Parameter selection of Polystyrene-Dietilenetriaminepenta acetate Resin Synthesis for the separation of rare Earth Elements by using Plackett-Burman Experimental Design

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RESEARCH ARTICLE

Parameter selection of Polystyrene-Dietilenetriaminepenta acetate Resin Synthesis for the separation of rare Earth Elements by using Plackett-Burman Experimental Design

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ABSTRACT:

The development of the separation method has an essential role in developing science and technology for the separation and purification of an element or compound from other mixtures based on differences in physical and chemical properties. This research is more focused on the selection parameters of polystyrene-based resin production using diethylene triamine penta-acetate (DTPA) light, which used as a prototype for improved scale production. The Plackett-Burman design was used to select variables that have significant influence in Methylaminopolystyrene-Diethylenetriaminepentaacetate (MAP-DTPA) resin synthesis. Eleven variables such as mol ratio of Methylamino Polystyrene and diethylene triamine penta-acetate ligands, solvent volume, reaction time, stirring rate, reaction temperature, total volume, reaction pH, incubation time, ammonia concentration, and the addition of methanol were carried out for the selection of parameters or variables in the process of MAP-DTPA resin synthesis through a statistical approach in studies for design experiments using Software Design Expert 9.0.6.2. Of the eleven variables in resin synthesis obtained, six variables have a positive influence on the yield ratio value (percent yield ratio) of MAP-DTPA resin are the mol ratio of MAP and DTPA, Stirring Rate, reaction temperature, total volume, degree of acidity, and ammonia concentration.

KEYWORDS: Resin, polystyrene, diethylene triamine penta-acetate, Plackett-Burman.

INTRODUCTION:

Rare Earth Element (REE) has an essential role in developing science and high-tech industries. In modern technology, REE is one of the supporting material classes for creating innovative goods and other special products. For this purpose, REE needed with high purity[1]. They have unique physical and chemistry properties and use for therapeutic and diagnostic in modern pharmaceutical and medicines such as high performance permanents magnets, magnetic resonances images scanning system, superconductors and laser technology[20]. The use of polystyrene as the resin has been developed to improve the efficiency of synthetic peptides as polymers with excellent mechanical stability, including those derived from polystyrene divinylbenzene[2]. Harris, 2011[3] reported the use of polystyrene methylamino resin (MAP) widely used in facilitating the purification of synthesis of polypeptides and oxytocin. Polystyrene can be activated so that one of

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the aromatic carbon chains can bind with electrophilic n-hydroxymethyl acetamide to form a white MAP resin[4]

This research is more focused on parameter choice to get polystyrene-based resins[21] using diethylene triamine penta-acetate (DTPA) ligand, which used as a prototype for improved scale production using the Plackett Burman experimental design. The research begins by selecting resin synthesis parameters by using an experimental design of all possible resin synthesis experiments from the initial stage to the final stage and determining what parameters are needed to assess whether the input variable responds automatically when combined, or not at all. The design of the experimental design that carried out is to design all the parameters that play a role in making resins from the initial stage to the final stage both low to high levels as required in making the sample matrix with the Plackett Burman experimental design so that it can be determined which parameters have positive relevance to result of resin yield ratio percentage. The optimization factor will be used as the optimum condition for making polystyrene resin (MAP) - DTPA. The use of secondary group REE sequential parameter selection was obtained from the Burman Plackett experimental design selection.

Experimental design has an important role as a way to maximize the information obtained. More than just a method, the experimental design also makes it easy for us to make choices on significant input and output variables. In the design of an experiment always produces risks that need us to find an input variable that has a significant effect on output and to plan overall experiments that are possible from an early stage and decide what data is needed to assess whether the input variable responds automatically when combined, or not at all[5].

Plackett-Burman experimental design has been applied out to conduct screening and optimization in determining the factors that influence the production process. Therefore, the purpose of this study is to apply the Plackett Burman experimental design to select parameters or variables that are likely to increase the acquisition value of the resin yield ratio in production because the number of experiments needed is small and will save time, money and chemicals[6].

