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Research Article

Foundational steps in crafting an effective process for synthesizing Sodium Diethyldithiocarbamate through the response surface method

Nguyen Thi Anh Hong*, Le Thi To Nhu

ABSTRACT

This study designed and optimized the reaction conditions for the synthesis of sodium diethyldithiocarbamate (DDTC) using the response surface method. A factorial design (FD) with three levels and two factors was applied. DDTC was synthesized at room temperature from carbon disulfide, diethylamine, and sodium hydroxide. The independent variables were the concentration (*X1*) and the molar equivalence ratio (*X2*) of the sodium hydroxide solution. The dependent variables were the reaction yield (*Y1*), product purity (*Y2*), and crystal melting point (*Y3*). To assess the effects of different combinations of these factors, various response surface graphs and contour plots were generated. The predicted values closely matched the experimental values for the optimized formulation, which were *X1* = 1.98 eq. and *X2* = 29.9%. The observed experimental results were as follows: *Y1* (%) = 78.44 ± 2.54; *Y2* (%) = 99.62 ± 0.1 and *Y3* (°C) = 93.85 ± 0.92. This study effectively demonstrated that using an experimental optimization model to determine optimal reaction conditions is a strategic approach to enhancing the synthesis of chemical compounds.

Key words: optimization, response surface method, sodium diethyldithiocarbamate

INTRODUCTION

For decades, extensive research on dithiocarbamates has been conducted to address their growing use in various fields, including chemistry, industry, and medicine [1–3]. Their applications extend beyond industrial and commercial sectors to the agricultural domain, where they are used as pesticides, herbicides, and fungicides [4]. Moreover, dithiocarbamates play a crucial role in a variety of industrial and commercial applications as biocides, as well as in household products and public health initiatives. While multiple methods for synthesizing N,N-dialkyl dithiocarbamate have been proposed that use different raw materials, such as secondary amines and dimethyl formaldehyde [5], an optimal synthesis process has remained elusive.

Recently, response surface methodology (RSM) [6] has gained significant attention for optimizing experimental outcomes in scientific research, particularly within the field of chemistry. To understand the effects of formula variables (independent factors) and the interactions among these factors on the response (dependent factors), factorial design (FD) is considered an effective surface method, particularly suitable for research involving a limited number of independent factors (i.e., fewer than three). Moreover, the experimental elements in this work were assessed at three distinct levels.

The objective of this study was to establish a procedure for synthesizing sodium diethyldithiocarbamate (DDTC) by employing FD in conjunction with a desired function. Additionally, the study evaluated the primary impacts of the formulation variables on three key responses: reaction yield, product purity, and crystal melting point.

MATERIALS AND METHODS

NMR spectra were recorded on a Bruker AM600 FTNMR spectrometer (Bruker, Karlsruhe, Germany) using TMS as an internal standard at the Institute of Chemistry - Vietnam Academy of Science and Technology, Hanoi, Vietnam. The crystal melting points were determined using a HINOTEK SGWX-4 melting-point apparatus with a microscope at Cantho University, Vietnam. Fourier transform infrared (FTIR) spectra were recorded on an FT/IR-4X spectrometer (JASCO, Japan).

Carbon disulfide 99% (CS_2) and diethylamine 99% (Et_2NH) were supplied by Tokyo Chemical Industry Co., Ltd., Japan. The sodium hydroxide solution 40% (extra pure) and sodium thiosulfate standardized solution (0.01 N) were obtained from Techmate Ltd., UK. Diethyl ether was supplied by Merck, Germany.

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All other chemicals were of analytical grade.

To prepare a 0.1 N iodine/KI solution, 40 g of potassium iodide (KI) was weighed into a 500-mL stoppered glass flask and dissolved in 100 mL of purified water. After the solution reached room temperature, 12.7 g of resublimed iodine (I_2) was added. The flask was stoppered, and the contents were mixed until the iodine had completely dissolved. The resulting solution was then quantitatively transferred to a 1-L volumetric flask, 3 drops of 37% hydrochloric acid (HCl) were added, and the solution was diluted to volume with purified water. Finally, the mixture was thoroughly mixed and transferred to a glass-stoppered, alkali-resistant, amber-colored bottle for storage.

