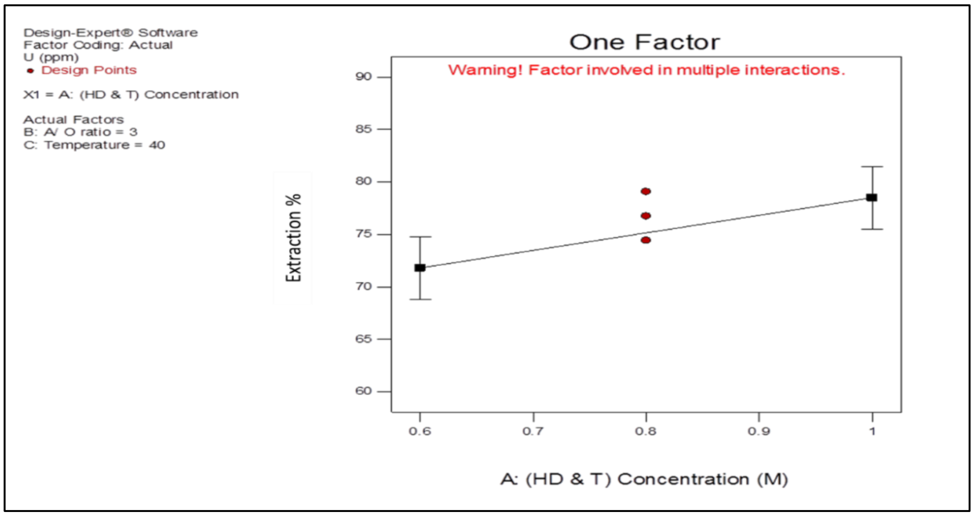

Figure 3: Effect of organic solvent concentrations on uranium extraction

3.3.2. Effect of aqueous/ organic ratio: Effect of aqueous/ organic ratio on uranium extraction is presented on Figure 4**.** The Figure implies that raising the aqueous/ organic ration from 2:1 to 4:1 improves the uranium extraction from high strength phosphoric acid. This behavior differs than the behavior obtained by (OFAT) method investigation, where OFAT methodology shows that by increase the aqueous/ organic ratio, the uranium extraction efficiency decreases[19].

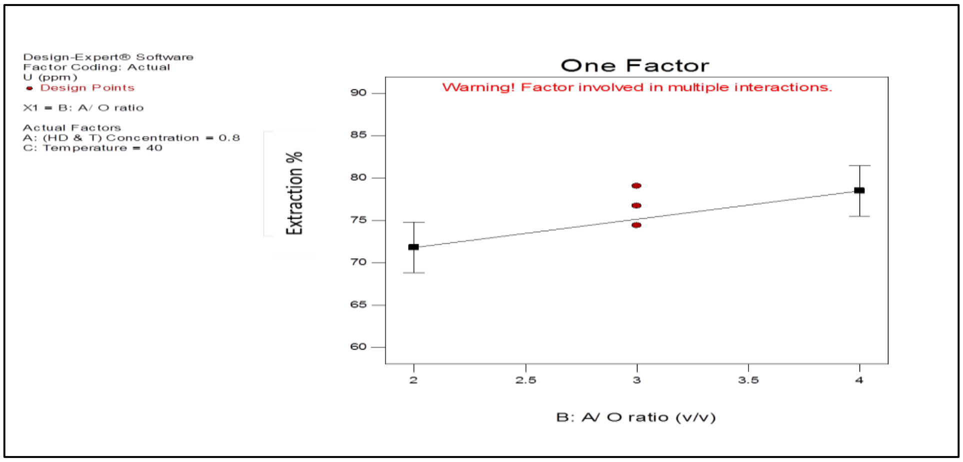

Figure 4: Effect of aqueous/ organic ratio on uranium extraction

3.3.3. Effect of reaction temperature: The effect of reaction temperature on uranium extraction from commercial phosphoric acid, 45 % P_2O_5, is obtained in Figure 5. The obtained results show that the increase in reaction temperature from 30 to 50 ^oC is enhancing the uranium extraction efficiency. This behavior differs than the behavior obtained by (OFAT) method investigation. The OFAT methodology shows that by increase the temperature, the uranium extraction efficiency decreases[19-25], however, the DoE methodology clear that the increase in aqueous/ organic ratio improving the uranium extraction efficiency.

