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Cyclic Voltammetric Profiling of *Bis*(2-nitrophenyl)Disulfides in a Benzothiazole Precursor Series

Abstract

Cyclic voltammetry was applied to a series of substituted *bis*(2-nitrophenyl)disulfides in acetonitrile containing tetraethylammonium tetrafluoroborate under unified experimental conditions. Seven compounds were initially considered (**S01**–**S07**). One of them (**S07**) proved practically insoluble in acetonitrile and was excluded from further analysis. As a result, the electrochemical study was performed for six compounds (**S01**–**S06**). Among them, three compounds had voltammograms suitable for semiquantitative treatment, including the comparison of cathodic peak currents, whereas the remaining three compounds provided only qualitative electrochemical information due to their limited solubility and attenuated current response. The multistage cathodic behavior was observed in all cases suitable for analysis. The comparison with nitrobenzene measured under identical conditions indicated a nitro-related reduction process in the region of approximately –1.1 V *vs* Ag/AgCl and a stronger cathodic process near –1.7 V, which was consistent with the cleavage of the disulfide bond and might overlap with a deeper nitro-related reduction. Substituent effects were evident both in peak potentials and, for the more soluble subset, in the cathodic current value. The results show that cyclic voltammetry is a useful screening tool for substituted aromatic nitrodisulfides, even when the solubility prevents the uniform quantitative comparison across the whole series.

Keywords: cyclic voltammetry; aromatic disulfides; nitroarenes; benzothiazoles; redox properties; substituent effects

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Циклічна вольтамперометрія *біс*(2-нітрофеніл)дисульфідів – попередників бензотіазолів

Анотація

Циклічну вольтамперометрію застосовували для дослідження серії заміщених *біс*(2-нітрофеніл)дисульфідів в ацетонітрилі з додаванням тетраетиламоній тетрафлуороборату. Вимірювання здійснювали в уніфікованих експериментальних умовах. Було розглянуто 7 сполук (**S01**–**S07**), одна з яких (**S07**) виявилася практично нерозчинною в ацетонітрилі, тому її було виключено з подальшого аналізу. У результаті електрохімічне дослідження виконували для шести сполук (**S01**–**S06**). Для трьох із них отримали вольтамперограми, придатні для напівкількісної обробки, зокрема для порівняння катодних пікових струмів. Інші три сполуки через обмежену розчинність і слабший струмовий відгук дали лише якісну електрохімічну інформацію. У всіх випадках, придатних для аналізу, спостерігали багатостадійну катодну поведінку. Порівняння з нітробензеном, виміряним у тих самих умовах, дозволило віднести процес у ділянці близько –1,1 В щодо Ag/AgCl до відновлення нітрогрупи. Більш інтенсивний катодний процес поблизу –1,7 В узгоджується з розщепленням дисульфідного зв’язку, хоча він також може частково перекриватися з глибшим відновленням нітрогрупи. Вплив замісників проявлявся як у зміні пікових потенціалів, так і, для краще розчинних сполук, у величині катодного струму. Отримані результати свідчать, що циклічна вольтамперометрія є корисним методом первинного електрохімічного скринінгу заміщених ароматичних нітродисульфідів навіть тоді, коли обмежена розчинність не дозволяє виконати повноцінне кількісне порівняння для всієї серії.

Ключові слова: циклічна вольтамперометрія; ароматичні дисульфіди; нітроарени; бензотіазоли; редокс-властивості; вплив замісників

