Revised: 11 March 2020

ARTICLE



One-pot synthesis of 2*H*-indazolo[2,1-*b*]phthalazine-triones via nano γ -Al₂O₃/BF₃/Fe₃O₄ as an efficient catalyst and theoretical DFT study on them

Mahnaz Mahmoodi Fard Chegeni¹ | Abdolhamid Bamoniri¹ Avat Arman Taherpour^{2,3}

¹Department of Organic Chemistry, Faculty of Chemistry, University of Kashan, Kashan, Iran

²Department of Organic Chemistry, Faculty of Chemistry, Razi University, Kermanshah, Iran

³Medical Biology Research Center, Kermanshah University of Medical Sciences, Kermanshah, Iran

Correspondence

Avat Arman Taherpour, Department of Organic Chemistry, Faculty of Chemistry, Razi University, PO Box 67149-67346, Kermanshah, Iran.

Email: avatarman.taherpour@gmail.com

Abstract

Experimental and computational studies were carried out for the synthesis of 2*H*-indazolo[2,1-*b*]phthalazine-triones using γ -Al₂O₃/BF₃/Fe₃O₄ as а nanocatalyst in optimized and solvent-free conditions. The most significant features of the existing protocol are easy preparation of the catalyst, short reaction times, environmentally benign, and milder reaction conditions. The analysis data were reported using the experimental results of this investigation, such as: H-NMR, FT-IR (Fourier-transform infrared spectroscopy), X-ray diffraction, vibrating-sample magnetometer, Thermal gravimetric analysis (TG-DTG), nitrogen adsorption isotherm, Field Emission Scanning Electron Microscopy, and Transmission electron microscopy images of nanocatalyst. In this study, 2H-indazolo[2,1-b]phthalazine-triones have also been theoretically investigated using DFT-B3LYP/6-31G method. Also, some of the physical chemistry properties have examined for conformers of products, which there was good agreement between the computational results and obtained experimental for the products.

1 | INTRODUCTION

In the last years, the synthesis of novel heterocyclic compounds has been a subject of great interest due to their broad applicability. Heterocyclic compounds are widely happened in nature and are essential for life.^[1] Large range of heterocyclic compounds containing phthalazine moiety have attracted significant attention because of their pharmacological and biological activities.^[2-4] Research has shown that phthalazine derivatives have cardiotonic and anticonvulsant vasodilator activities.^[5,6] Therefore, the synthesis of heterocycles containing phthalazine skeleton was done using SO₃H-Silica Materials,^[7] Y Functionalized Mesoporous $(OTf)_{3}$, [8] Mg(HSO₄)₂,^[9] sulfonated poly (ethyleneglycol),^[10] p-TSA, cyanuric chloride,^[11] N-

halosulfonamides,^[12] tungstosilicic acid,^[13] nanosilica sulfuric acid^[14] and phosphosulfonic acid,^[15] $Fe_3O_4@SiO_2-ZrCl_2-MNPs$,^[16] H_2SO_4 ,^[17] CuCl, and CuI nanoparticles.^[18] as catalysts derivatives. However, design of novel methods for the synthesis of heterocycles containing a phthalazine ring is an important challenge.^[19–22]

Multicomponent reactions with magnetic and heterogeneous catalyst and solvent-free process are more attractive to the researchers because they will minimize the waste and hazardous chemicals, and also because of their selectivity and reactivity in organic changes.^[23–27] As a result, in the present work γ -Al₂O₃/BF_n/Fe₃O₄ nanoparticles (NPs) were utilized as a reusable catalyst for the synthesis of 2*H*-indazolo[2,1-*b*]phthalazine-trione derivatives (Scheme 1). 2 WILEY



SCHEME 1 Synthesis of 2*H*-indazolo[2,1-*b*]phthalazine-triones in the presence of nano γ -Al₂O₃/BF₃/Fe₃O₄



FIGURE 1 XRD patterns of (A) nano- γ -Al₂O₃/BF₃, (B) Fe₃O₄, and (C) γ -Al₂O₃/BF₃/Fe₃O₄