Sample preparation method

Preparation of sodium diethyldithiocarbamate

The method for the preparation of DDTC is based on the reaction between NaOH, CS_2, and Et_2NH under different concentrations and molar equivalence ratios of the NaOH solution[7,8]. An exact amount of NaOH solution was added to the reaction vessel, which contained a magnetic rod. The vessel was in the water bath on the induction stove, and the reaction was performed at a stirring speed of 600 rpm. The temperature was monitored using a thermometer. Then, exactly 104.5 μL Et_2NH (10 mmol), which corresponds to 1 molar equivalent (1 eq.), was added to the reaction vessel. A further 610.4 μL CS_2 (1 eq., 10 mmol) was added dropwise to the mixture. These steps ensure that the temperature of the reaction solution does not rise by more than 5°C. After all of the CS_2 was added, the mixture was stirred for a further 15 minutes to allow the reaction to complete. The amount of NaOH solution used for each treatment is presented in Table 1:

Table 1: NaOH solution for preparing DDTC

Molar equivalent (Eq.)	Substrate (g)	Concentration (%)
1	8.000	5
1	2.667	15
1.5	4.000	15
2	5.333	15
1	1.333	30
1.5	2.000	30
2	2.667	30

The product crystallized immediately in the reaction solution at 0°C after 1 hour. It was then filtered under low pressure and washed three times with 0.5 mL of diethyl ether. The resulting product was a fish scale crystal with the formula $(C_2H_5)_2NCSSNa \cdot 3H_2O$. The melting temperature of this crystal was determined, and FTIR spectra and proton NMR spectra were obtained.

Factorial experimental design

To investigate and optimize the main, quadratic, and interaction effects of the formulation ingredients on the reaction yield, a two-factorial, three-stage FD was used. To determine the experimental error and precision of the experimental design, the FD required 8 experimental runs with 2 central points. A total of 8 experimental runs were created and analyzed using the Design-Expert software (version 13.0.5.0; Stat-Ease Inc., Minneapolis, MN, USA)[9]. The major response factors for evaluating the quality of the reaction, the reaction yield (Y_1), the product purity (Y_2), and the crystal melting point (Y_3), were also determined (Table 2). The actual and coded values according to the design for the selected factors are presented in Table 2 and Table 3. The results obtained for each response were fitted to a quadratic polynomial model represented by a nonlinear equation (1):

$$y = \beta_0 + \beta_1 X_1 Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2 + \beta_4 X_1^2 + \beta_5 X_2^2 \quad (1)$$

Here, y is the measured response, $\beta_0 - \beta_5$ are regression coefficients, and X_1 and X_2 are independent factors. The models were used to fit the experimental data and validated using ANOVA, lack-of-fit tests, and R^2 as measures of goodness of fit.

* Values taken from the literature[5].

The central (medium) level for the NaOH parameters in the experimental design (Table 2) was selected on the stoichiometry of the reaction involved in the formation of diethyldithiocarbamate (DDTC)[7,8]. According to the reaction equation, the molar requirement for NaOH is approximately 1 eq. However, previous studies have shown that using up to 2 eq. of NaOH can be effective without causing side reactions. Therefore, the NaOH equivalent was varied within this practical range, with 1.5 eq. selected as the center point. Regarding NaOH concentration, a range of 5% to 30% (w/v) was chosen to explore both dilute and concentrated conditions. A concentration of 15% was selected as the center level of the model, representing a balanced midpoint for evaluating its effects on the synthesis efficiency.

