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Synthesis and Spectroscopic Analysis of Naphthalimide Dye Sensitizers Featuring a 3-Amino-2-Propyl-1*H*-Benzo[*DE*]Isoquinoline-1,3(2*H*)-Dione Moiety as the Diazo Component

[*1]Agho, O.B., [2]Yakubu, M.K., [3]Bello, K.A., and [4]Abdelmalik, A.A.

[1,2,3]Department of Polymer and Textile Engineering, Ahmadu Bello University, Zaria

[4]Department of Physics, Ahmadu Bello University, Zaria, Kaduna State, Nigeria

[*]Corresponding Mail: aghoosazebright@gmail.com

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ABSTRACT

Two novel naphthalimide-substituted azo dyes (Dye 1 and Dye 2) were synthesized for potential application in dye-sensitized solar cells (DSSCs). Both dyes were obtained as dark brown solids with yields of 72.0% (Dye 1) and 70.0% (Dye 2), melting points of 170-173 °C and 175-178 °C, and molecular weights of 503.48 and 518.49 g/mol, respectively. UV-Visible analysis showed strong visible absorption with λmax at 467 and 517 nm for Dye 1, and 459 and 504 nm for Dye 2 (in ethanol and DMSO). Dye 2 exhibited a higher molar extinction coefficient (6.58×10^4 $Lmol^{-1}cm^{-1}$) than Dye 1 (5.28×10^4 $Lmol^{-1}cm^{-1}$), indicating superior light-harvesting ability. FT-IR spectra confirmed N-H/O-H (3254-3608 cm^{-1}), azo (1505-1569 cm^{-1}), carbonyl (1654-1729 cm^{-1}), and cyano (2278-2288 cm^{-1}) groups. Mass spectra showed molecular ion peaks at m/z 503.0 (Dye 1) and 515.7 (Dye 2) with characteristic fragment ions supporting structural integrity. ^1H and ^{13}C NMR spectra further validated the structures: Dye 1 showed COOH (δ10.88 ppm) and aromatic (δ7.87–8.20 ppm) protons, while Dye 2 displayed COOH/OH protons (δ11.96/10.69 ppm). Carbonyl resonances (Dye 1: δ166.46-179.78 ppm; Dye 2: δ167.16-185.80 ppm) indicated extensive π-electron delocalization and strong donor-acceptor interactions and thus, exhibit favorable photo-physical properties for DSSC applications.

KEYWORDS: Naphthalimide-substituted azo dyes, sensitizers, nitration, imidation, intermediate, cyanorated coupling components

INTRODUCTION

The increasing global demand for sustainable and renewable energy sources has intensified research into alternative photovoltaic technologies capable of overcoming the limitations

associated with conventional silicon-based solar cells. Among these emerging technologies, dye-sensitized solar cells (DSSCs) have attracted considerable attention due to their low production cost, ease of fabrication, environmental friendliness, and relatively high photoelectric conversion efficiency under low-light conditions. Since the pioneering work of Michael Grätzel and co-workers in the early 1990s, DSSCs have become a prominent area of research in materials chemistry and renewable energy science [1].

Naphthalimide derivatives have emerged as important functional chromophores in the development of advanced optoelectronic materials due to their excellent photo-physical, electrochemical, and thermal properties [2]. The naphthalimide moiety possesses a highly conjugated aromatic system that promotes strong intramolecular charge transfer, broad absorption spectra, high fluorescence quantum yield, and remarkable electron-accepting ability. These unique characteristics make naphthalimide-based compounds attractive candidates for application in solar energy conversion devices, particularly DSSCs [3]. Furthermore, structural modification of the naphthalimide core through substitution reactions provides opportunities for tuning the electronic properties, absorption wavelength, and charge transport characteristics of the resulting dyes [4].

Substituted naphthalimide dyes have demonstrated improved light-harvesting efficiency due to their extended π-conjugation systems and enhanced donor-π-acceptor (D-π-A) architecture. The incorporation of electron-donating and electron-withdrawing groups into the molecular framework can significantly improve charge separation and electron injection efficiency in DSSCs [5].

In spite of the promising potential of naphthalimide substituted dyes, challenges such as limited absorption in the visible and near-infrared regions, charge recombination losses, and long-term operational stability still hinder their practical application in DSSCs. Therefore, there is a continuous need to synthesize and characterize new naphthalimide-based sensitizers with improved structural and electronic properties capable of enhancing solar energy conversion efficiency [6].

In this study, two naphthalimide substituted dyes were synthesized and characterized using various analytical and spectroscopic techniques including Melting point, Fourier Transform Infrared Spectroscopy (FT-IR), Ultraviolet–Visible Spectroscopy (UV-Vis) and Nuclear Magnetic Resonance Spectroscopy (NMR). The study aims to establish the relationship between molecular

structure and optical behavior of the synthesized dyes, thereby contributing to the development of efficient organic sensitizers for renewable solar energy applications.