The theoretical study of heterocyclic compounds has attracted much attention, recently. Because this approach will allow us to have a better understanding of product structure.^[28] Changes in the molecular structure (such as tautomerism studies) of molecules result in large changes in both physical and chemical properties such as solubility and stability in the vacuum and selected solvents, and electronic properties, energy gaps, dipole moments, polarizabilities, energies, and frontier orbital energies.^[29] As a result, in the present work γ -Al₂O₃/BF₃/Fe₃O₄ NPs were used as a reusable catalyst for the preparation of 2*H*indazolo[2,1-*b*]phthalazine-trione derivatives. To achieve the best result, in this study, these derivatives are theoretically investigated by DFT-B3LYP/6-31G method.^[30]

2 | EXPERIMENTAL

2.1 | General

All reagents were bought from Merck and Aldrich companies and used without further purification. FTIR spectra were gained using a Bruker, Equinox 55 spectrometer.



FIGURE 2 FT-IR (ATR) spectrum of (A) Fe₃O₄, (B) γ -Al₂O₃/ BF₃/Fe₃O₄



FIGURE 3 Thermal gravimetric analysis (TG-DTG) pattern of $\gamma\text{-Al}_2\text{O}_3/\text{BF}_3/\text{Fe}_3\text{O}_4$



FIGURE 4 VSM images of (A) Fe_3O_4 and (B) $Al_2O_3/BF_3/Fe_3O_4$

A Bruker (DRX-400 Avance) NMR was used to record the ¹HNMR spectra. Vibrating-sample magnetometer (VSM) measurements were performed by using a vibrating sample magnetometer (Meghnatis Daghigh Kavir Co., Kashan, Iran). X-ray diffraction (XRD) pattern using Philips Xpert MP diffractometer (Cu K α , radiation, k = 0.154056 nm) was attained. Field Emission Scanning Electron Microscopy (FESEM) was obtained a Mira Tescan Phenom proX. The thermal gravimetric analysis (TGA) was done with the "STA 504" instrument. Transmission electron microscopy (TEM) image was obtained using a Philips CM120 with a LaB6 cathode and accelerating voltage of 120 kV Spartan '10 package was used to calculate the energy of each products.

2.1.1 | General procedure for the synthesis of 2*H*-indazolo[1,2-*b*]phthalazine-triones

A mixture of aldehyde (0.13 g, 1.2 mmol), dimedone (0.14 g, 1 mmol), phthalicanhydride (0.14 g, 1 mmol), hydrazinhydrate (5 g, 1.2 mmol) and nano- γ -Al₂O₃/BF_n/ Fe₃O₄ (0.08 g) was initially stirred in an oil bath at 80°C under solvent-free conditions. After the termination of the reaction which was monitored by TLC: *n*-hexane: ethyl acetate (8:2), 5 mL of ethanol was added to the mixture of the reaction and the catalyst was separated by an external magnet. By adding H₂O (5 mL) to residue, the solid product was appeared and then recrystallized from ethanol to reach the pure product.

2.2 | Preparation steps for catalysts

2.2.1 | Preparation of Fe₃O₄ nanoparticles

In a two-necked flask (250 mL), a mixture of FeCl₃· $6H_2O$ (5.838 g, 0.022 mol), FeCl₂· $4H_2O$ (2.147 g, 0.011 mol), and 100 mL of distilled water was stirred at 80°C under nitrogen atmosphere. Afterwards, 10 mL of aqueous NH₃ solution (32%) was added dropwise to the mixture with a vigorous mixing. Magnetic nanoparticles were separated from reaction mixture by an external magnet and washed with distilled water. Finally, the magnetic product was dried at 80°C.



