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Synthesis of 8-Aryl-7*H*-acenaphtho[1,2-*d*]imidazoles Using Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ as a Green and Recyclable Magnetic Nanocatalyst

F. Hasanzadeh[a] and F. K. Behbahani[a,*]

[a] *Department of Chemistry, Karaj Branch, Islamic Azad University, Karaj, 314/85313 Iran*

[*] *e-mail: farahnazkargar@yahoo.com*

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Abstract—A general procedure has been developed for the rapid synthesis of 8-aryl-7*H*-acenaphtho[1,2-*d*]-imidazoles in high yields using Fe_3O_4NPs@GO@$C_4H_8SO_3H$ as a green and recyclable magnetic nanocatalyst under reflux conditions. The nanocatalyst was prepared and characterized by FT-IR, XRD, and EDX data. A variety of aromatic aldehydes underwent condensation with NH_4OAc and acenaphthenequinone to give 8-aryl-7*H*-acenaphtho[1,2-*d*]imidazole derivatives. The use of magnetic nanoparticles, easy separation of the catalyst with an external magnet, high yields, and short reaction times are the main advantages of this catalytic method.

Keywords: magnetic nanocatalyst, acenaphthoquinone, imidazole, Fe_3O_4 NPs@GO@$C_4H_8SO_3H$

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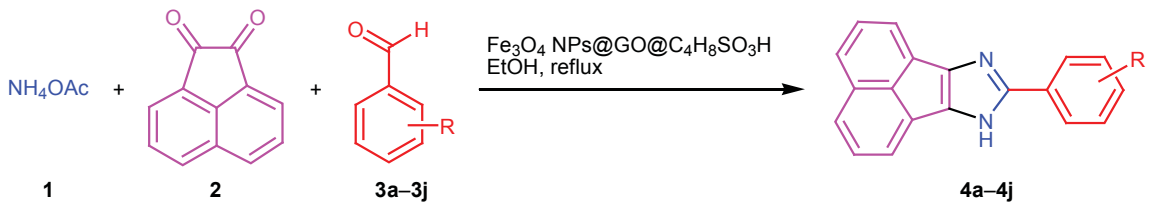
INTRODUCTION

Imidazoles as an important class of heterocyclic compounds reveal various biological activities such as herbicidal, antiallergic, analgesic, antidepressant, antitubercular, anticancer, anti-inflammatory, antifungal, and antiviral [1–9]. Imidazole ring is present in histidine [10] and the related hormone histamine [11], and some of imidazole derivatives are employed in electronic and optoelectronic devices [12]. Tetrasubstituted imidazoles have been synthesized by the four-component cyclocondensation of a 1,2-diketone, aldehyde, primary amine, and ammonium acetate using various Lewis or protic acids as catalysts, namely BF_3–SiO_2 [13], silica supported $NaHSO_4$ [14], HPA-EtOH [15], L-proline [16], $K_5CoW_{12}O_{40}\cdot 3H_2O$ [17], and HY zeolite–$Cu(NO_3)_2$ [19]. reactions between a 1,2-diketone, nitrile, and primary amine under microwave irradiation [20] and between 1,3-oxazolium-5-olates and *N*-(arylmethylidene)benzenesulfonamides [21] have also been reported. Multicomponent reactions (MCRs) are a very powerful tool in organic and medicinal chemistry for the preparation of bulky products in a one-pot fashion from simple starting materials. A combination of magnetic nanocatalysts and multicomponent reactions could provide efficient and sustainable procedures for green syntheses [22]. Moreover, to the best of our knowledge, Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ as a new reusable heterogeneous nanocatalyst has not been utilized previously for one-pot preparation of 8-aryl-7*H*-acenaphtho[1,2-*d*]imidazoles. Therefore, in continuation of our studies on the synthesis of heterocyclic compounds [23–27], we examined a wide variety of substituted benzaldehydes as starting materials to establish the catalytic importance of Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ for one-pot multicomponent

Scheme 1.



R = 3-NO_2 (**a**), 3-OH (**b**), 4-Me (**c**), 4-Br (**d**), 4-F (**e**), H (**f**), 2-OH (**g**), 2-OH-3-OMe (**h**), 2-OMe (**i**), 2,6-Cl_2 (**j**).

synthesis of 8-aryl-7*H*-acenaphtho[1,2-*d*]imidazoles via condensation with acenaphthenequinone and ammonium acetate (Scheme 1).