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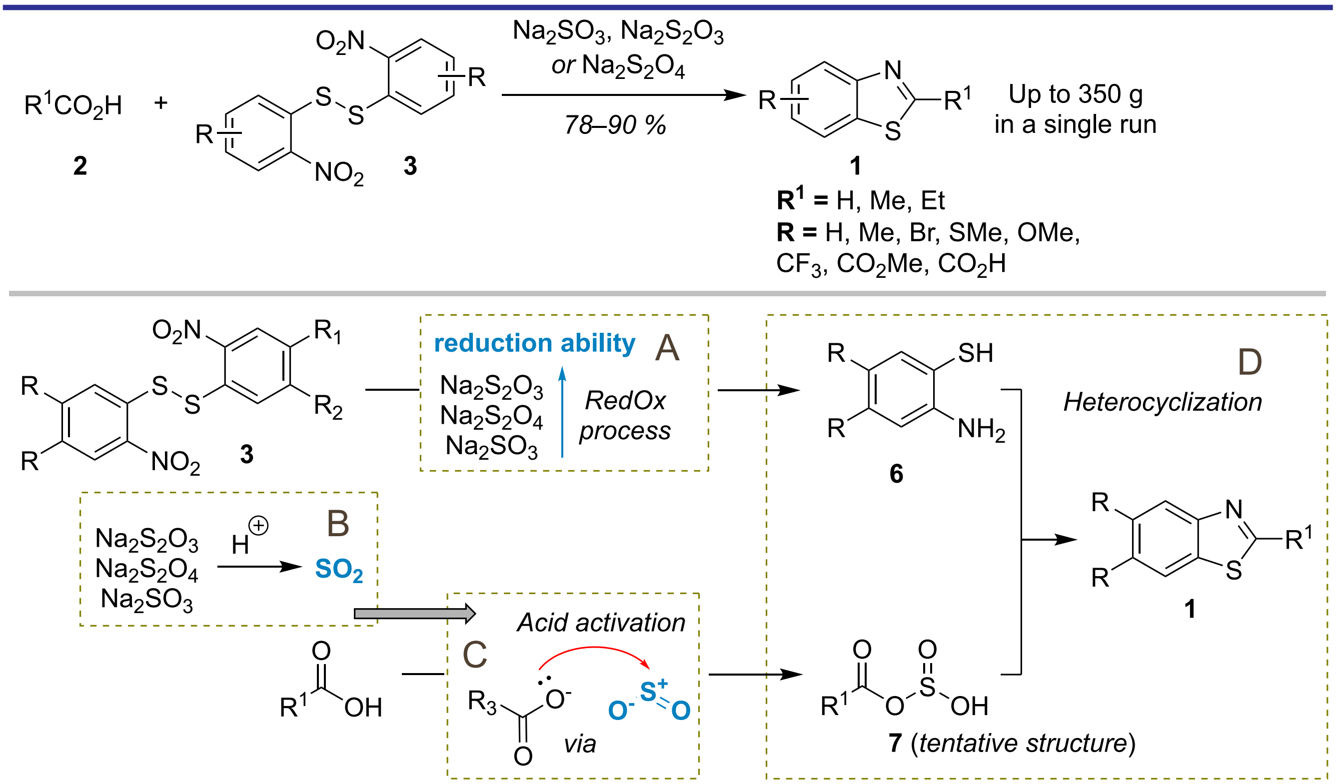
■ Introduction

Aromatic nitro compounds and aromatic disulfides represent two important classes of redox-active organic molecules. Their cathodic behavior is often multistage and may involve coupled electron-transfer and chemical steps, which makes cyclic voltammetry a useful tool for comparing the effect of the structure and substituents on reduction pathways [1–3]. Nitroarenes are known to display complex reduction profiles in aprotic media, whereas aromatic disulfides may undergo characteristic bond-cleavage processes after electron uptake [2–5].

Substituted *bis*(2-nitrophenyl)disulfides combine both of these electroactive motifs in one molecule. For such systems, the cyclic voltammetric analysis is potentially informative in at least three aspects: first, it allows the comparison of reduction potentials within a structurally related series; second, it provides a simple way to distinguish qualitatively between nitro-related and disulfide-related cathodic processes; and third, it helps to reveal practical limitations, such as insufficient solubility in the aprotic medium, that may strongly affect the electrochemical response.

In our previous work [2], we proposed a scalable single-step procedure for producing 2-alkyl-substituted benzothiazoles from the corresponding *bis*(2-nitrophenyl)disulfides (**Scheme 1**). The reaction conditions were carefully optimized with respect to reducing agents (diverse sodium salts), solvents, ratios, and reaction time. While optimizing, we noted that the reducing agent played a crucial role in the reaction efficiency. Against this background, cyclic voltammetric profiling of the *bis*(2-nitrophenyl)disulfides from the above benzothiazole platform appears a natural next step. Therefore, in the present communication, a set of substituted *bis*(2-nitrophenyl) disulfides was examined by cyclic voltammetry in acetonitrile under unified conditions. The aim



Scheme 1. The “direct” synthesis of benzothiazoles **1** from acids **2** and *bis*(2-nitrophenyl)disulfides **3** promoted by sulfur oxo salts, with the preliminary mechanistic explanation

of the work was to evaluate the effect of substituents on the voltammetric profile of this class of compounds and determine which conclusions can be drawn quantitatively and which can only be drawn qualitatively because of solubility limitations.