MATERIALS AND METHODS:

Materials:

The chemicals used in this study were obtained from Sigma Aldrich and Merck such as hydrochloric acid, ethylene acid diamine tetra-acetic acid, diethylene triamine penta-acetic acid, nitric acid, oxalic acid, hydrogen peroxide, magnesium sulfate, methanol, methylene chloride, sodium hydroxide, sodium hypochlorite, sodium carbonate sodium sulfide, dimethylformamide, and pyridine.

Determination of variable for MAP– DTPA synthesis with the Plackett Burman experimental design:

Optimization of the synthesis parameters that are applied is done to determine the parameters that have a major influence on the yield value of the resin yield in the manufacture of MAP-DTPA resins by using the Plackett Burman experimental design using Design Expert 9.0.6.2 software. The number of experiments used for Plackett-Burman must meet 4n experiments, with n = 1, 2, 3, 4, etc. In this study used n = 3, so the number of experiments conducted was twelve (12), with the number of variables used was Eleven (4n-1). These variables are the mol ratio of Methylamino Polystyrene and Diethylenetriamine penta-acetate ligands, solvent volume, reaction time, stirring rate, reaction temperature, total volume, reaction pH, incubation time, ammonia concentration, and methanol addition. The addition of a dummy variable was carried out in an experiment to meet the Plackett-Burman requirements of eleven variables (4n-1) for twelve experiments (4n). In the eleven variables used for the Plackett-Burman experimental design, the determination of the upper limit (+1) and lower limit (–1) values is shown in Table 1.

Table 1. The determination of 11 variables on the experimental design of Plackett-Burman

No	Variable	Code	Unit	Limit	
				Lower (–1)	Upper (+1)
1	A mole ratio of MAP and DTPA	A	–	1:2	1: 1
2	Volume of Solvent	B	mL	2.5	5 mL
3	Reaction Time	C	Hour	3	6
4	Stirring Rate	D	RPM	300	600
5	Reaction Temperature	E	°C	25	60
6	Total Volume	F	mL	5	10
7	Acidity Level (pH)	G	–	3	6
8	Incubation Time	I	Minute	30	120
9	Concentration of Ammonia	H	Molar	0.05	0,1
10	Addition of Methanol	J	mL	5	10
11	Dummy	K	–	–1	(+1

Eleven variables were used to find out which variables had the main influence on the experiment. Then the eleven variables were included in the experimental design of Plackett Burman using Software Design Expert 9.0.6.2 with and without coding for the twelve experiments to be carried out shown in Table 2 and Table 3.

Table 2 Experimental design of Plackett-Burman for the synthesis of MAP-DTPA resin without coding

Run	**A:**	**B:**	**C:**	**D:**	**E:**	**F:**	**G:**	**H:**	**I:**	**J:**	**K:**	**R:**
	Mole ratio MAP-DTPA	Volume of Solvent	Reaction Time	Stirring Rate	Reaction Temperature	Total Volume	Acidity Level (pH)	Incubation Time	Concentration of ammonia	Addition of Methanol	Dummy	Yield Resin
1	1: 2	5	6	300	60	10	6	30	0.1	5	+1	Y_1
2	1: 2	2.5	6	300	60	10	3	60	0.5	10	– 1	Y_2
3	1: 2	5	3	600	60	5	6	60	0.5	5	– 1	Y_3
4	1 1	2.5	6	600	25	10	6	60	0.1	5	– 1	Y_4
5	1 1	2.5	3	300	60	5	6	60	0.1	10	+1	Y_5
6	1 :2	5	6	600	25	5	3	60	0.1	10	+1	Y_6
7	1 : 2	2.5	3	300	25	5	3	30	0.1	5	– 1	Y_7
8	1 : 1	5	3	600	60	10	3	30	0,1	10	– 1	Y_8
9	1 : 1	5	3	300	25	10	3	60	0.5	5	+1	Y_9
10	1 : 1	.5	6	600	60	5	3	30	0.5	5	+1	Y_{10}
11	1 : 1	5	6	300	25	5	6	30	0.5	10	– 1	Y_{11}
12	1 : 2	2.5	3	600	25	10	6	30	0.5	10	+1	Y_{12}