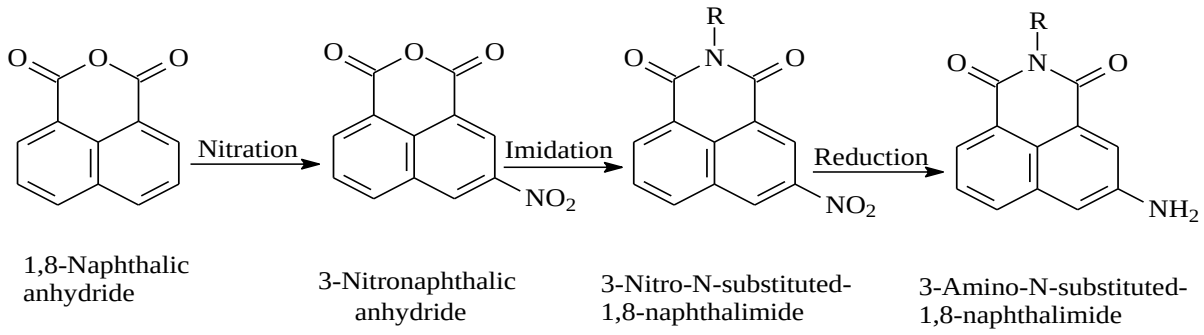
MATERIALS AND METHODS

Chemicals/Reagents and Equipment

Analytical grade reagents and chemicals used for the synthesis of the intermediates and dyes were purchased from Weifang Senya Chemical Company Limited, China. Some of the chemicals and equipment used in this research work are Propylamine, 3-Aminobenzoic acid, 3,4-Diaminobenzoic acid, Tetracyanoethylene, 1,8-naphthalic anhydride, methanol, DMSO, Agilent CARY 300 UV-visible spectrophotometer, Agilent CARY 630 FT-IR, Agilent Gas chromatography-mass spectrometry (7890B GC System). Agilent (^{1}H and ^{13}C NMR) 300 MHz spectrometer and Gallenkamp melting point apparatus

Synthesis of N-Substituted Naphthalimide Derivatives

The synthesis of the N-Substituted Naphthalimide Derivative was achieved following the procedure reported in the work of Fed'ko and Anikin [7] as outlined in Scheme 1:



Scheme 1: Synthesis of Naphthalimide Intermediates

Where R represent (-CH_2)$_2$$CH_3$)

Synthesis of 3-nitro-1, 8- naphthalic anhydride

Sodium nitrate (1.30 g, 15 mmol) was added portion wise to the solution of 1,8-naphthalic anhydride (3.00 g, 15 mmol) in 30 ml of concentrated sulfuric acid. The reaction mixture was heated for 2 h on a water bath, then pour onto ice, the precipitate was filtered, washed with water and dried at 110 °C. The crude product was purified by crystallization from acetic acid to obtain 3-nitronaphthalic anhydride as yellow solid crystals.

Synthesis of 3-nitro-propyl-1, 8-naphthalimide

A suspension of 3-nitro-1, 8- naphthalic anhydride (0.02 mol, 4.86 g) and propylamine (0.02 mol, 4.71 g) was stirred under reflux for 7 hours in ethanol (100 ml). the cooled suspension was filtered out and recrystallized with ethanol to obtain yellow crystals.

Synthesis of 3-amino-propyl-1, 8-naphthalimide

A solution of 3-nitro-propyl-1, 8-naphthalimide (1.00 g, 4 mmol) in ethanol (100 ml) and hot water (50 ml) was made. Sodium dithionite (0.55 g) was added portion wise while stirring. The reaction mixture was refluxed for 3 h and concentrated on a water bath. Hydrochloric acid (10 ml) was added to the residue, the precipitate was filtered and dried. The crude product was purified by crystallization from ethanol as brown crystals.

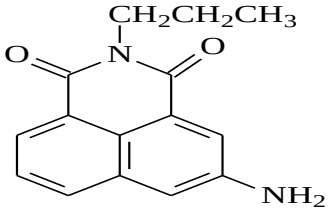
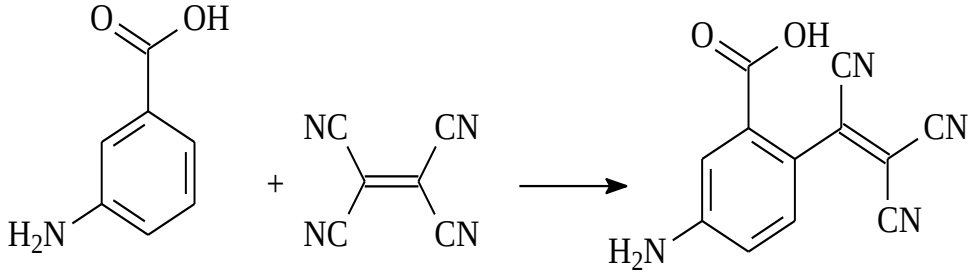


Figure 1: Structure of Naphthalimide Diazo Component

Synthesis of Cyanorated Coupling Components

A solution of the requisite benzoic acid derivative (0.01 mol, 3 g) and (0.01 mol, 0.8 g) tetracyanoethylene (TCNE) in dimethylformamide (DMF) (20 ml) were stirred at 70 °C for 6 h. The solvent was removed and the residual solid was collected and recrystallized from toluene/chloroform mixture (1:3) [8]. The reaction is presented in schemes 2:

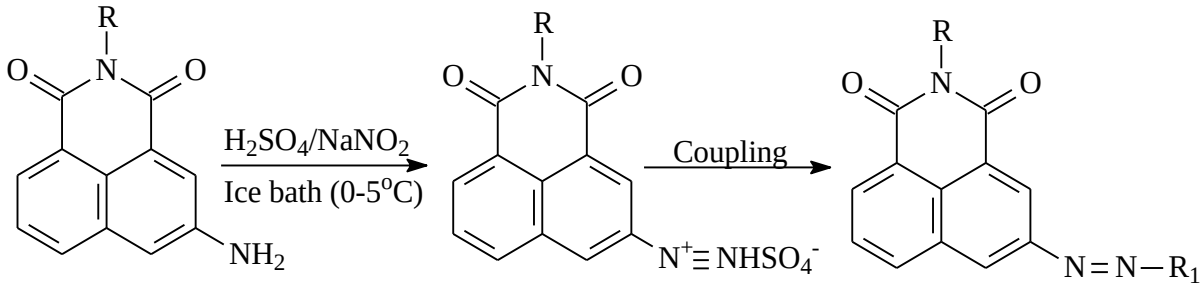


3-Aminobenzoic acid TCNE 3-Amino-6-(tricyanoethenyl)benzoic acid

Scheme 2: Tricyanovinilation of 3-Aminobenzoic acid

Procedure for Diazotization and Coupling Reaction

Dry sodium nitrite (1.5 mmol, 0.104 g) was added to cold conc. H_2SO_4 (98 %, 1.1 ml) at such rate that yellow fume was not evolved. The reaction temperature was gradually increased to 65 ^oC using water bath until the sodium nitrite was dissolved. The resulting solution was cooled to 0-5 ^oC and then added dropwise at 5-20 ^oC with the mixture of propionic acid and acetic acid (10 ml, 1.5:8.5). the finely ground powder of 3-amino-N-substituted-1,8-naphthalimide was added portion wise at less than 10 ^oC, then the liquor was stirred for 3 hours. The obtained clear solution was used immediately in coupling reactions as shown in Scheme 3. The Diazonium solution was immediately coupled with the cyanorated coupling components, 3-amino-6-(tricyanoethynyl)benzoic acid and 3,4-diamino-6-(tricyanoethynyl)benzoic acid to form Dye 1 and 2 respectively [9].



Scheme 3: Diazotization and Coupling Reaction

Where R represent propyl amine ($-CH_2)_2CH_3$) and R_1 represent the cyanorated coupling components

Characterization of the Synthesized Dyes

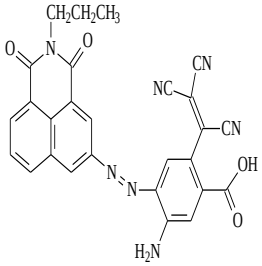
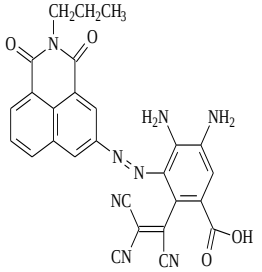
The synthesized dyes were characterized via melting point determination using Gallenkamp melting point apparatus, UV-visible spectroscopy using Agilent CARY 300 UV-visible spectrophotometer. Mass spectrometry (MS) was determined using mass spectrometer of model 7890B GC System), Fourier transform infra-red spectroscopy was determined using Agilent

CARY 630 FT-IR, and H-NMR and ^{13}C-NMR were determined using Agilent (^{1}H and ^{13}C NMR) 300 MHz spectrometer respectively.

RESULTS AND DISCUSSION

The physical properties of the naphthalimide-substituted dye sensitizers are presented in Table 1:

Table 1: Physical Properties of the Synthesized Dyes

Dye No	Emperical formula	Molecular weight (g/mol)	Melting point (^{o}C)	Percentage yield (%)	Appearance	Dye Structure
Dye 1	$C_{27}H_{17}N_7O_4$	503.48	170-173	72.0	Dark brown	
Dye 2	$C_{27}H_{18}N_8O_4$	518.49	175-178	70.0	Dark brown	

The physicochemical properties presented in the Table 1, provide important evidence for the successful synthesis and purity of the prepared naphthalimide azo dyes intended for Dye Sensitized Solar Cell (DSSC) applications. The empirical formulas and molecular weights obtained for Dye 1 ($C_{27}H_{17}N_7O_4$, 503.48 g/mol) and Dye 2 ($C_{27}H_{18}N_8O_4$, 518.49 g/mol) are consistent with the proposed molecular structures containing imide, azo, amino, and cyano functional groups. The melting point ranges of 170-173°C for Dye 1 and 175-178°C for Dye 2 indicate the formation of relatively thermally stable, good purity and highly conjugated aromatic compounds. The

percentage yields of 72.0% for Dye 1 and 70.0% for Dye 2 demonstrate that the diazotization and azo coupling reactions proceeded successfully with appreciable synthetic efficiency while the dark brown appearance of both dyes is characteristic of highly conjugated azo chromophores with extended π-electron delocalization. Such coloration suggests strong absorption within the visible region of the electromagnetic spectrum, which is an essential requirement for effective DSSC sensitizers [10].

The summarized UV-Visible Absorption Spectroscopy of the synthesized naphthalimide-substituted dye sensitizers is presented in Table 2.

Table 2: Visible absorption Spectroscopy of Dyes

Dye No	Ethanol λ_{max} (nm)	DMSO λ_{max} (nm)	ε_{max} in DMSO × (10^4Lmol^{-1}cm^{-1})
Dye 1	467.00	517.00	5.28
Dye 2	459.00	504.00	6.58

Both dyes exhibited strong absorption within the visible region, as presented in Table 2, confirming the presence of extended π-conjugation arising from the naphthalimide core, azo linkage (-N=N-), and electron withdrawing cyano substituents. Such broad visible absorption is essential for efficient solar light harvesting in DSSC systems. Dye 1 showed absorption maxima (λmax) at 467 nm in ethanol and 517 nm in DMSO, while Dye 2 exhibited λmax values at 459 nm and 504 nm respectively. The observed bathochromic shift (red shift) in DMSO compared to ethanol indicates solvent polarity effects on the electronic transitions of the dyes. This behavior suggests the occurrence of strong intramolecular charge transfer (ICT) within the dye molecules, which is a desirable feature for DSSC sensitizers. The molar extinction coefficients (Ɛmax) obtained in DMSO further demonstrate the excellent light absorbing capability of the synthesized dyes. Dye 2 exhibited a higher molar absorptivity (6.58×10^4 Lmol^{-1}cm^{-1}) than Dye 1 (5.28×10^4 Lmol^{-1}cm^{-1}), indicating stronger photon harvesting efficiency. Thus, suggest suitable photophysical properties for DSSC applications [11].

The FT-IR Spectrum and summarized functional groups with their respective vibrational frequencies of the synthesized naphthalimide-substituted dye sensitizers is presented in Figures 2-3 and Table 3.