■ Materials and methods

Materials

The substituted *bis*(2-nitrophenyl)disulfides **S01–S07** were used as the analytes in the present study (**Figure 1**). The compounds were available from the previous synthetic work or prepared as described in the work [5]. Acetonitrile of electrochemical grade (stated purity 99.993%) was used as a solvent. Tetraethylammonium tetrafluoroborate was used as a supporting electrolyte at 0.1 mol L^{-1}. Nitrobenzene was used as a reference substrate. Ferrocene was used as a calibration standard [6].

Cyclic voltammetry

Cyclic voltammetric measurements were carried out on an Elins P-8S potentiostat in a three-electrode cell at 18 °C. The working electrode was a Metrohm glassy-carbon electrode, 2.0 mm in diameter. A glassy-carbon rod (2 mm diameter, immersed to *ca.* 2 cm) was used as a counter electrode. The reference electrode was Ag/AgCl (3 mol L^{-1} KCl) connected through a 3 mol L^{-1} KCl aqueous bridge. Potentials in the present paper are reported versus Ag/AgCl.

The nominal concentration of each analyte was 5×10^{-3} mol L^{-1}. However, for partially soluble compounds, the effective concentration was lower than the nominal value. Prior to the measurements, the solutions were degassed with argon (99.99%). The scan rate was 100 mV s^{-1}. The blank electrolyte and nitrobenzene were recorded under the same experimental conditions as the analytes. Repeated scans were performed on the same solution.

The instrumental potential window of the system allowed scanning approximately from -2.7 to +2.3 V, while the practically reliable range was approximately -2.5 to +2.0 V. The ferrocene calibration was performed under the same reference-electrode conditions.

■ Results and discussion

The structures of the compounds examined are given in **Figure 1**. Seven substituted *bis*(2-nitrophenyl)disulfides **S01–S07** were initially selected for the cyclic voltammetric analysis in acetonitrile. One compound, **S07**, exhibited only a very weak electrochemical response due to the practically complete insolubility under the conditions used and was therefore excluded from further discussion. The remaining six compounds, **S01–S06**, yielded analyzable electrochemical data, but the quality of the information obtained was not uniform.

For three compounds, the voltammograms were of sufficient quality to permit the semiquantitative comparison, including the comparison of cathodic peak currents. For the other three compounds, the current response was too strongly limited by the incomplete dissolution to allow the meaningful current-based comparison; however, the peak positions and overall voltammetric shape still provided the qualitative electrochemical information. Accordingly, the discussion below is divided into two levels: a semiquantitative interpretation for the more soluble subset and a qualitative interpretation for the limited-solubility subset.

Since no mixed-solvent system was explored, the present paper treats the difference in solubility not as an optimization problem, but as an intrinsic experimental limitation of the dataset. For this reason, absolute peak currents are discussed only for the more soluble subset, whereas for the limited-solubility subset, the interpretation is restricted to cathodic peak potentials and general voltammetric features.

The voltammetric profiles of all compounds analyzed differ clearly from those of the blank