To optimize diverse responses, the parameters must

Table 2: Variables used in the factorial experimental design

Independent variables	Unit	Levels, actual (coded)		
		Low (−1)	Medium (0)	High (+1)
X_1: Molar equivalent of NaOH solution	Eq.	1	1.5	2
X_2: Concentration of NaOH solution	%	5	15	30
Dependent variables			Goals	
Y_1: Reaction yield	%		Maximize	
Y_2: Product purity	%		>99.5	
Y_3: Crystal melting point	°C		92–98*	

be closely related. It is highly unlikely that values that optimize the effects of one response will have the same effect on a second response. Therefore, the most favorable trade-off zone for each reaction that does not cause deviations must be found. In the present study, all responses were optimized simultaneously with the desirability function using the numerical optimization method introduced by Derringer and Suich in the Design-Expert software. Recently, several publications have reported on the desirability function approach for optimizing multiple responses.

Product purity

Preparation of the 0.08 N DDTC (X) solution: To prepare the 0.08 N DDTC solution, 4.506 g of synthesized DDTC was placed in a 50-mL glass-stoppered flask and completely dissolved in 25 mL of purified water. The solution was quantitatively transferred into a 250-mL volumetric flask and diluted to 250 mL with purified water. This final solution was stored in an amber-colored, alkali-resistant glass bottle.

Exactly 10 mL of the 0.08 N DDTC (X) solution was pipetted into a 125-mL Erlenmeyer flask containing a magnetic rod, and 5 mL of diethyl ether was added. Exactly 10 mL of the 0.1 N I_2/KI solution was added to this Erlenmeyer flask, along with 5 drops of starch solution. The solution was stirred magnetically at 600 rpm at room temperature for 5 minutes to allow complete reaction of the DDTC and the I_2. The stirring speed was kept constant, and the excess I_2 was titrated with 0.01 N $Na_2S_2O_3$ solution until the solution became transparent, forming thiuram disulfide $(S_2CNEt_2)_2$, which separated from the solution. The reaction equations of the titration process are[10,11]:

$$2NaS_2CNEt_2 + I_2 \rightarrow (S_2CNEt_2)_2 + 2NaI$$

$$2Na_2S_2O_3 + I_{2(excess)} \rightarrow Na_2S_4O_6 + 2NaI$$

According to the above reaction equations, the molar equivalent of DDTC (X) corresponds to the molar equivalent of $Na_2S_2O_3$, and both molar concentrations correspond to the stoichiometric concentration (C_N=C_M):

$$C_{I_2}V_{I_2} = C_XV_X + C_{Na_2S_2O_3}V_{Na_2S_2O_3}$$

$$\text{So, } C_X = \frac{10\times0.1-V_{Na_2S_2O_3}\times0.01}{10}\ (N)$$

$$\textit{The product purity}\ (\%) = \frac{C_X}{0.08}\times100$$

Table 3: Experimental matrix and observed responses from randomized runs in the FD

Run	Independent variables		Dependent variables		
	X_1	X_2	Y_1	Y_2	Y_3
1	−1	−1	17.75	99.50	94
2	−1	0	44.24	99.63	93
3	0	0	57.99	99.67	94
4	1	0	64.65	99.50	93
5	−1	1	73.53	99.50	94
6	0	1	78.41	99.50	93
7	1	1	80.78	99.58	94
8	0	0	51.63	99.63	94

RESULTS

Structure confirmation

The structure of the synthesized product was characterized by proton NMR and FTIR spectra and compared with the data in the spectral library (Figure 1) of the National Institute of Advanced Industrial Science and Technology, Japan (AIST).

Statistical analysis

The reaction efficiency of DDTC synthesis depended on two factors: the concentration and the molar equivalent of the NaOH solution. As both factors increased, the reaction efficiency decreased. This decline in reaction efficiency with decreasing NaOH concentration can be attributed to the abundance of the solvent (water), which resulted in the dissolution of a significant amount of the product. The release data were analyzed at a statistical significance level of