FIGURE 5 Nitrogen adsorption isotherm at 77.36 K of nano- γ -Al₂O₃/ BF_n/Fe₃O₄



FIGURE 6 FE-SEM images of nano- γ -Al₂O₃/BF_n/Fe₃O₄



FIGURE 6 Recyclability of the catalyst in the reaction reported in Table 2, entry 3



FIGURE 7 TEM images of nano- $\gamma\text{-}Al_2O_3/BF_n/Fe_3O_4$

▲ WILEY-



Entry	Catalyst (mg)	Solvent/T (°C)	Time (min)	Yield ^b (%)
1	$H_2SO_4(15)$	[bmim]BF ₄ H ₂ O-EtOH/80	40	85
2	Fe ₃ O ₄ (20)	—/110	80	80
3	CuI NPs (15)	—/80	25	90
4	$Fe_3O_4@SiO_2-ZrCl_2$ (15)	—/80	25	90
5	$PMA-SiO_2(15)$	—/80	30	80
6	TBBDA (7)	—/100	10	89
7	H ₄ SiW ₁₂ O ₄₀ (10)	—/100	10	90
8	Nano SiO ₂ -OSO ₃ H (125)	—/80	40	80
9	PSA (7)	—/100	10	90
10	Nano-γ-Al ₂ O ₃ /BF _n /Fe ₃ O ₄ (8)	—/80	10	98 [This work]
11	Nano- γ -Al ₂ O ₃ /BF _n /Fe ₃ O ₄ (8)	—/90	10	98
12	Nano- γ -Al ₂ O ₃ /BF _n /Fe ₃ O ₄ (8)	—/60	35	75
13	Nano- γ -Al ₂ O ₃ /BF _n /Fe ₃ O ₄ (8)	H ₂ O/reflux	120	25
14	Nano- γ -Al ₂ O ₃ /BF _n /Fe ₃ O ₄ (8)	EtOH/reflux	50	62
15	Nano- γ -Al ₂ O ₃ /BF _n /Fe ₃ O ₄ (8)	CH ₃ CN/reflux	50	57

^aPhthalicanhydride (1 mmol), hydraziniumhydroxide (1 mmo1), benzaldehyde (1 mmol), and dimedone (1 mmol). ^bIsolated yield.

2.2.2 | Preparation of γ -Al₂O₃/BF₃/Fe₃O₄ nanoparticles

Fe₃O₄ nanoparticles (1.5 g) were added to nano- γ -Al₂O₃/BF_n (1/5 g) in CH₂Cl₂ (40 mL) and were dispersed by ultrasonic bath for 40 minutes. Afterward, the reaction mixture was filtered, the precipitate was washed several times with CH₂Cl₂ and dried at room temperature.

2.3 | Computational methods

The optimized structures have been achieved using Spartan '10 package. This software calculates the ground-state molecular geometry parameter, FT-IR and NMR spectra, the geometry energy optimizations. The energy optimizations of structures were first carried out without any symmetry constraints by the analytical gradient methods of B3LYP using the standard polarized basis set, 6-31G* implemented in the Spartan '10 software package.

3 | **RESULTS AND DISCUSSIONS**

3.1 | Catalyst characterization results

XRD pattern of the γ -Al₂O₃/BF₃ (A), Fe₃O₄ (B) and γ -Al₂O₃/BF₃/Fe₃O₄ (C) is characterized in Figure 1. The signals at 2 θ equal to 40 (c) and 67 (d) display nano- γ -Al₂O₃ structure. Two additional signals at 2 θ equal to 15 (a) and 28 (b) are exposed the presence of bonded BF₃ to nano- γ -Al₂O₃, respectively. According to Debye-Scherrer equation ($\tau = \frac{K\lambda}{\beta\cos\theta}$) the crystallite size equal to 6.5 nm ($\beta = 0.5$, $\theta = 11$, K = 0.94, $\lambda = 0.154$ nm) has been detected.

In the spectra of Fe₃O₄ NPs, the wide band at 1627 and 3446 cm⁻¹ are corresponding to the surface adsorbed water and hydroxyl groups of Fe₃O₄ NPs, while the peaks at 459 and 598 cm⁻¹ are respectively corresponding to the octahedral bending and tetrahedral stretching vibration of the Fe –O functional group and the peak at 630 cm⁻¹ approves the existence of Fe₃O₄ structure. The FT-IR spectra of γ -Al₂O₃/BF₃/Fe₃O₄ display significant ⁶ ____WILEY_

TABLE 2 Synthesis of 2*H*-indazolo[2,1-*b*]phthalazine-trione derivatives in the presence of nano-γ-Al₂O₃/BF₃/Fe₃O₄