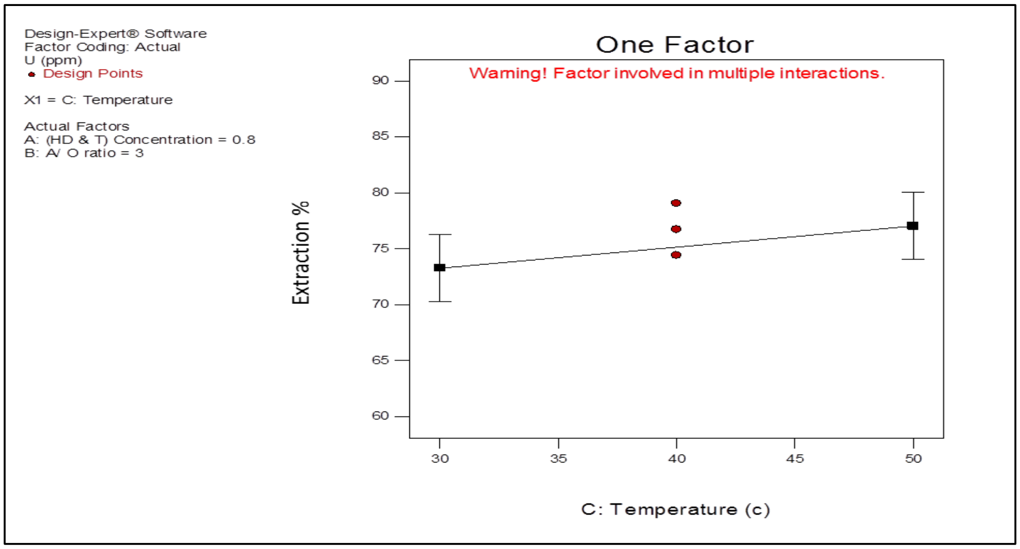

Figure 5: Effect of temperature on uranium extraction

3.4. Influence of factors interactions on uranium extraction process: One of main advantages of factorial design procedure is the ability to show the interaction between the different factors under the investigation. The interaction effect for the uranium extraction from phosphoric acid, 45 % P_2O_5, is shown in Figure 6 (I-III). Where if the lines of two factors are parallel, this means that there is no interaction. On the contrary, when the lines are far from being parallel, the two factors do not interact. Figure 8 shows the following interactions; (1) the interaction between D_2EHPA & TOPO concentration (A) and A/ O ratio (B) at constant temperature 40 ^oC; (2) the interaction between D_2EHPA & TOPO concentration (A) and temperature (C) at constant A/ O ratio of 3; and (3) the interaction between A/ O ratio (B) and temperature (C) at constant 0.8 M D_2EHPA & 0.2 M TOPO concentration. From the Figure, it is clear that the two lines is intersect in all the interaction plots, which indicated that the interaction of the main effects have statistically significant on the uranium extraction process.

The surface plot is used to show a graphic representation of how two factors can simultaneously affect the leaching efficiency together. In this regard, Figures 7 represent 3D plot for the effect of varying factors of A (D_2EHPA & TOPO concentration) and B (aqueous/ organic phase ratio) at constant temperature 30 ^oC. The Figures show that the maximum uranium extraction efficiency percent, 88.3 %, was achieved at 1.0 M D_2EHPA & 0.25 M TOPO mixture in kerosene and aqueous/ organic phase ratio equal 4.