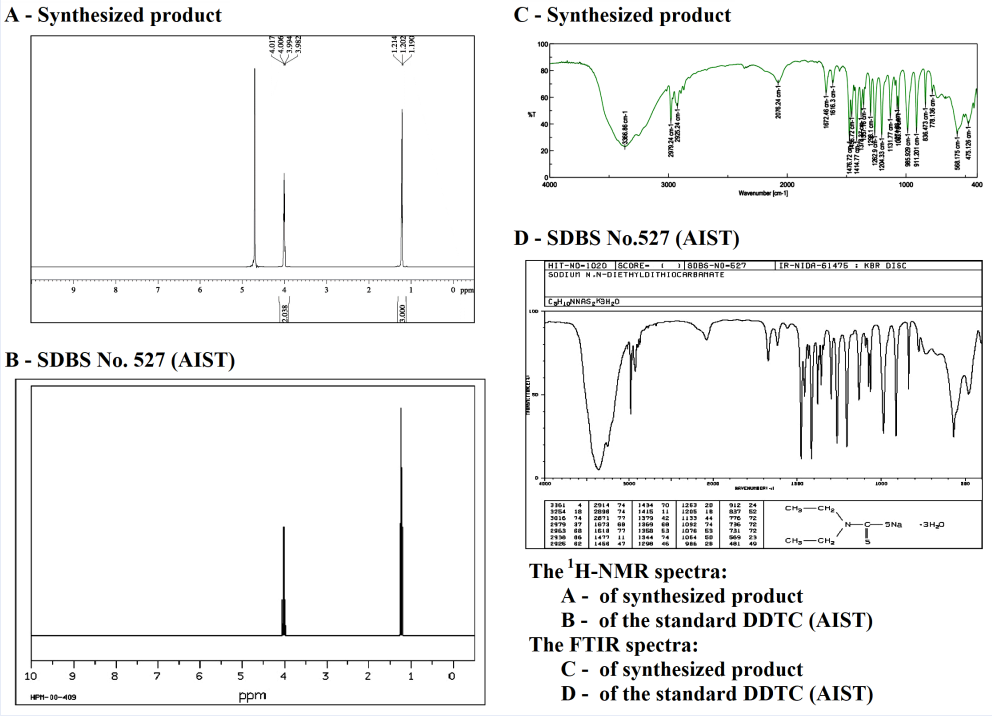

Figure 1: ^{1}H-NMR and FTIR spectra of synthesized product and reference DDTC

$\alpha = 0.05$, and the results were deemed statistically significant because the p-value remained below 0.05 in all instances.

A 2-factor, 3-stage fractional design requires 8 trial runs. Based on the experimental runs generated through various combinations of the factor levels, a series of experiments was conducted. Table 3 presents the experimental matrix from the randomized runs for the independent variables and the corresponding observed responses. Out of the batches analyzed, three achieved a percent reaction yield *(Y_1)* exceeding 70%, with the overall range of Y_1 being 17.8% to 80.8%. In comparison, the range of the product purity *(Y_2)* was 99.50% to 99.67%, while the crystal melting point *(Y_3)* remained almost constant, ranging from 93 to 94°C. Consequently, when conducting the ANOVA for the responses Y_2 and Y_3, the Mean model was selected, yielding intercepts of 99.56 and 93.63, respectively.

The response Y_1 was analyzed using the two-factor interaction (2FI) model, and the adequacy of this model was assessed through ANOVA, lack-of-fit tests, and the coefficient of determination (R^2). The results of the lack-of-fit test and the ANOVA for the 2FI model concerning Y_1 are presented in Table 4. In the ANOVA, the p-values for the F-statistic of the model were 0.0001, while the p-values for the X_1, X_2, and X_1X_2 terms were 0.0021, 0.0003, and 0.0182. Given these p-values, the fit of Y_1 within the 2FI model is considered significant ($p < 0.05$). Furthermore, the lack of a goodness-of-fit test serves as a robust statistical measure to evaluate the suitability of the model. This test compares the residual error to the pure error derived from replicated design points. A model that demonstrates a lack of significant fit (p-value > 0.10) would indicate poor predictive capability, so achieving a non-significant lack of fit is highly favorable. The analysis showed that the fit of Y_1 to the 2FI model exhibited a non-significant lack of fit ($p > 0.1$), confirming the adequacy of the model.