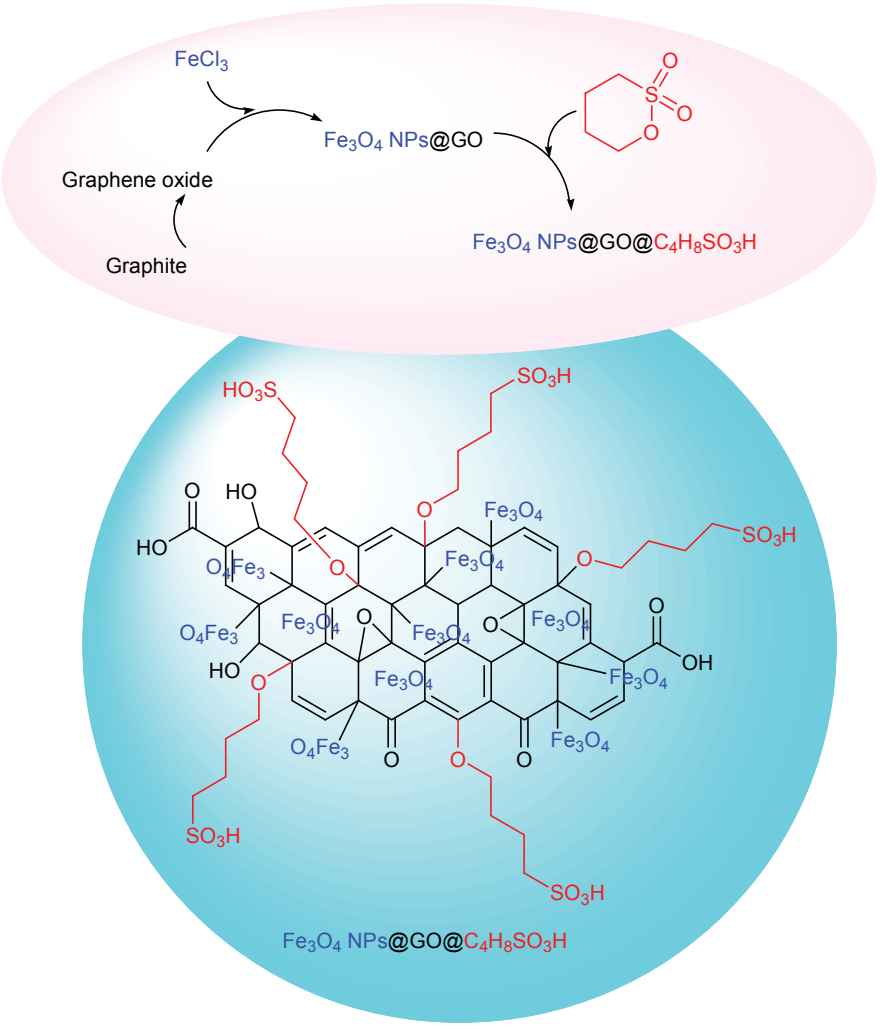
RESULTS AND DISCUSSION

Initially, graphene oxide (GO) was synthesized from graphite according to procedure described in [29], and Fe_3O_4 NPs@GO and Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ were prepared as reported in [30]. The synthesis of Fe_3O_4 NPs@GO@$C_4H_8SO_3H$, the growth of Fe_3O_4 nanoparticles, and the loading of $C_4H_8SO_3H$ onto graphene oxide are illustrated by Scheme 2.

To confirm the structure of the nanocatalyst, its FT-IR spectrum was measured (Fig. 1). The FT-IR spectrum of graphene oxide exhibits absorption bands for the functionalities containing oxygen atoms such as OH group (~3435 cm^{-1}), carboxylic C=O group (~1719 cm^{-1}), and C=C (~1585 cm^{-1}) and C–O bonds (~1385 cm^{-1}) (Fig. 1a). The presence of Fe–O band (~564.13 cm^{-1}) in the FT-IR spectrum of Fe_3O_4 NPs@GO confirms that Fe_3O_4 NPs are located on the GO structure (Fig. 1b). Figure 1c shows new bands at 2919 and 1029 cm^{-1} which were assigned to stretching vibrations of Csp^3–H and C–S bonds, respectively, indicating that butane-1,4-sultone was loaded on Fe_3O_4 NPs@GO@$C_4H_8SO_3H$.

The XRD pattern of the prepared Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ composite is shown in Fig. 2. The peaks appearing at 30.22, 35.62, 43.62, 53.92, 57.32, and 62.77° confirmed loading of Fe_3O_4 NPs on GO. These peaks are due to the cubic spinel crystal planes of Fe_3O_4. The presence of butane-1,4-sultone groups on the surface of Fe_3O_4NPs@GO was further confirmed by energy dispersive spectroscopy (EDS) (Fig. 3). According to the EDS data, the prepared catalyst contains 30.14% of carbon, 33.56% of oxygen; 1.74% of sulfur, and 35.69% of iron.