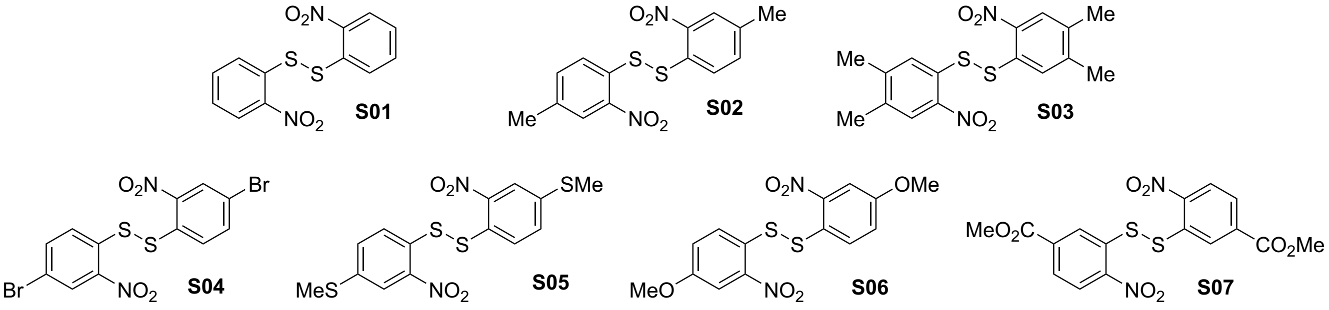


Figure 1. Structures of substituted *bis*(2-nitrophenyl)disulfides **S01 – S07** investigated in the present study

electrolyte and nitrobenzene recorded under identical conditions (for more details, *see* SI files). In each case, more than one cathodic process is observed, indicating that the reduction of substituted *bis*(2-nitrophenyl)disulfides in aprotic media is a multistage rather than a simple one-wave process. For the more soluble subset (**Figure 2**), both cathodic peak potentials and peak-current values can be compared semiquantitatively. For the limited-solubility subset (**Figure 3**), only the positions of the main cathodic processes and their relative shifts can be interpreted with confidence.

The full voltammetric overlays for the informative compounds are shown in **Figure 2**. In all three cases, the analyte traces clearly differ from the blank background and from nitrobenzene recorded under identical conditions. The analytes display multistage cathodic responses and lack the simple matched anodic return waves, consistent with the chemically coupled, overall irreversible behavior rather than a single reversible one-electron process [3–5].

The comparison with nitrobenzene is useful for determining the main cathodic processes. Under the present conditions, nitrobenzene exhibits principal cathodic features at approximately –1.16 and –1.91 V versus Ag/AgCl. In the disulfide series, the cathodic process observed near –1.1 V, with a substituent-dependent shift of several tenths of a volt, is reasonably associated with the reduction of the nitro group. In contrast, the more intense process centered near –1.7 V is consistent with the cleavage of the disulfide bond and may overlap with a deeper nitro-related reduction step. Since no non-nitro disulfide control has not been measured, this assignment is best regarded as well-supported rather than definitive.

A clear substituent effect is observed across the series. Depending on the substituent pattern, the nitro-related cathodic process shifts either to more negative or to less negative potential relative to nitrobenzene. For the more soluble subset, this effect is accompanied by substantial