DISCUSSION

Structure confirmation

The ^{1}H-NMR spectrum of the synthesized product showed the common feature of carbon sp^3 carbon protons. The protons of the methylene (-CH_2-) appeared as a quartet signal at δ_H 4.00 with a J-value of 7.2 Hz. A triplet at δ_H 1.20 with a J-value of 7.2 Hz was assigned to the three protons of the methyl group (CH_3-). **^{1} H-NMR** (600 MHz, $CDCl_3$,), d_H, ppm: 4.00 (2H, *q*, J = 7.2 Hz, -CH_2-), 1.20 (3H, *t*, J = 7.2 Hz, CH_3-).

Table 4: Statistical analysis of Y_1 according to the 2FI model.

ANOVA for 2FI model						
Response 1: Y_1						
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3031.94	3	1010.65	113.74	0.0003	significant
A-X_1	445.45	1	445.45	50.13	0.0021	
B-X_2	1262.72	1	1262.72	142.11	0.0003	
AB	131.97	1	131.97	14.85	0.0182	
Residual	35.54	4	8.89			
Lack of Fit	15.31	3	5.10	0.2521	0.8595	Not significant
Pure Error	20.24	1	20.24			
Corr Total	3067.48	7				
Fit Statistics						
Std. Dev.	2.98	R2		0.9884		
Mean	58.62	Adjusted R2		0.9797		
C.V.%	5.08	Adeq Precision		29.0341		
Final Equation in Terms of						
Coded Factors			**Actual Factors**			
Y_1 =			Y_1 =			
+ 57.83			+ 32.95410			
+ 10.40	* A		+ 41.66992	* X_1		
+ 20.20	* B		+ 3.40411	* X_2		
- 7.45	* AB		- 1.19228	* X_1* X_2		

The results of FTIR analysis show that the synthesized product contains SSC-N, based on the features of the C-N group at 3367 cm^{-1} (3361 cm^{-1}, AIST reference spectrum) and -CSS- at the peak pair 986 and 911 cm^{-1} (986 and 912 cm^{-1}, AIST reference spectrum). In addition, the spectroscopic data of the product showed the presence of carbon sp^3 at 2979 and 2925 cm^{-1}. By comparison with the standard spectral data from AIST, the results obtained in the present study are in good agreement with the chemical structure of DDTC.

Statistical analysis

Coefficient Estimation, Regression Equation, and Response Surface Analysis for Y_1: The experimental responses (Y_1) obtained at various levels of the independent variables were analyzed using multiple linear regression to develop a predictive model. The resulting equation (2), expressed in terms of the coded factors, has an intercept of 57.83, with coefficient values of 10.40 for factor A (X_1), 20.20 for factor B (X_2), and an interaction term of −7.45 for A × B:

$$Y_1 = 57.83 + 10.40 \times A + 20.20 \times B - 7.45 \times A \times B \quad (2)$$

To complement the regression analysis and provide deeper insight into the influence of the independent variables on the response, two-dimensional contour plots and three-dimensional response surface plots were constructed, as shown in Figure 2. These graphical tools are instrumental in visualizing the main and interaction effects of the variables, validating and extending the interpretation of the regression equation. Figure 2A shows the Figure 2D contour plot, while Figure 2B presents the corresponding 3D response surface plot. Both depict the effects of the interaction between factor A (X_1) and factor B (X_2) on the response Y_1 (%). Increasing values along both axes in the plots reflect the positive main effects of A and B. However, the negative interaction term (−7.45 ×

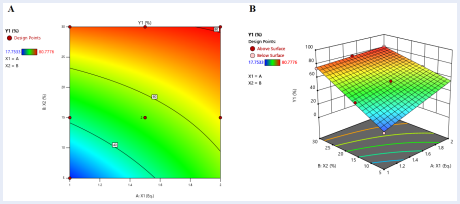

Figure 2: Effects of X_1 and X_2 on reaction yield: (A) contour plot and (B) response surface.