Table 3. Experimental design of Plackett-Burman for the synthesis of MAP-DTPA resin with coding

Run	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**R**
1.	– 1	+1	+1	– 1	+1	+1	+1	– 1	– 1	– 1	+1	Y_1
2.	– 1	– 1	+1	– 1	+1	+1	– 1	+1	+1	+1	– 1	Y_2
3.	– 1	+1	– 1	+1	+1	– 1	+1	+1	+1	– 1	– 1	Y_3
4.	+1	– 1	+1	+1	– 1	+1	+1	+1	– 1	– 1	– 1	Y_4
5.	+1	– 1	– 1	– 1	+1	– 1	+1	+1	– 1	+1	+1	Y_5
6.	– 1	+1	+1	+1	– 1	– 1	– 1	+1	– 1	+1	+1	Y_6
7.	– 1	– 1	– 1	– 1	– 1	– 1	– 1	– 1	– 1	– 1	– 1	Y_7
8.	+1	+1	– 1	+1	+1	+1	– 1	– 1	– 1	+1	– 1	Y_8
9.	+1	+1	– 1	– 1	– 1	+1	– 1	+1	+1	– 1	+1	Y_9
10.	+1	– 1	+1	+1	+1	– 1	– 1	– 1	+1	– 1	+1	Y_{10}
11.	+1	+1	+1	– 1	– 1	– 1	+1	– 1	+1	+1	– 1	Y_{11}
12.	– 1	– 1	– 1	+1	– 1	+1	+1	– 1	+1	+1	+1	Y_{12}

Parameter/variable selection for MAP–DTPA Resin synthesis with experimental design:

The selection and acquisition of variables that increase the acquisition of percent yield ratio of resin are further studied interactions between each factor with each other and determining variables that have a positive influence on making MAP-DTPA resin with the highest percentage of resin yield ratio. In the experimental design, Plackett Burman not only used the upper limit (+1) and the lower limit (-) but also involved the middle limit (0). Furthermore, ANOVA statistical tests will be performed to find out whether the results show significant values. Next, the prediction of the optimum value of each variable is determined to obtain the optimum percent yield ratio of resin.

RESULTS AND DISCUSSION:

Determination of Positive Variable for MAP–DTPA synthesis with the Plackett Burman experimental design:

Determination of variables that have a positive effect on response is determined using the coefficient calculation (b) for each variable in the experimental data using Plackett Burman's experimental design. The coefficient of the eleventh variable (b1, b2, b3, b4, b5, b6, b7, b8, b9, b10, and b11) that can be calculated in two ways, namely by using the classic method of multiplying each result with the value of each variable (+1 –1) for each experiment and divide by the number of experiments. For example, for MAP and DTPA mole ratio, the coefficient values are:

b1 = (–73,23–77,93–61,57+73,43+ 65,86–60,14–79,16+ 60,95+ 88,16+ 66,07+ 82,02– 82,23
= (2,23 / 12) = **+2,23**

Coefficient b1 shows a positive value, so it can be concluded that from an average of 12 experiments conducted in the acquisition of a resin yield percent value of 0.1858%. The higher if the MAP and DTPA mole ratio (variable A) are used increases from 1: 2 to 1: 1. This means that the use of the MAP and DTPA mole ratio in the reaction will increase the yield of the MAP – DTPA resin yield value. Likewise, the stirring rate, reaction temperature, total volume, acidity, and ammonia concentration increase the percentage yield of resin yield. For some negative coefficient (b) (solvent volume, reaction time, incubation time/rest time, and methanol addition) shows that increasing the value of each will not increase but decreases the yield of the percent resin yield. Calculation of the acquisition value of the percent yield of resin MAP-DTPA (R1) statistically according to the formula Y is:

$$Y = \beta o + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 + \beta_9X_9 + \beta_{10}X_{10} + \beta_{11}X_{11}$$