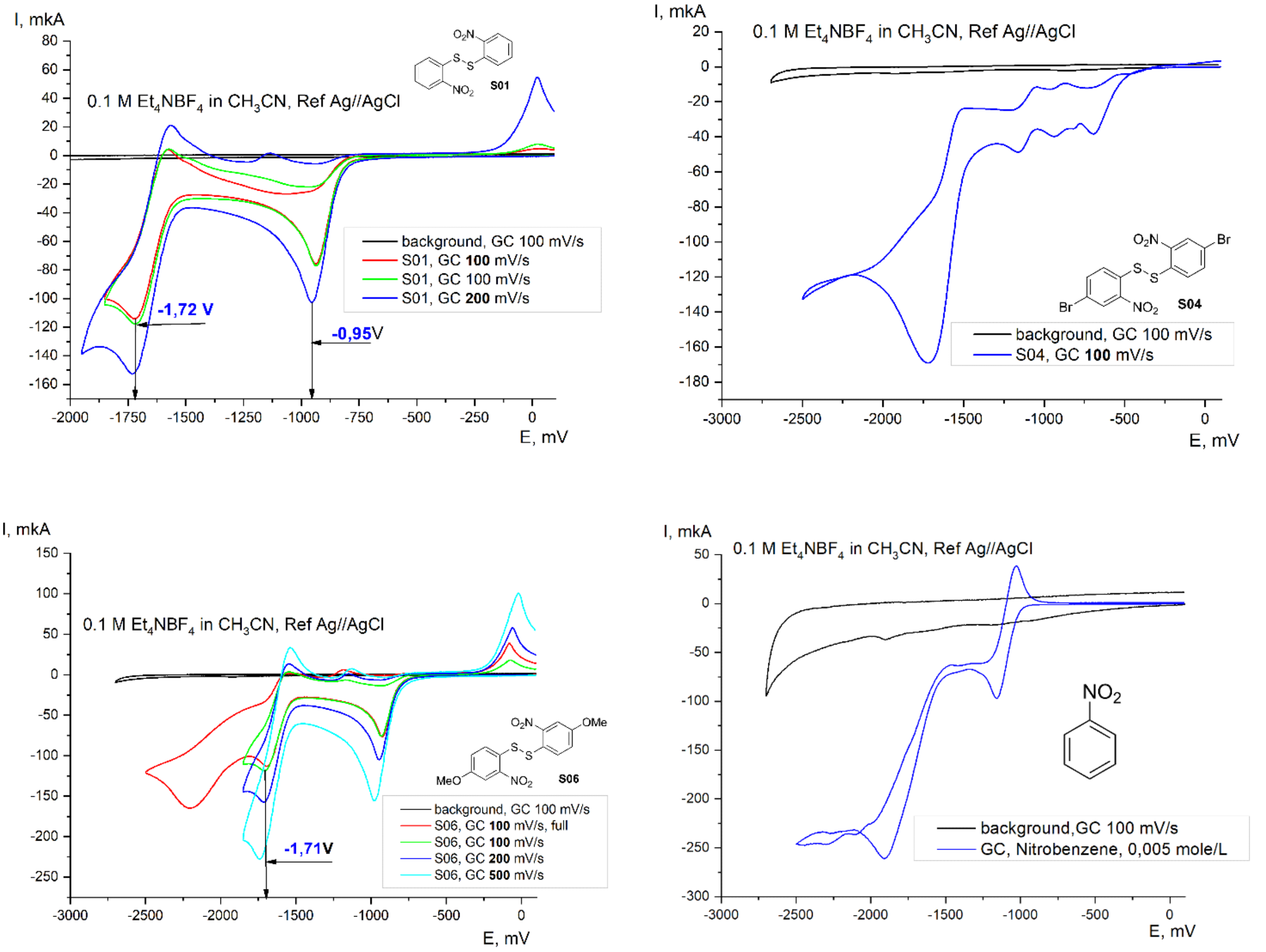


Figure 2. Cyclic voltammograms of the three compounds (**S01**, **S04**, **S06**) affording semiquantitative electrochemical data and that of nitrobenzene in MeCN / 0.1 mol L^{-1} Et_4NBF_4 at 100 mV s^{-1} and 18 °C on a glassy-carbon working electrode versus Ag/AgCl. For each analyte, the corresponding blank electrolyte recorded under identical conditions is overlaid