Table 3: The Infra-Red Spectra of the Synthesized Dyes

Dye No	Vibrational frequencies (cm^{-1})
Dye 1	N-H/OH str. 3608, 3350, 3254; C-H str. Ar. 2963; C-H str. Aliphatic 2929; C=O str. 1654; C-N str. 1390; -N=N str. 1505, 1569; CN str. 2278
Dye 2	N-H/OH str. 3380; C-H str. Ar. 2970; C-H str. Aliphatic 2933; C=O str. 1729; C=C str. 1610; C-N str. 1319; -N=N str. 1513; CN str. 2288

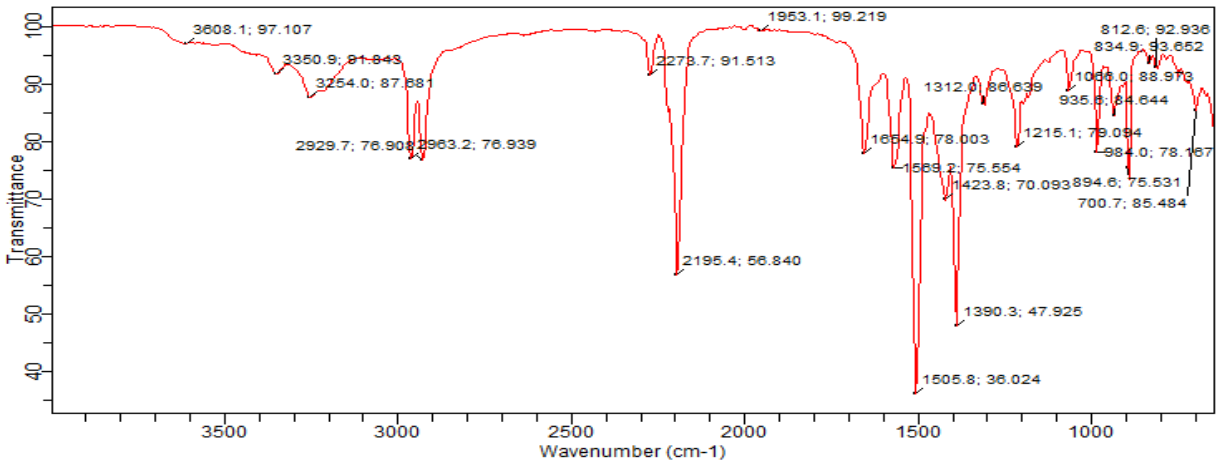


Figure 2: FT-IR of Dye 1

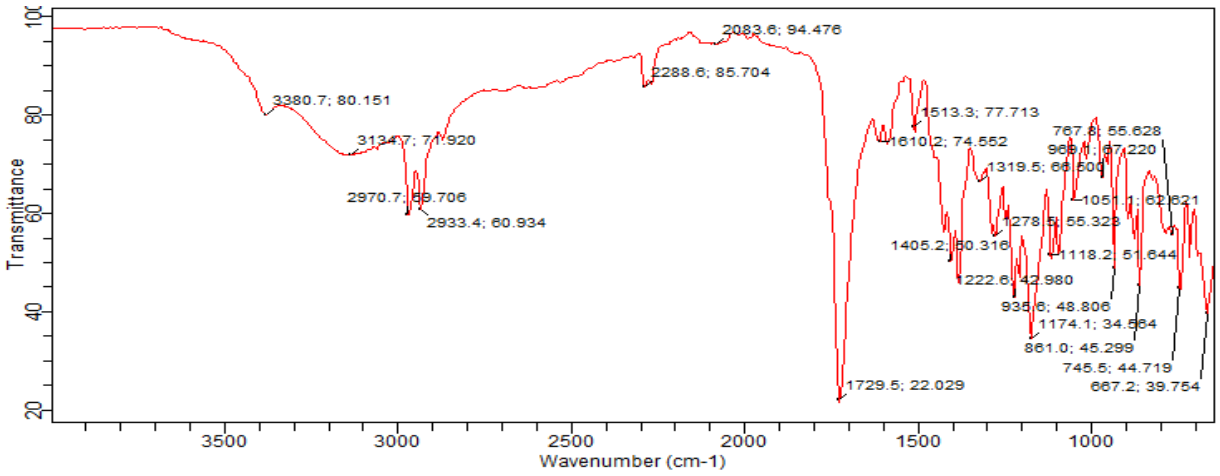


Figure 3: FT-IR of Dye 2

The FT-IR spectrum of the dyes is presented in Figure 2-3 and the observed data is summarized in Table 3. The results confirm the successful synthesis of the naphthalimide substituted azo dyes through the presence of characteristic functional group absorptions corresponding to the proposed molecular structures. The observed absorption bands provide strong evidence for the incorporation of amino/hydroxyl (N-H and O-H stretching vibrations at 3254 - 3380 cm^{-1}), azo (-N=N-) at the frequency range of 1505 and 1569 cm^{-1}, imide carbonyl (C=O stretching vibration) at the vibrational frequency range of 1610-1654 cm^{-1}, aromatic/aliphatic (C-H stretching vibrations) appears at 2929-2970 cm^{-1}, and cyano functionalities (C≡N) appears at the vibrational frequency range of 2278-2288 cm^{-1} respectively, which are essential structural features for efficient Dye Sensitized Solar Cell (DSSC) sensitizers [12].

The mass spectrum and summarized fragmentation patterns of the synthesized naphthalimide-substituted dye sensitizers is presented in Figures 4-5 and Table 4.