Where Y: response

X_i: a factor that influences the response

β : Intercept

Positive or negative effects of the eleven variables (mol ratio of MAP and DTPA (A), solvent volume (B), reaction time (C), Stirring Rate (D), reaction temperature (E), total volume (F), degree of acidity / pH (G), incubation time the (H), addition of methanol (I), ammonia concentration (J) and dummy (K, L) can be seen in Figure 1. shows the normal distribution graph for the eleven variables selected in making MAP-resin DTPA with the Plackett-Burman experimental design using Software Design Expert 9.0.6.2.

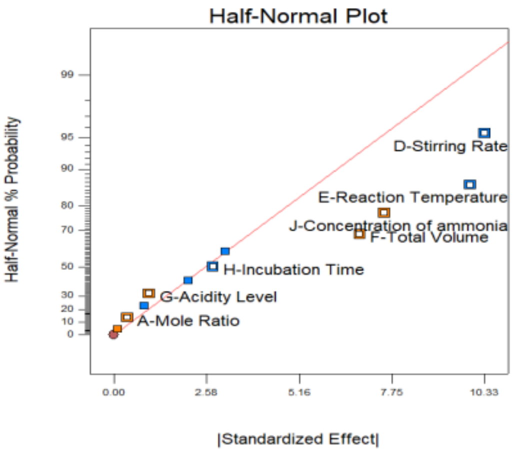

Figure 1 Normal distribution plot of 11 variables on variable determination for MAP-DTPA resin synthesis

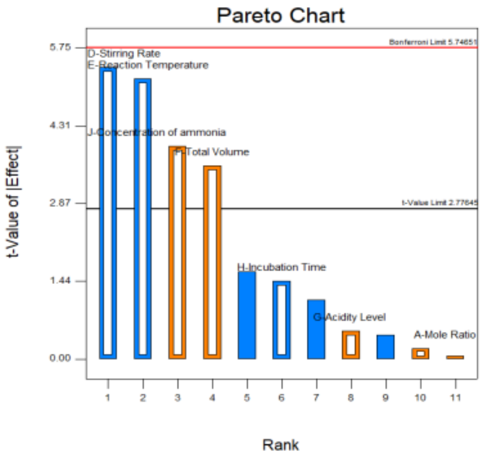

Figure 2. Pareto chart of 11 variables on variable determination for MAP-DTPA resin synthesis

The results show that for variables A (mol ratio MAP and DTPA), D (Stirring Rate), E (reaction temperature), F (total volume) G (acidity), and H (ammonia concentration) show a positive effect compared to variables B (DMF volume), C (reaction time), I (incubation time), J (addition of methanol) and K (dummy) which produce a negative effect on normal % probability. Pareto chart for eleven variables can be seen in Figure 2 shows that variables A, D, E, F, G, and H show positive results, while variables B, C, I, J, and K show negative results on the t-value on experiments conducted. So it can be concluded that the determination of the variables that increase the percent yield ratio of resin yield by using the Plackett-Burman experimental design is variable A would be the mol ratio of MAP and DTPA this is because one of the reactants must be given excess so that the compound formed maximally (in this reaction diethylene triamine penta-acetate is made excess), the second variable is D, namely the stirring rate, stirring is very influential on the reaction because the process of forming the MAP-DTPA resin will be maximal if stirring is carried out at an optimal speed, the third variable is E, namely the reaction temperature in this case the stirring reaction temperature is very influential on percent exchange yield ratio of resin. The fourth variable is F which is the total volume it relates to the concentration of reactants used, the fifth variable is G which is the degree of acidity, and the sixth variable is H is the ammonia concentration shows that the magnitude of the resin yield ratio is influenced by the concentration of ammonia used. Dummy is considered not very influential, and the dummy itself is a variable that has no direct effect in the experiment, such as the color of the laboratory coat, the color of the furniture in the experiment, and so on[5].