Entry	Aldehyde	Time (min)	Product	Yield ^a (%)	Mp (°C) [Ref]
1	4-NO ₂ C ₆ H ₄ -CHO (1a)	12	$ \overset{\mathbf{O}}{\underset{\mathbf{O}}{\bigvee}} \overset{\mathbf{NO}_2}{\underset{\mathbf{O}}{\bigvee}} \overset{\mathbf{O}}{\underset{\mathbf{O}}{\bigvee}} (1b) $	95	270-272 ^[18]

2	4-HCOOC ₆ H ₄ -CHO (2a)	10	(2b)	98	250-265 ^[18]
3	3-ClC ₆ H ₄ -CHO (3a)	12	$ \begin{array}{c} & & & \\ & & & & \\ & & & \\ & & $	97	208-210 ^[13]

4	4-MeC ₆ H ₄ -CHO (4a)	15	O O O O O O O O O O	90	245-246 ^[8]
5	2-ClC ₆ H ₄ -CHO (5a)	16		96	264-266 ^[13]



-WILEY -7

TABLE 2 (Continued)

Entry	Aldehyde	Time (min)	Product	Yield ^a (%)	Mp (°C) [Ref]
6	4-HOC ₆ H ₄ -CHO (6a)	13	o o o o o o o o o (6b)	92	258-260 ^[18]
7	4-OMeC ₆ H ₄ -CHO (7a)	17	ocH ₃ o v v v v v v v v v v v v v v v v v v	95	220-222 ^[8]
8	2-HO-5-BrC ₆ H ₃ -CHO (8a)	14	$ \begin{array}{c} & & \\ & & $	90	240-255 ^[18]
9	2-NO ₂ C ₆ H ₄ -CHO (9a) ^b	60	(9b)	<50	_
10	2-N(CH3) ₂ C6H4-CHO (10a) ^b	65	$ \bigcirc \\ 0 \\ 0 \\ 0 \\ (10b) $	<55	_

^aIsolated yield. ^bThe product could not be separated because of low yields.

-8



SCHEME 2 A plausible mechanism for the formation of 2*H*-indazolo[2,1-*b*]phthalazinetrione in the presence of nano- γ -Al₂O₃/BF_n/Fe₃O₄

peaks at 1095 and 796 cm⁻¹ corresponding to symmetrical and asymmetrical vibrations of Al-O-Al, respectively (Figure 2B). Weak band at 459 cm⁻¹ regarding to the Al-O-Fe stretching vibrations of the γ -Al₂O₃/Fe₃O₄. These results show that Fe₃O₄ is immobilized on the surface of Al₂O₃. The successful covalent bonding of BF₃ on the surface of Al₂O₃ was confirmed by the band available at 1623 cm⁻¹, which originates from the absorption of O-BF₃ (Figure 2B).

(III)

Thermal gravimetric analysis (TG-DTA) pattern of γ -Al₂O₃/BF_n/Fe₃O₄ was identified using heating from 0°C to 800°C (Figure 3). TGA curve of the catalyst advises a preliminary weight loss of 0% below 200°C, owing to the physically adsorbed water on the Al₂O₃. According to the TGA diagram of nano-Al₂O₃/BF_n/Fe₃O₄, it was

shown that this catalyst is suitable for the catalysis of organic reactions up to 100° C.

The magnetization curve of magnetite nanoparticles is shown in Figure 4 at room temperature by VSM. Within the VSM magnetization curves of Fe_3O_4 and γ -Al₂O₃/BF₃/Fe₃O₄ nanoparticles, there is a lack of hysteresis, and the remanence and coercivity is negligible, which reveals the superparamagnetism of these nanomaterials (Figure 4). The saturation magnetization value of γ -Al₂O₃/BF₃/Fe₃O₄ (28.3 emu g⁻¹) is below that of Fe₃O₄ (62.3 emu g⁻¹) because of the existence of a nonmagnetic Al₂O₃/BF₃ coating.