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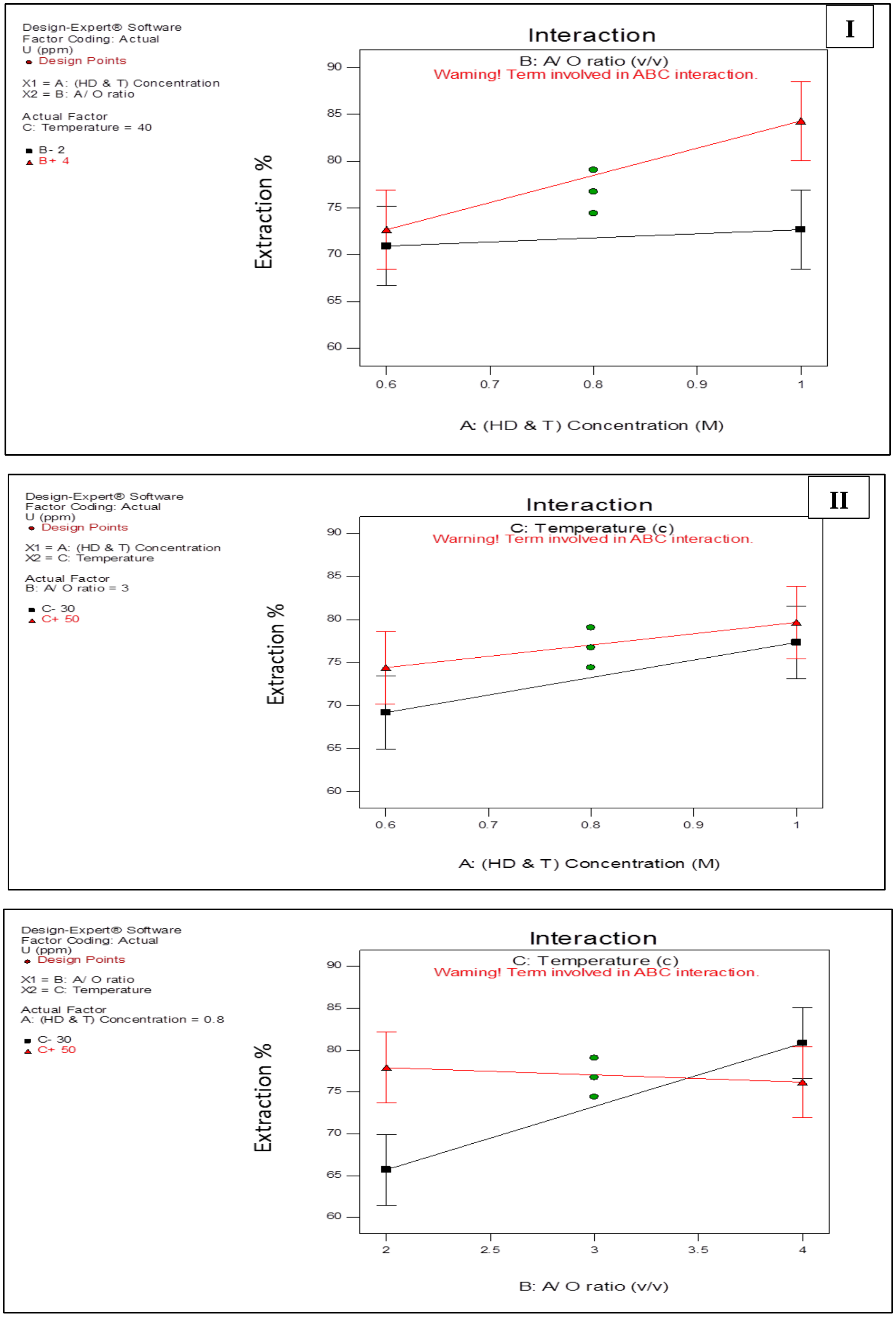

Figure 6 (I-III): Interaction effect plot for uranium extraction process. **III**

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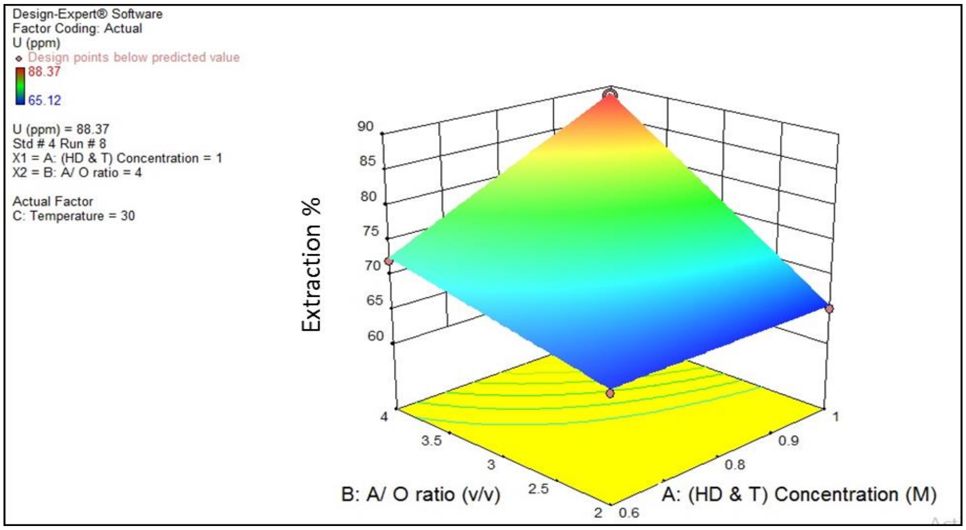