Determination of variable for MAP– DTPA resin synthesis with the experimental design

Determination of variables that give a positive value to the acquisition of percent yield of resin in the manufacture of MAP-DTPA was done using an experimental design done to see the interaction between each factor so that a mathematical model is obtained to determine the optimum variable used for making MAP-DTPA. In the design of this experiment, not only the upper (+1) and lower (-1) limits are involved, but the middle limit (0) is also used. This is because to determine which variables have a significant influence on the acquisition of response or the value of the percent yield of the MAP – DTPA resin cannot only use the upper and lower limits because the difference is too far and will produce values on one side only so that it gives a less response difference significant. Table 4 shows the six variables that increase the yield ratio of percent yield of MAP – DTPA resin.

Table 4. The gain of resin yield ratio value (R) and variable coefficient value, (b) of experiment result for MAP-DTPA resin synthesis by the experimental design of Plackett-Burman using Design Expert 9.0.6.2. Software

Run	A	B	C	D	E	F	G	H	I	J	K	R
1.	– 1	+1	+1	– 1	+1	+1	+1	– 1	– 1	– 1	+1	73.23
2.	– 1	– 1	+1	– 1	+1	+1	– 1	+1	+1	+1	– 1	77.93
3.	– 1	+1	– 1	+1	+1	– 1	+1	+1	+1	– 1	– 1	61.57
4.	+1	– 1	+1	+1	– 1	+1	+1	+1	– 1	– 1	– 1	73.43
5.	+1	– 1	– 1	– 1	+1	– 1	+1	+1	– 1	+1	+1	65.86
6.	– 1	+1	+1	+1	– 1	– 1	– 1	+1	– 1	+1	+1	60.14
7.	– 1	– 1	– 1	– 1	– 1	– 1	– 1	– 1	– 1	– 1	– 1	79.16
8.	+1	+1	– 1	+1	+1	+1	– 1	– 1	– 1	+1	– 1	60.95
9.	+1	+1	– 1	– 1	– 1	+1	– 1	+1	+1	– 1	+1	88.16
10.	+1	– 1	+1	+1	+1	– 1	– 1	– 1	+1	– 1	+1	66.07
11.	+1	+1	+1	– 1	– 1	– 1	+1	– 1	+1	+1	– 1	82.02
12.	– 1	– 1	– 1	+1	– 1	+1	+1	– 1	+1	+1	+1	82.23
b	**+2,23**	**-18,61**	**-5,11**	**-61,97**	**-59,53**	**+41,11**	**+5,93**	**-16,57**	**+45,21**	**-12,49**	**+0,63**	

The obtained percent yield ratio of MAP–DTPA resin produced (R1) was included in the experimental design table for the six variables: MAP and DTPA (A) mole ratio with optimal software value of 0.892, stirring rate (D) with optimal software value of 304.758 rpm, stirring temperature (E) with optimal software value of 25.29 °C, total volume (F) with optimal software value of 9,857 mL, Acidity degree (G) with optimal software value of 5.41 and ammonia concentration (H) with optimal value software for 0.49 M. From the acquisition of the resin yield percent value for each experiment, the subsequent acquisition of data is processed in software design expert 9.0.6.2. The results show that of the six variables, the effect of a significant increase in the acquisition of percent yield ratio of resin in the manufacture of MAP-DTPA resin with a response value estimated by the software is equal to 89.66%.

The percent yield ratio of the resin referred to in this study is a comparison of the amount (quantity) of resin produced or the results of the recovery from the MAP-DTPA synthesis process.

CONCLUSION:

Based on the results obtained by selecting parameters with the experimental design of Plackett Burman using Software Design Expert 9.0.6.2 for making MAP-DTPA resins, parameters that have a positive effect on the percent yield ratio of MAP-DTPA resins are MAP and DTPA mole ratios, stirring rates, reaction temperatures, total volume, degree of acidity, and concentration of ammonia with an optimal value based on successive software is 0.892; 304,758 rpm; $25,29^0$C; 9,857 mL; 5,41; and 0.49 M.

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