The specific surface area of catalyst was measured via Brunauer-Emmett-Teller (BET) theory. The BET surface

8

FIGURE 8 Theoretical and

experimental FT-IR Spectra for entry 4: (A) experimental spectrum of En 4; (B) theoretical spectrum of En 4



area is assigned as 131.73 m² g⁻¹. The Nitrogen adsorption isotherm of catalyst is described in Figure 5.

The FE-SEM images of the γ -Al₂O₃/BF₃/Fe₃O₄ nanoparticles are shown in Figure 6A,B. By using SEM, the particle size and morphology of the γ -Al₂O₃/BF₃/ Fe₃O₄ was examined. An irregular spherical shape has been displayed for nanoparticles below 5 µm.

TEM measurement was used to confirm the structure of γ -Al₂O₃/BF₃/Fe₃O₄ as nanocatalyst in Figure 7A,B. The TEM image of γ -Al₂O₃/BF₃/Fe₃O₄ displays an integrated γ -Al₂O₃/BF₃ coating gathered on the exterior of Fe₃O₄, demonstrating the core/shell structure of the catalyst.

3.2 | Synthesis

The condensation of dimedone with benzaldehyde, phthalicanhydride, and hydrazinium hydroxide is chosen as a model reaction for the production of 2*H*indazolo[2,1-*b*]phthalazine trione. The obtained results of this reaction in the presence of various catalysts under different conditions such as temperature, solvent, and amount of catalyst were summarized in Table 1. The best result was obtained at 80°C and 8 mg of nano- γ -Al₂O₃/BF_n/Fe₃O₄ under solvent-free condition (Table 1, entry 10).

Using these optimized reaction conditions, the choice and efficiency of these procedures were

discovered for the synthesis of a broad range of substituted 2*H*-indazolo[2,1-*b*]phthalazine-triones. Both aromatic aldehydes containing electron-donating or electron-withdrawing groups act well in these reaction conditions (Table 2).

To examine the reusability of the catalyst, the condensation reaction of 3-chlorobenzaldehyde, phthalicanhydride, hydrazinehydrate, and dimedone (Table 2, entry 3) was studied. After completion of reaction, the catalyst was separated washed with CH_2Cl_2 , dried at 50°C under vacuum for 1 hour, and reused for the same reaction. This process was performed over five runs and all reactions led to the pure product with high yield (Figure 7).

3.2.1 | Plausible mechanism

The proposed mechanism for the synthesis of 2*H*-indazolo [2,1-*b*]phthalazinetrione is shown in Scheme 2. It was anticipated that, at first, the nano- γ -Al₂O₃/BF_n/Fe₃O₄ accelerates the formation of unsaturated carbonyl compounds (I) by the coordination of the carbonyl group of aldehyde to boron anchored onto the nano- γ -Al₂O₃/BF_n/Fe₃O₄. Then, phthalhydrazide attacks the electrophilic intermediate via a Michael-type addition to produce the intermediate (II), which can be converted to the product (III) via an intramolecular cyclization.^[16]





3.3 | Experimental selected spectroscopic data

10

3.3.1 | 3,4-Dihydro-3,3-dimethyl-13-(4-methylphenyl)-2H-indazolo[2,1-b] phthalazine-1,6,11(13H)-trione (Table 2, entry 4, 4b)

FT-IR $[\bar{v} \text{ (cm}^{-1}((\text{KBr}))]: 1275 \text{ (C-N Stretch)}, 1312 \text{ (CH}_3)$ bend), 1468, 1625 (C=C aromatic stretch), 1660 (C=O stretch), 2957)C-H aliphatic stretch).

¹H NMR (DMSO- d_6 , 400 MHz δ_{ppm}): 1.08 (s, CH₃), 1.11 (s, CH₃), 2.49 (s, CH₂), 3.29 (q, CH₂), 6.22 (s, CH),

7.09 (d, 2H, J = 8 Hz), 7.29 (d, 2CH, J = 8.4 Hz), 7.94 (t, 2CH, J = 8 Hz), 8.07 (d, 1H, J = 8.4 Hz), 8.24 (d, 1H, J = 8.4 Hz), 8.35 (s, CH).