A × B) indicates that the simultaneous increase of both factors resulted in a less-than-additive effect—in other words, the benefit of increasing one factor decreases as the other increases.

This interaction is observed in Figure 2A, where the non-parallel, curved contour lines and nonlinear color gradients imply the significant interplay between A and B. For example, the influence of A is more pronounced when B is at a lower level, and vice versa. As both variables reach higher values, the response starts to plateau or slightly decline, which is consistent with the saddle-shaped curvature seen in Figure 2B. The 3D plot also illustrates this behavior, showing a peak region where Y_1 is maximized but flattens as both factors simultaneously increase, confirming the moderating effect of the interaction.

The response values range from approximately 17.35% (lowest response at low A and B) to 80.78% (highest response at high A and B, but near the threshold where the interaction begins to suppress further gains). The center point (A = 1.5 Eq, B = 15%) lies near a region of strong curvature and intermediate response, supporting its appropriateness for model calibration and optimization. Furthermore, the design points (red dots) are well-distributed across the surface, enhancing the statistical reliability and predictive strength of the model.

These response surface and contour plots are not only illustrative but also practical. They enable the identification of an optimal operating range for maximizing Y_1, allowing researchers or process engineers to select factor levels within the red-to-orange region to achieve high yields while avoiding diminishing returns caused by negative interactions. Additionally, the model offers flexibility for process adjustment by considering real-world constraints, such as reagent availability, cost, and operational safety at high concentrations.

Optimization and evaluation of the optimized formulation: Building upon the regression model and response surface analysis discussed above, a comprehensive optimization study was conducted to determine the most favorable combination of the independent variables (X_1 and X_2) that would simultaneously optimize the responses Y_1, Y_2, and Y_3. This was achieved through a desirability function approach, which transforms each response into a dimensionless desirability scale: d_1 for Y_1, d_2 for Y_2, and d_3 for Y_3.

To guide the optimization process, the following constraints were applied: Y_1 and Y_2 were set to be maximized, while Y_3 (reaction temperature) was restricted to a target range of 92 to 98°C, ensuring practical and safe processing conditions. Equal weight and importance were assigned to each response to maintain a balanced optimization strategy.

The overall (global) desirability (D) was then calculated as the geometric mean of the individual desirabilities. A grid-based search and feasibility analysis, conducted using Design-Expert software, enabled the identification of the most promising formulation conditions. The resulting response surface and contour plots of the global desirability function are shown in Figure 2, providing a visual representation of the optimal region within the experimental space.

The optimized formulation, which yielded a predicted desirability value (D) of 0.77, was identified at X_1 = 1.98 Eq and X_2 = 29.9%. Under these conditions, the model forecasted a Y_1 response of 80.87%, indicating a high degree of synthesis efficiency.

To validate the predictive accuracy of the optimization, the optimized formulation was experimentally tested in five independent trials, and the results were compared with the predictions of the model. As summarized inTable 5, the observed responses closely matched the predicted values, with bias percentages below 15% for all responses. Specifically, the observed Y_1 was 78.44% ± 2.54%, Y_2 was 99.62% ± 0.1%, and Y_3 was 93.85 ± 0.92°C. These minimal residuals confirm the model's reliability and the practical applicability of the optimization strategy.

*Bias (%) = [(predicted value − observed value) × 100] / observed value

CONCLUSIONS

This study compellingly illustrates that employing an experimental optimization model to identify the ideal conditions for compound reactions is a highly effective approach for enhancing chemical reaction synthesis over time. The findings show that reaction efficiency significantly improves with increased concentration and molar equivalents of NaOH solution, un-

Table 5: Comparison of predicted and observed experimental values of DDTC prepared under optimum conditions.

Responses	Predicted value	Observed value	Residuals	Bias* (%)
Y_1 (%)	80.87	78.44 ± 2.54	−2.43	3.98
Y_2 (%)	99.56	99.62 ± 0.1	0.06	0.06
Y_3(°C)	93.63	93.85 ± 0.92	0.22	0.23

derscoring the potential of these optimization techniques. Furthermore, the study successfully validated the FD model paired with the desirability function to optimize various reactions among the reactants in the mixture, with observed values closely aligning with estimated results.