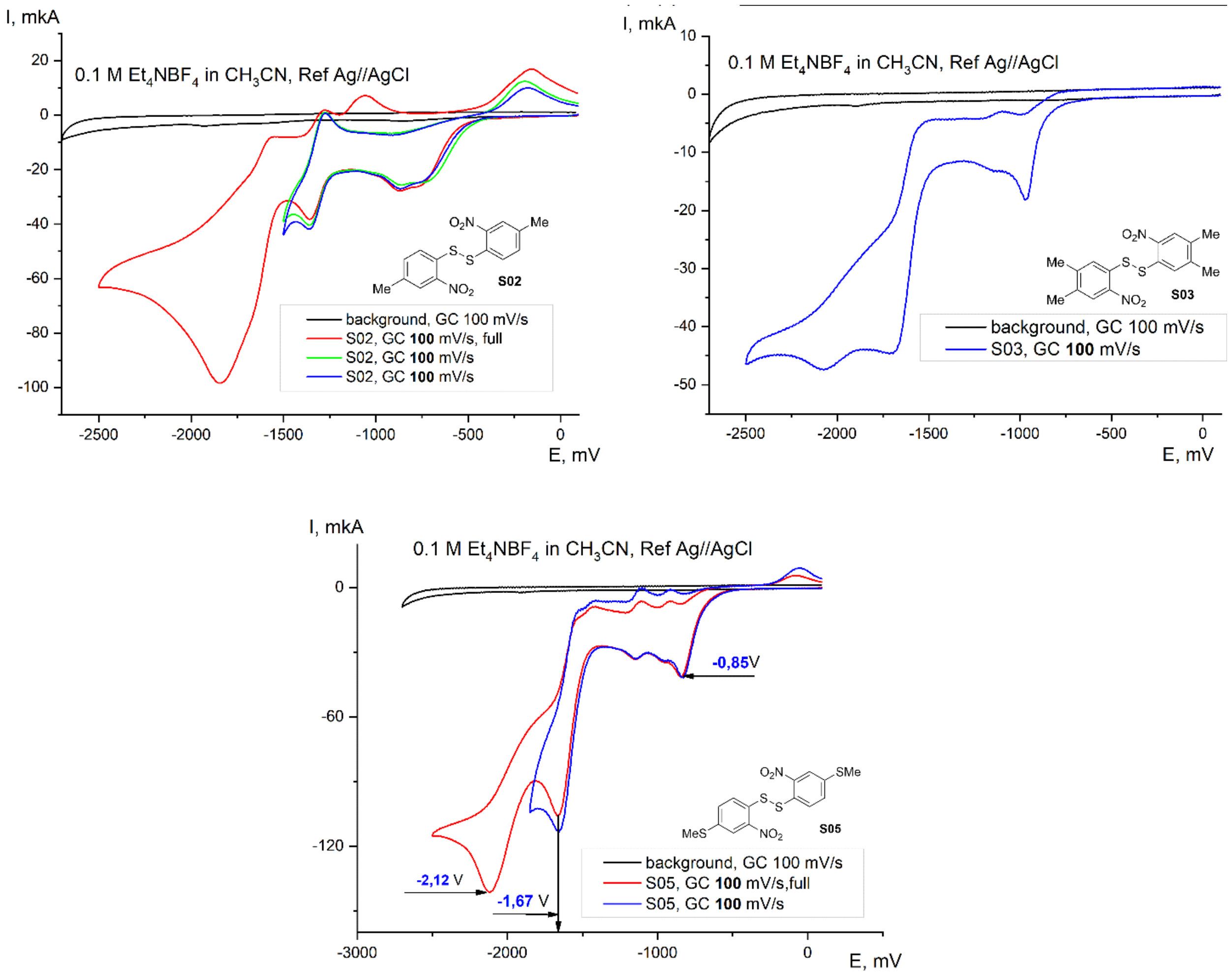


Figure 3. Cyclic voltammograms of the three compounds affording only qualitative electrochemical data under the same conditions as in Figure 2. Because of the limited solubility in MeCN, these voltammograms are discussed in terms of cathodic peak positions and the overall profile rather than the peak-current value

differences in the cathodic peak-current value, which indicates that the substituent variation affects not only the reduction potential, but also the practical electrochemical response observed under identical concentration and instrumental conditions. For the limited-solubility subset, the same trend can still be discussed qualitatively on the basis of peak positions although current values are no longer suitable for comparison.

Thus, the six compounds analyzed should be treated as two subsets: **S01**, **S04**, and **S06**, which gave semiquantitative electrochemical data, and **S02**, **S03**, and **S05**, which afforded only qualitative electrochemical information, whereas **S07** was excluded because of the practical insolubility in MeCN.

Repeated scans performed on the same solution showed that the principal cathodic features remained recognizable although changes in the current profile and the return-wave region were observed. This behavior is consistent with a multistage electrode process involving the electron transfer followed by the chemical transformation and/or adsorption effects on the electrode surface. Since the main purpose of the present communication is a comparative profiling of the compound series rather than a detailed kinetic analysis, these repeat-scan effects are noted here only as supporting evidence that the recorded cathodic processes are real and reproducible within the same solution.

For convenience, the key electrochemical observations are summarized in **Table 1**. Due to the concentration uncertainty resulting from the incomplete solubility, the table is limited to qualitative or semiquantitative descriptors rather than kinetic or mechanistic parameters.