3.3.2 | 3,4-Dihydro-3,3-dimethyl-13-(2-hydroxy-5-bromophenyl)-2H-indazolo [2,1-b]phthalazine-1,6,11(13H)-trione (Table 2, entry 8, 8b)

FT-IR $[\bar{v} \text{ (cm}^{-1}((\text{KBr}))]$: 1288 (C—N Stretch), 1322 (CH₃) bend), 1416 (CH₂ bend), 1457, 1608 (C=C aromatic



FIGURE 11 The structures of the tautomers T₁, T₂ of **8b** molecule

stretch), 1611 (C=O stretch), 2997)C-H aliphatic Stretch), 3431 (OH stretch).

¹H NMR (DMSO-*d*₆, 400 MHz δ_{ppm}): 0.99 (s, CH₃), 1.12 (s, CH₃), 1.23 (s, CH), 2.21 (q, CH₂), 2.46 (s, CH₂), 4.71 (s. OH),5.49 (s, CH), 7.19 (t, 2H, *J* = 8 Hz), 7.23 (d, 2H, *J* = 8.4 Hz), 7.26 (s, 1H), 7.86 (d, 1H, *J* = 8.4 Hz), 7.99 (d, 1H, *J* = 8.4 Hz).

3.4 | Experimental and theoretical selected spectroscopic data

There is good arrangement between the obtained experimental and computational results for the products **1b-8b**, that were synthesized from **1a-8a** by the use of the nanocatalyst **C**.



FIGURE 12 Theoretical and experimental ¹HNMR spectra for entry 8: (A) experimental spectrum of En 8; (B) theoretical spectrum of En 8 (T₂)

To interpret and confirm the obtained experimental results for the products 1b-8b were investigated the IR and NMR spectra, Mulliken charges, HOMO and LUMO frontier orbitals, and solvent effects on chemical shifts by applying the DFT-B3LYP/6-31G* method (eg, entries 4 and 8; Figures 8-12). Due to the experimental and theoretical obtained results for the products, the structures of the compounds 1b-8b were obviously confirmed (). For product 8b, there was a difference in the chemical shift for H atom. This difference somehow could be related to the values of the electrostatic and Mulliken charges, and also the solvent effects on chemical shifts by the use of frontier orbitals (F.O.s) concepts. So, to determine this point the structure of 8b was investigated. There are two conformers for 8b product by rotation around C8-C18

12

bond. In these two conformers H_2 has made two hydrogen bonds with the oxygen atoms of the carbonyl functional groups on the two sides of 8b molecule structure. See Figure 11.

The calculations were performed on these two conformers in the gas phase and DMSO media (similar to the experimental NMR conditions). There is a notable difference for the obtained chemical shifts for two conformers. So, the nearest obtained chemical shift for H₂ (in DMSO; calculation) has been chosen to determine that which conformer appears in the experimental NMR issue? The theoretical results have shown that T_2 conformer has the nearest data to the empirical results. At the structure of DMSO molecule the external cortex has covered the positive charges of this molecule, so, the

external cortex with δ - charge make a repulsion with the nitrogen loan pairs of **8b** molecule (like the N-atoms in the :N-C=O amide functional groups).

It seems that due to this case (discussed repulsion) the amidic resonance would be activated in **8b** than anomeric effect of N-atom on C_8 - H_3 . The experimental (FT-IR) vibrational frequencies for C=O group in amide functional groups in **8b** were 1611 cm⁻¹, which is lower than the normal amides (about 1650-1690 cm⁻¹). So, C_8 - H_3 has not shown anomeric effect under loan pair N-atom effect. Due to this point H_3 has shown the chemical shift in the more down field in ¹H-NMR spectra (4.71 ppm). The Mulliken charges of $H^{\delta+}_3$ in **8b** product (T₂ conformer) were calculated +0.195 esu. To compare the electronic effects on H_3 of **8b** molecule was designed a selected molecule, that is, 4-bromo-2 isopropylphenol (**S**) (Figure 13), which has not N-atoms near to isopropyl



4-bromo-2-isopropylphenol

FIGURE 13 Selected molecule in comparison with 8b molecule

group. The calculation on this molecule was performed in DMSO media. The calculated Mulliken charges for the selected molecule 4-bromo-2 isopropylphenol (**S**) were +0.146 esu. Due to the electronegativity and induction effect of N-atom, the Mulliken charge of $H^{\delta+8}$ in **8b** is +0.049 esu more positive than C_{sp3} - $H^{\delta+}$ of the selected (**S**) molecule. The results show that the N-atoms have performed their resonance effects as a part of amide functional group with C=O functional group and demonstrate the induction effect on **H**₃-atom in **8b** and other similar **1b-7b** molecules.