To delve deeper into the impact of different formulation variables on outcomes, response surface plots and contour plots were employed. The results strongly indicate that RSM is an invaluable tool for gaining insight into formulation variables and effectively optimizing formulations. While this study focused on a simple reaction, it paves the way for further investigations that will explore the dynamics of more complex reactions and the role of catalysis in organic synthesis.

ABBREVIATIONS

2FI: The two-factor interaction
ANOVA: Analysis of Variance
DDTC: Sodium diethyldithiocarbamate
FD: Factorial design
FTIR: Fourier Transform Infrared
HCl: Hydrochloric acid
KI: Potassium iodide
NaOH: Sodium hydroxide
NMR: Nuclear Magnetic Resonance
RSM: Response surface methodology

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

Nguyen Thi Anh Hong conceived the idea and designed the works. Le Thi To Nhu performed experiments. All authors analyzed data, read and final approval manuscript for publication.

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REFERENCES

1. Van Leeuwen C, Maas-Diepeveen JL, Niebeek G, Vergouw WH, Griffioen PS, Luijken MW. Aquatic toxicological aspects of dithiocarbamates and related compounds. I. Short-term toxicity tests. Aquat Toxicol. 1985;7(3):145–64. Available from: https://doi.org/10.1016/S0166-445X(85)80002-3.
2. Nieuwenhuizen P, Reedijk J, van Duin M, McGill WJ. Thiuram- and dithiocarbamate-accelerated sulfur vulcanization from the chemist's perspective; methods, materials and mechanisms reviewed. Rubber Chem Technol. 1997;70(3):368–429. Available from: https://doi.org/10.5254/1.3538436.
3. Hogarth G. Transition metal dithiocarbamates: 1978–2003. Prog Inorg Chem. 2005;53:71–561. Available from: https://doi.org/10.1002/0471725587.ch2.
4. Vettorazzi G, Almeida WF, Burin GJ, Jaeger RB, Puga FR, Rahde AF, et al. International safety assessment of pesticides: dithiocarbamate pesticides, ETU, and PTU—a review and update. Teratog Carcinog Mutagen. 1995-1996;15(6):313–37. Available from: https://doi.org/10.1002/tcm.1770150608.
5. Aly AA, Brown AB, Bedair TM, Ishak EA. Dithiocarbamate salts: biological activity, preparation, and utility in organic synthesis. J Sulfur Chem. 2012;33(5):605–17. Available from: https://doi.org/10.1080/17415993.2012.718349.
6. Allaix DL, Carbone VI. An improvement of the response surface method. Struct Saf. 2011;33(2):165–72. Available from: https://doi.org/10.1016/j.strusafe.2011.02.001.
7. Shuai W, Kuangdi X. Sodium Diethyl Dithiocarbamate, in The ECPH Encyclopedia of Mining and Metallurgy. Springer. 2023;p. 1–2. Available from: https://doi.org/10.1007/978-981-19-0740-1_899-1.
8. Kobayashi N, Fujisawa T. The reactions of sodium diethyldithiocarbamate and tetraethylthiuram disulfide with mercury (II) chloride. Bull Chem Soc Jpn. 1976;49(10):2780–3. Available from: https://doi.org/10.1246/bcsj.49.2780.
9. Derringer G, Suich R. Simultaneous optimization of several response variables. J Qual Technol. 1980;12(4):214–9. Available from: https://doi.org/10.1080/00224065.1980.11980968.
10. Šedivec V, Vašak V. Diethyldithiocarbamate as a reagent in volumetric analysis. Collect Czech Chem Commun. 1950;15:52–64. Available from: https://doi.org/10.1135/cccc19500052.
11. Linch A. Determination of Purity and Water Content of Xanthates and Dithiocarbamates. Use of Iodine Reagents. Anal Chem. 1951;23(2):293–6. Available from: https://doi.org/10.1021/ac60050a018.