Taken together, these data do not establish a complete electroreduction mechanism for substituted *bis*(2-nitrophenyl)disulfides in the aprotic medium. They do, however, show that the compounds analyzed do not behave as simple one-wave nitroarenes. Instead, the voltammograms are consistent with at least two chemically distinct cathodic processes: a substituent-dependent nitro-related reduction in the region near –1.1 V and a stronger process near –1.7 V

Table 1. Electrochemical characteristics of the substituted *bis*(2-nitrophenyl)disulfides studied in MeCN

Compound	Structural feature	Data level used in the discussion	Current-based comparison	Screening current, μA	Comment
S01	unsubstituted	semiquantitative	yes	150	suitable for the comparison of potentials and currents
S02	dimethyl-substituted	qualitative	no	100	discussion restricted to potentials and the voltammetric shape
S03	polymethyl-substituted	qualitative	no	60	discussion restricted to potentials and the voltammetric shape
S04	dibromo-substituted	semiquantitative	yes	180	suitable for the comparison of potentials and currents
S05	bis(methylthio)-substituted	qualitative	no	120	limited-solubility dataset
S06	dimethoxy-substituted	semiquantitative	yes	200	highest current response among the compounds analyzed
S07	ester-substituted	excluded	no	20	practically insoluble in MeCN

that is consistent with the disulfide bond cleavage and overlaps with a deeper nitro-related reduction. The work also shows that the solubility in MeCN is not a minor experimental inconvenience, but a major variable determining whether the given member of the series can be treated quantitatively or only qualitatively.

Conclusions

A cyclic voltammetric study of seven substituted *bis*(2-nitrophenyl)disulfides in acetonitrile has been performed under unified aprotic conditions. One compound, **S07**, proved practically insoluble in MeCN and was excluded from the electrochemical interpretation. The remaining six compounds, **S01**–**S06**, yielded analyzable data, but at two different levels of reliability: three compounds gave semiquantitative voltammograms suitable for the comparison of both peak potentials and peak-current values, whereas three compounds provided only qualitative electrochemical information because of their limited solubility.

In all the cases analyzed, the multistage cathodic behavior was observed. The comparison with nitrobenzene measured under identical conditions supports the assignment of the process near –1.1 V to the nitro-group reduction, while the stronger process near –1.7 V is consistent with the disulfide bond cleavage, possibly overlapping with a deeper nitro-related reduction. A clear substituent effect was observed across the series, manifested as shifts in cathodic peak potentials and, for the more soluble subset, differences in the peak-current value.

Thus, cyclic voltammetry is shown to be a useful comparative method for substituted *bis*(2-nitrophenyl)disulfides. At the same time, the study demonstrates that solubility in the aprotic medium is a decisive practical factor that limits the uniform quantitative comparison within the series of these compound.

References

1. Henary, M.; Paranjpe, S.; Owens, E. A. Synthesis and applications of benzothiazole-containing cyanine dyes. *Heterocycl. Commun.* **2013**, *19*, 1–11. https://doi.org/10.1515/hc-2013-0012.
2. Puskov, V. O.; Babii, S. B.; Adamenko, I. V.; Melnychuk, S. O.; Druzhenko, T. V.; Lyapunov, A. Y.; Popov, S. V.; Volochnyuk, D. M.; Ryabukhin, S. V. Practical one-pot synthesis of 2-alkyl-substituted benzothiazoles from bis-(2-nitrophenyl)-disulfides. *Org. Process Res. Dev.* **2024**, *28*, 4273–4280. https://doi.org/10.1021/acs.oprd.4c00136.
3. Orlandi, M.; Brenna, D.; Harms, R.; Jost, S.; Benaglia, M. Recent developments in the reduction of aromatic and aliphatic nitro compounds to amines. *Org. Process Res. Dev.* **2018**, *22*, 430–445. https://doi.org/10.1021/acs.oprd.6b00205.
4. Huang, Y.; Lessard, J. Electrochemical behaviour of nitrobenzene, nitrosobenzene, azobenzene, and azoxybenzene on Hg, Pt, Cu, and Ni electrodes in aprotic medium. *Electroanalysis* **2016**, *28*, 2716–2727. https://doi.org/10.1002/elan.201600216.
5. Antonello, S.; Daasbjerg, K.; Jensen, H.; Taddei, F.; Maran, F. Formation and cleavage of aromatic disulfide radical anions. *J. Am. Chem. Soc.* **2003**, *125*, 14905–14916. https://doi.org/10.1021/ja036380g.
6. Gagné, R. R.; Koval, C. A.; Lisensky, G. C. Ferrocene as an internal standard for electrochemical measurements. *Inorg. Chem.* **1980**, *19*, 2854–2855. https://doi.org/10.1021/ic50211a080.

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