The difference between the stability of the two conformers of **8b** is about 1.27 kcal mol⁻¹, but some other data could be applied to determine T_2 conformer has more preference in DMSO solvent than T_1 conformer.

The comparison of the HOMO and LUMO energy levels of the two conformers (T_1 and T_2) has demonstrated that the energy level of HOMO orbital in the both conformers are almost the same (in T_1 6.03 eV and in T_2 6.04 eV) Figure 14. So, the basic or nucleophilic role of this molecule in both conformers is the same. But, the energy level of LUMO orbital in T_2 conformer is more stable about 0.21 eV than T_1 conformer. So, T_2 conformer is better electrophile and/or softer acid than T_1 conformer. So, T_2 conformer accepts the external cortex of DMSO solvent with δ - charge than T_1 form. Due to this effect, the signals of T_2 conformer appear in DMSO solvent and NMR experiments. On the other hand due to the discussions, the DMSO solvent has chosen T_2





FIGURE 14 Calculated HOMO-LUMO band gap ($\Delta E_{HOMO-LUMO}$) of the T₁, T₂ conformers of **8b** molecule

conformer of **8b** and the signals of this conformer have appeared in the NMR data.

4 | CONCLUSION

This study was described a very simple, efficient, clean, and eco-friendly method for the synthesis of 2H-indazolo [2,1-b]phthalazine-triones derivatives by nano γ -Al₂O₃/ BF_3/Fe_3O_4 in solvent-free conditions. This green protocol permits to gain the products in excellent yields. Also, these products have been theoretically investigated by DFT-B3LYP/6-31G* method. The calculated band gap of HOMO-LUMO orbitals, FT-IR and 1HNMR spectra, Electrostatic and Mulliken charge in DMSO media have examined for conformers of the products. The comparison of the HOMO and LUMO energy levels of T_1 and T_2 conformers for energy 8 demonstrated that the energy level of HOMO orbital in the both conformers were almost the same. The basic or nucleophilic role of this molecule in both conformers was seen the same. Due to the energy level of LUMO orbital in T_2 conformer that was more stable than T_1 conformer, T_2 conformer has shown better electrophile and/or softer acid properties than T_1 conformer. So, T_2 conformer accepts the external cortex of DMSO solvent with δ - charge than T_1 form. The analysis data such as: ¹H-NMR, FT-IR, XRD, VSM, Thermal gravimetric analysis(TG-DTG), Nitrogen adsorption isotherm, FE-SEM and TEM images of nanocatalyst, and the theoretical calculation demonstrated that there is good agreement between the obtained experimental and computational results for the products **1b-8b**, that were synthesized from **1a-8a** by the use of the nano-catalyst **C**.

ORCID

Avat Arman Taherpour D https://orcid.org/0000-0002-8933-1505

REFERENCES

- M. Sayyafi, M. Seyyedhamzeh, H. R. Khavasi, A. Bazgir, *Tetra*hedron 2008, 64, 2375.
- [2] H. R. Shaterian, A. Hosseinian, M. Ghashang, *ARKIVOC* 2009, 2, 59.
- [3] R. Tayebee, M. F. Abdizadeh, B. Maleki, E. Shahri, J. Mol. Liq. 2017, 241, 447.
- [4] A. Hasaninejed, M. R. Kazerooni, A. Zare, ACS Sustain. Chem. Eng. 2013, 1, 679.
- [5] H. R. Shaterian, M. Ghashang, M. Feyzi, Appl. Catal. A 2008, 345, 128.
- [6] J. Safaei-Ghomi, H. Shahbazi-Alavi, A. Ziarati, R. Teymuri, M. R. Saberi, *Chin. Chem. Lett.* **2014**, *25*, 401.
- [7] A. A. Amiri, S. Javanshir, Z. Dolatkhah, M. G. Dekamin, *New J. Chem.* 2015, 39, 9665.
- [8] K. Turhan, Z. Turgut, Russ. J. Org. Chem. 2019, 55, 250.