Table 4: MS Fragmentations of the Synthesized Dyes

Dye No	Molecular Formula	Experimental values of m/z fragment	Corresponding positive charge fragment	Theoretical value
Dye 1	$C_{27}H_{17}N_7O_4$	55.1, 93.1, 150.0, 207.0, 503.0	$C_3H_5N^+$, $C_5HO_2^+$, $C_8H_{12}N_3^+$, $C_{11}N_3O_2^+$, M	503.48
Dye 2	$C_{27}H_{18}N_8O_4$	74.0, 143.1, 298.2, 515.7	C_5N^+, $C_8H_5N_3^+$, $C_{14}H_{13}N_4O_4^+$, M	518.49

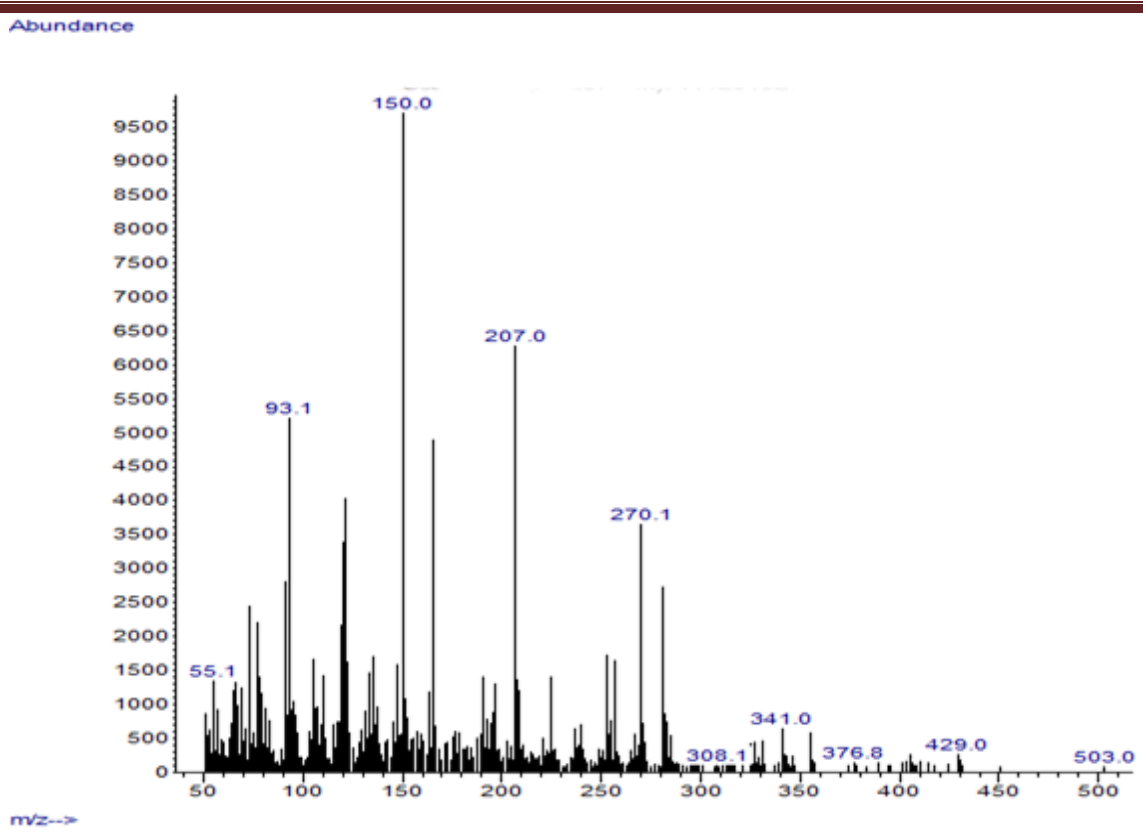


Figure 4: MS Spectrum of Dye 1

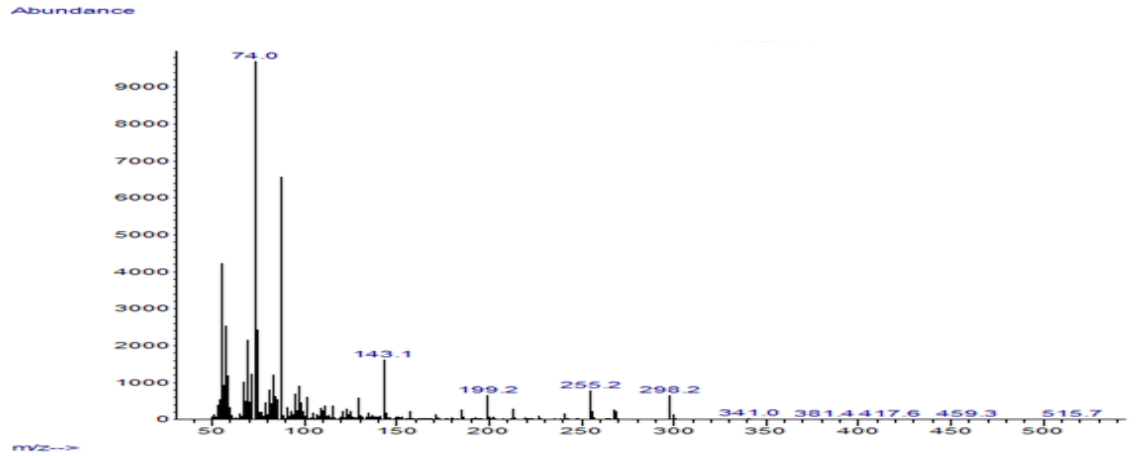


Figure 5: MS spectrum of Dye 2

The MS spectrum of the dyes is presented in Figures 4 and 5 and the observed data is summarized in Table 4. For Dye 1 with molecular formula $C_{27}H_{17}N_7O_4$, several characteristic fragment ions

were observed at m/z values of 55.1, 93.1, 150.0, 207.0, and 503.0. The fragment at m/z 55.1 corresponding to $C_3H_5N^+$ indicates cleavage involving nitrogen-containing aliphatic moieties, while the fragment at m/z 93.1 ($C_5HO_2^+$) may be attributed to aromatic oxygen-containing fragments derived from the carboxyl or imide portions of the molecule. The fragments at m/z 150.0 and 207.0 further confirm the stability of nitrogen-rich aromatic intermediates generated during fragmentation. The molecular ion peak observed at m/z 503.0 corresponds closely to the molecular mass of the synthesized dye, confirming successful synthesis of the target compound.