Figure 7: Surface plots of uranium extraction

3.5. Validation of the model: The experimental results of uranium extraction from phosphoric acid, 45 % P_2O_5, and the predicted results obtained using the re-fitted models for each level of the central composite design matrix are given in Figure 8. The predicted results are calculated by using Equation 3. The correlation of the linear regression is found to be $R^2 = 0.94$. Statistically, this means that 94.2 % of the sample variation can be explained by the independent variables. This indicates that the first-order polynomial equation (Eq. 3) is satisfactory for identifying the optimum level of the investigated factors. The validation of the model was achieved by performing additional experiments under the predicted optimal conditions; 1.0 M D_2EHPA & 0.25 M TOPO mixture in kerosene and aqueous/ organic phase ratio equal 4, reaction temperature 30 ^oC, and reaction time of 4 min. The two experiments yielded an average uranium extraction efficiency of 86.7 %, which clear that there is an agreement between the predicted and experimental results confirmed the experimental adequacy of the models and the existence of the optimal conditions.

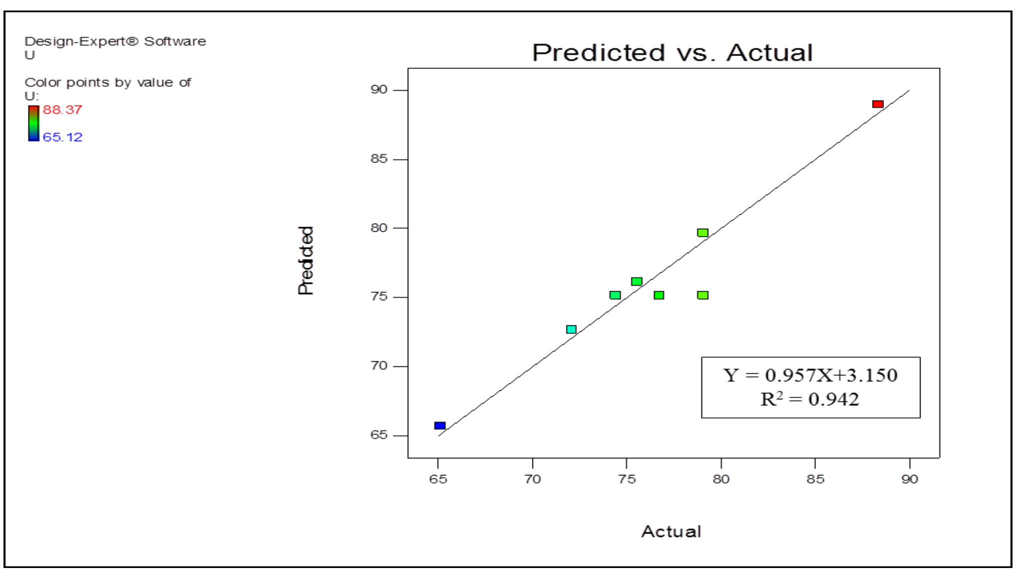

Figure 8: Scatter diagram of actual values versus predicted values by Equation (2)

3.6. Uranium Extraction Isotherm: To develop a process for counter-current extraction of uranium from high strength phosphoric acid, 45 % P_2O_5, the number of stages for uranium extraction should be evaluated. In this concern, the isotherm of uranium extraction process was investigated. Based on the aforementioned results, the following preferred conditions have been applied for studying the isotherm of uranium extraction from 45 % P_2O_5 green phosphoric acid; 1.0 M D_2EHPA & 0.25 M TOPO mixture in kerosene, shaking time of 4 min, temperature 30 ^oC, aqueous/ organic phase ratio ($R_{aq/org}$) equal 4, and ORP 650 mv. The results are shown in Table (7). From the obtained results, it is clear that 2 stages are sufficient for extracting about 90 % of the total uranium.

Table 7: The Mac-Cab Thiele data for uranium extraction process

No. of stages	Uranium concentration, ppm		D	Separation time, sec
	aqueous	organic		
Zero	80	zero	0	-
1	30	50	1.67	15
2	12	18	1.50	50
3	5	7	1.40	180

4. CONCLUSION:

The multivariate 2^3 full factorial methodologies is used to study the effect of D_2EHPA & TOPO concentration, aqueous/ organic ratio and reaction temperature on the uranium extraction from commercial high strength phosphoric acid using organic solvent; D_2EHPA & TOPO mixture in kerosene. The obtained results were statistically analyzed by using analysis of variances (ANOVA) to measure the adequacy of the fitted model. Based on the design of the experiments, the first order regression model has been constructed to approximate the uranium extraction process. According to the optimum conditions, the validity of the model has been verified, and the results clear that there is an agreement between the predicted and experimental data which confirm the experimental adequacy of the models and the existence of the optimal conditions.

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