MAHMOODI FARD CHEGENI ET AL.

- [9] M. Kidwai, A. Jahan, R. Chauhan, N. K. Mishra, *Tetrahedron Lett.* 2012, 53, 1728.
- [10] A. Hasaninejad, A. Zare, M. Shekouhy, *Tetrahedron* 2011, 67, 390.
- [11] X. Wang, W. W. Ma, L. Q. Wu, F. L. Yan, J. Chin. Chem. Soc. 2010, 57, 1341.
- [12] R. Ghorbani-Vaghei, R. Karimi-Nami, Z. Toghraei-Semiromi, M. Amiri, M. Ghavidel, *Tetrahedron* 2011, 67, 1930.
- [13] H.-J. Wang, X.-N. Zhang, Z.-H. Zhang, Monatsh. Chem. 2010, 141, 425.
- [14] H. Hamidian, S. Fozooni, A. Hassankhani, S. Z. Mohammadi, *Molecules* 2011, 16, 9041.
- [15] A. R. Kiasat, A. Mouradzadegun, S. J. Saghanezhad, J. Serb, *Chem. Soc.* 2013, 78, 469.
- [16] F. Kamali, F. Shirini, New J. Chem. 2017, 41, 11778.
- [17] H. R. Shaterian, F. Rigi, Res. Chem. Intermed. 2014, 40, 1989.
- [18] C. V. Karunaratne, R. G. Sarkisian, J. Reeves, Y. Deng, K. A. Wheeler, H. Wang, *Org. Biomol. Chem.* **2017**, *15*, 4933.
- [19] H. R. Shaterian, F. Khorami, A. Amirzadeh, R. Doostmohammadi, M. Ghashang, J. Iran. Chem. Res 2009, 2009, 57.
- [20] M. Soheilizad, M. Adib, S. Sajjadifar, Monatsh. Chem. 2014, 145, 1353.
- [21] R. Tayebee, M. Jomei, B. Maleki, M. K. Razi, H. Veisi, M. Bakherad, J. Mol. Liq. 2015, 206, 119.
- [22] A. Patil, T. Lohar, A. Mane, S. Kamat, R. Salunkhe, J. Heterocyclic Chem. 2019, 56, 3145.
- [23] C. S. Maheswari, C. Shanmugapriya, K. Revathy, A. Lalitha, J. Nanostruct. Chem. 2017, 7, 283.
- [24] O. S. Zaky, M. A. Selim, M. M. Ebied, K. U. Sadek, J. Heterocyclic Chem. 2019, 56, 2796.
- [25] J. Sumalatha, C. Radha Rani, A. Sreedevi, J. Heterocyclic Chem. 2018, 55, 593.
- [26] M. V. Reddy, G. C. S. Reddy, Y. T. Jeong, *Tetrahedron* 2012, 68, 6820.
- [27] M. Abedini, F. Shirini, J. M.-A. Omran, J. Nanostruct. Chem. 2015, 212, 405.
- [28] A. A. Taherpour, F. Ghasemhezaveh, A. Yari, M. M. Khodaei, *Chem. Phys. Lett.* 2017, 676, 154.
- [29] A. A. Taherpour, M. M. F. Chegeni, M. M. Khodaei, N. Tamasoki, J. Iran. Chem. Soc. 2017, 14, 1613.
- [30] E. V. Anslyn, D. A. Dougherty, Modern Physical Organic Chemistry, University Science Books, 2006, USA.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Mahmoodi Fard

Chegeni M, Bamoniri A, Taherpour AA. One-pot synthesis of 2*H*-indazolo[2,1-*b*]phthalazine-triones via nano γ -Al₂O₃/BF₃/Fe₃O₄ as an efficient catalyst and theoretical DFT study on them. *J Heterocyclic Chem.* 2020;1–14. https://doi.org/10.1002/jhet.3989