Similarly, Dye 2 with molecular formula $C_{27}H_{18}N_8O_4$ exhibited significant fragment ions at m/z 74.0, 143.1, 298.2, and 515.7. The fragment at m/z 74.0 assigned to C_5N^+ and the peak at m/z 143.1 corresponding to $C_8H_5N_3^+$ suggest fragmentation involving cyano and azo-containing aromatic regions of the dye. The larger fragment at m/z 298.2 indicates the presence of stable conjugated aromatic segments incorporating nitrogen and oxygen functionalities. The molecular ion peak at m/z 515.7 further supports the successful formation of the synthesized dye structure [13].

The ^{1}H and ^{13}C-NMR spectrum and summarized vibrational frequencies of the synthesized naphthalimide-substituted dye sensitizers is presented in Figures 6-7 and Table 5.

Table 5: ^{1}H and ^{13}C-NMR (300 MHz, MeO-d_4): δH(ppm) Data of the Synthesized Dyes

Dye No	^{1}H and ^{13}C-NMR
Dye 1	10.88(S, 1H, COOH), 8.20(d, 1H, J=2H_2), 8.18(d, 1H, J=2H_2), 8.08(d, 1H), 7.87(S, 1H), 7.73(S, 2H, NH_2), 3.04(t, 2H, CH_2), 2.99(m, 2H, CH_2), 2.04(t, 3H, CH_3); ^{13}C-NMR(400 MHz, MeO-d_4):δ(ppm) 179.78, 176.93, 175.50, 172.66, 171.22, 166.46, 159.34, 151.72, 151.33, 143.42, 143.06, 138.39, 136.52, 125.43, 121.70, 115.03, 107.82, 94.23, 82.64, 80.71, 79.94, 74.21, 69.87, 45.73, 44.30, 42.87
Dye 2	11.96(S, 1H, COOH), 10.69(S, 1H, OH), 8.10(d, 1H), 7.95 (d, 2H), 7.91(S, 1H), 7.87(d, 1H), 7.83(S, 1H), 7.76(d, 2H), 7.64(d, 1H), 7.44(d, 1H), 7.09(d, 1H), 6.87(S, 2H, NH_2); ^{13}C-NMR(400 MHz, MeO-d_4):δ(ppm) 185.80, 184.27, 179.84, 178.40, 176.96, 175.53, 174.12, 172.68, 171.22, 170.80, 167.16, 153.93, 153.48, 142.13, 139.55, 134.87, 133.93, 130.00, 125.31, 122.50, 118.94, 114.74, 113.27, 106.45, 103.75, 100.84, 96.18, 93.19, 85.10

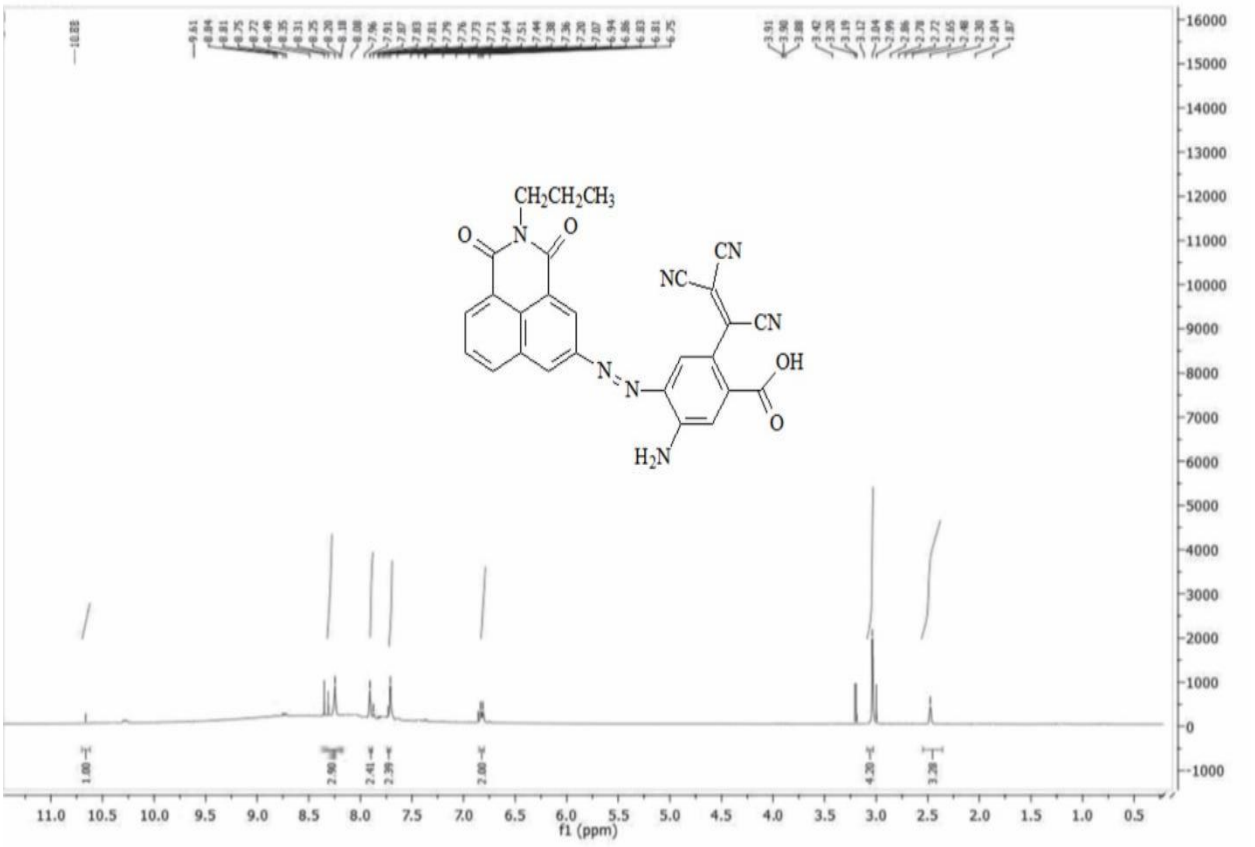


Figure 6: ^{1}H NMR of Dye 1

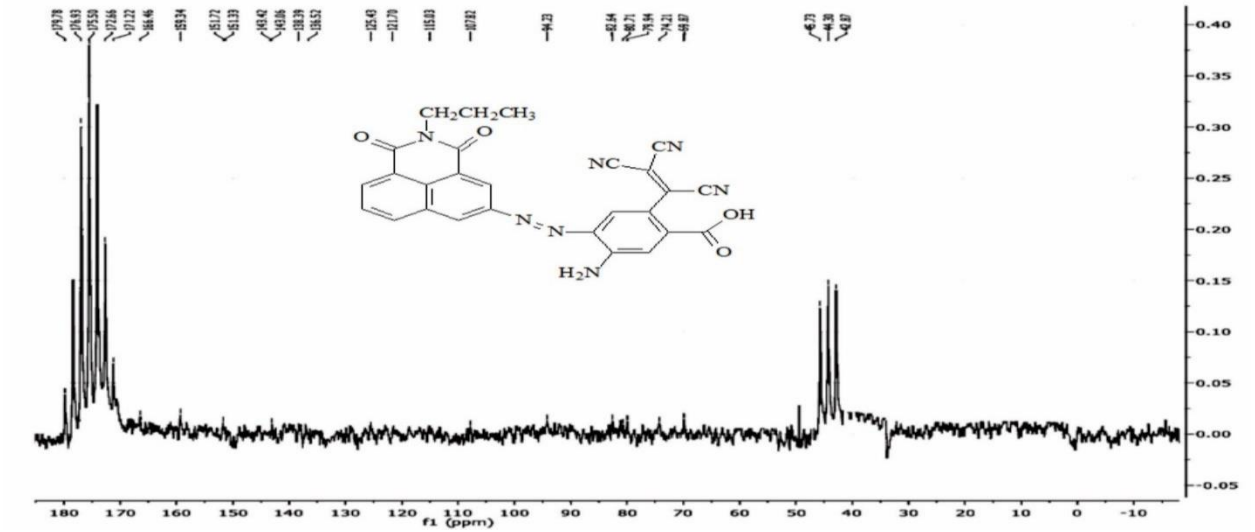


Figure 7: ^{13}C NMR of Dye 1

The ^{1}H and ^{13}C spectrum of the dyes is presented in Figures 6-7 and Table 5. The NMR spectral data confirm the successful synthesis and structural integrity of the naphthalimide azo dyes. The presence of conjugated aromatic systems, donor amino groups, electron withdrawing carbonyl and cyano functional group, together with carboxylic acid anchoring groups, indicates that the synthesized dyes possess favorable electronic structures for efficient light harvesting and electron transfer in DSSC applications. The observed chemical shifts are consistent with the proposed molecular frameworks containing aromatic rings, amino groups, azo linkages, cyano substituents, carboxylic acid groups, and the naphthalimide moiety.

For Dye 1, the singlet signal at δ 10.88 ppm corresponds to the proton of the carboxylic acid (COOH) group, confirming the presence of an anchoring functionality important for adsorption onto the TiO_2 surface in DSSCs. The aromatic proton signals appearing between δ 7.87–8.20 ppm are characteristic of highly conjugated aromatic systems associated with the naphthalimide and azo-linked benzene rings. The singlet at δ 7.73 ppm assigned to NH_2 protons confirms the amino substituent within the dye structure. Signals at δ 3.04, 2.99, and 2.04 ppm correspond to the propyl side chain protons (CH_2 and CH_3), indicating successful alkyl substitution on the naphthalimide nitrogen atom. Similarly, Dye 2 exhibited characteristic 1H-NMR signals confirming its proposed structure. The singlets at δ 11.96 ppm and 10.69 ppm correspond to carboxylic acid and hydroxyl protons respectively, indicating the presence of anchoring and hydrogen bonding functionalities. Multiple aromatic proton signals between δ 7.09-8.10 ppm confirm the highly conjugated aromatic framework of the dye, while the singlet at δ 6.87 ppm assigned to NH_2 protons indicates amino substitution [14].

The ^{13}C-NMR spectrum of Dye 1 further supports the proposed structure. Signals appearing between δ 166.46-179.78 ppm are attributed to imide and carboxylic carbonyl carbons, confirming the presence of strongly electron withdrawing carbonyl functionalities. Aromatic and conjugated carbons observed between δ 107.82-159.34 ppm indicate extensive π-electron delocalization throughout the dye molecule, which is essential for efficient light absorption and intramolecular charge transfer in DSSC applications [15]. The aliphatic carbon signals around δ 42.87-45.73 ppm correspond to the propyl substituent carbons. While, the ^{13}C-NMR spectrum of Dye 2 showed several downfield signals between δ 167.16-185.80 ppm attributable to carbonyl carbons of the imide and carboxylic groups. Aromatic and conjugated carbon resonances appearing

between δ 85.10-153.93 ppm confirm the presence of electron rich and electron deficient carbons within the conjugated dye backbone. These results suggest enhanced electron delocalization and donor–acceptor interactions within the molecule [16].

CONCLUSION

In this study, two novel naphthalimide substituted azo dyes were successfully synthesized through diazotization and azo coupling reactions and subsequently characterized using various spectroscopic and analytical techniques. The synthesized dyes exhibited appreciable percentage yields of 72.0% and 70.0% with melting point ranges of 170-173°C and 175-178°C respectively, indicating good purity and thermal stability of the compounds. The molecular structures proposed for the dyes were successfully confirmed through FT-IR, UV-Visible, Mass Spectrometry, and $^{1}H/^{13}C$-NMR analyses. The UV-Visible spectral studies revealed strong absorption within the visible region with λmax values ranging from 459-517 nm, demonstrating effective light-harvesting capability resulting from the extended π-conjugation and donor–π–acceptor architecture of the synthesized dyes. The high molar extinction coefficients, particularly 6.58×10^4 $Lmol^{-1}cm^{-1}$ for Dye 2, further indicate strong photon absorption characteristics desirable for dye sensitized solar cell applications. FT-IR spectra confirmed the successful incorporation of important functional groups such as azo, amino, carbonyl, and cyano moieties necessary for efficient intramolecular charge transfer and electron injection processes. Mass spectrometric fragmentation patterns and NMR spectral data further validated the structural integrity of the synthesized dyes by confirming the presence of aromatic conjugated systems, electron donating amino groups, and electron withdrawing carbonyl and cyano functional groups. These structural features are essential for enhancing charge separation, electron delocalization, and anchoring ability on semiconductor surfaces in DSSC systems. Thus, the synthesized naphthalimide azo dyes demonstrated favorable photo physical and structural properties suitable for potential application as organic sensitizers in dye sensitized solar cells.

REFERENCES

[1] Grätzel, M. (2003). Dye-sensitized solar cells, *Journal of Photochemistry and Photobiology*, 4(2), 145-153.

[2] Hosseinnezhad, M., Ranjbar, Z. & Moradian, S. (2023). Flexible dye-sensitized solar cells

as sustainable energy resources, *Journal of* Pigment *& Resin Technology*, *52*(3), 310-320.

[3] Nagarajan, B., Athrey, C. D., Elumalai, R., Sudakar, C. & Raghavachari, D. (2020). Naphthalimide-phenothiazine based A′-π-D-π-A featured organic dyes for dye sensitized solar cell applications, *Journal of Photochemistry and Photobiology A: Chemistry, 404*, 112820

[4] Xu, Z., Li, Y., Yuan, S., Hao, L., Gao, S. & Lu, X. (2020). Theoretical study of phenothiazine/carbazole-based organic dyes with naphthalimide as π-spacer for DSSCs. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *233*, 118-201.

[5] Dong, H. Q., Wei, T. B., Ma, X. Q., Yang, Q. Y., Zhang, Y. F., Sun, Y. J., Shi, B. B. & Yao, H. (2020). 1,8-Naphthalimide-based fluorescent chemosensors: Recent advances and perspectives. *Journal of Materials Chemistry C, 8*, 13501–13529.

[6] Hosseinnezhad, M., Nasiri, S., Nutalapati, V., Gharanjig, K. & Arabi, A. M. (2024). Application of organic dyes based on naphthalimide in optical and electrical devices. *Progress in Color, Colorants and Coatings*, *17*(4), 417–433.

[7] Fed'ko, A. & Anikin, V. (2015). Synthesis of naphthalimide derivatives, *Journal of Organic Chemistry*, 80(3), 1120–1132.

[8] Obadahun. J, K. A., Bello, Yakubu, M. K., Abdelmalik, A. A. & Abdulhakeem, A. A. (2023). Synthesis, Characterization and Photo-Electrochemical Conversion of 3,5-Diamino-4-[(E)-(6-Hydroxy-1, 3-Benzothiazol-2-Yl)Diazenyl]-2-(Tricyanoethenyl) Benzoic Acid, *Journal of Science Technology and Education*, 11(3), 186-193

[9] Agho, O.B., Nkeonye, P.O., Kogo, A.A., Enyeribe C.C., Obadahun J. & Idoko G.O. (2017). Synthesis and Application of Heterocyclic Disperse and Acid Dyes Derived from 2-Aminothiophene and Conventional Amines as the Diazo Components, *International Journal of Advanced Research and Publications (IJARP)*, 1(5), 437-444.

[10] Mishra, A., Fischer, M. K. R. & Bäuerle, P. (2020). Metal-free organic dyes for dye-sensitized solar cells: From structure to device performance, *Angewandte Chemie International Edition*, 59(8), 338-356.

[11] Kuang, D., Klein, C., Ito, S., Moser, J.E., Humphry-Baker, R., Zakeeruddin, M.S. & Gratzel M. (2007). High Molar Extinction Coefficient Ion-Coordinating Ruthenium Sensitizer for Efficient and Stable Mesoscopic Dye-Sensitized Solar Cells, *Advanced Functional Materials*, 17, 154-160.

[12] Nagarajan, B., Athrey, C. D., Elumalai, R., Sudakar, C. & Raghavachari, D. (2020). Naphthalimide-phenothiazine based A′-π-D-π-A featured organic dyes for dye sensitized solar cell applications. *Journal of Photochemistry and Photobiology A: Chemistry*, 404, 112-120.

[13] Chiu K.Y., Tran T.H., Chang S.H., Yang T.F. & Su. Y.O. (2017). A New Series of Azo Benzene-bridged Metal-free Organic Dyes and Application on DSSC. *Dyes and Pigments*, 146-148.

[14] Zhang, Q. & Cao, G. (2011). Nanostructured photoelectrodes for dye-sensitized solar cells. *Nano Today*, *6*(1), 91–109.

[15] Senthilvelan, J. & Venkatesan, P. (2016). Synthesis, characterization and photovoltaic properties of naphthalimide-based sensitizers for dye-sensitized solar cells. *Journal of Photochemistry and Photobiology A: Chemistry*, *324*, 1-8.

[16] Faezeh. A., Zohreh R.R. & Hassan F.E.G. (2022). Effect of Dye Complex Structure on Performance in DSSCs; An Experimental and Theoretical Study, *Journal of Photochemical Photobiology Chemistry*. 8(11), 231-238.