Scheme 2.



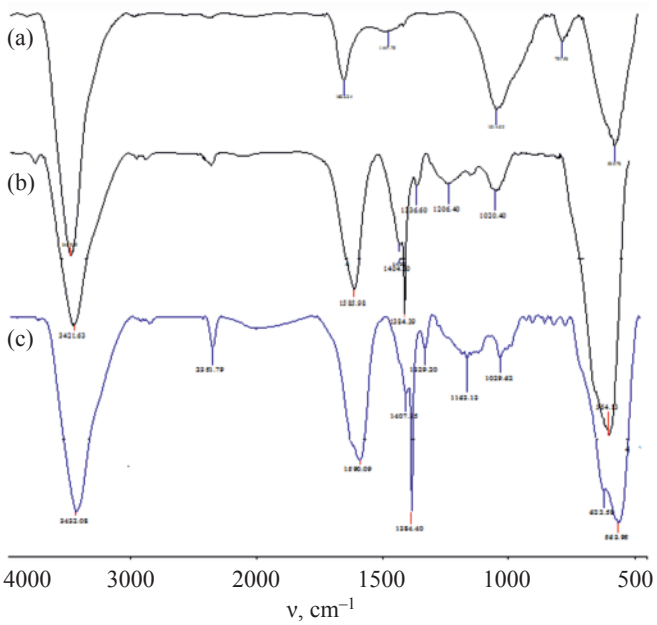


Fig. 1. FT-IR spectra of (a) graphene oxide (GO), (b) GO@Fe_3O_4 NPs, and (c) GO@Fe_3O_4 NPs@$C_4H_8SO_3H$.

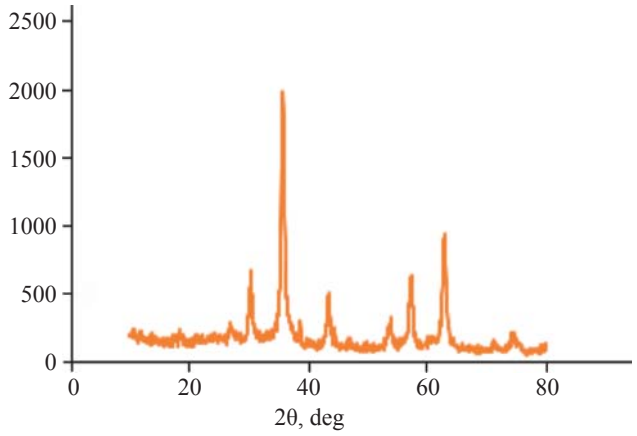


Fig. 2. XRD pattern of Fe_3O_4 NPs@GO @$C_4H_8SO_3H$.

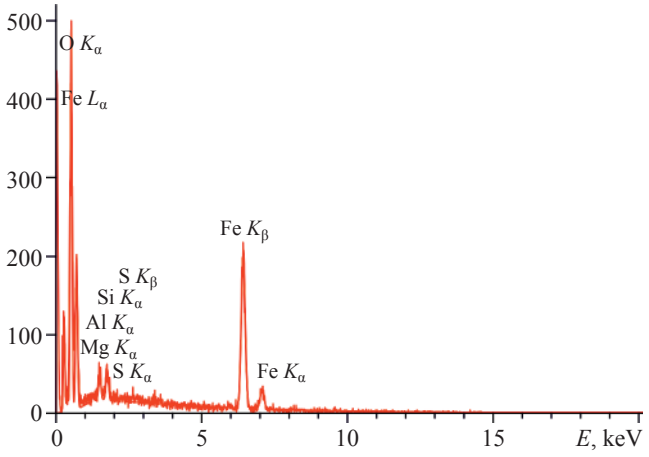


Fig. 3. EDS pattern of Fe_3O_4 NPs@GO@$C_4H_8SO_3H$.

As noted above, Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ has not been used previously for the synthesis of 8-aryl-7*H*-acenaphtho[1,2-*d*]imidazoles. Therefore, we decided to use this acidic magnetic nanocatalyst for the three-component condensation of substituted benzaldehydes, acenaphthenequinone, and ammonium acetate. For this propose, the effects of catalyst amount, temperature, and solvent nature were investigated in the model reaction with unsubstituted benzaldehyde. The results showed that the catalyst worked more efficiently in ethanol under reflux conditions (Table 1). The reaction was then performed in the presence of various amounts of Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ to examine their catalytic activity. An amount of 0.1 g was found to be most effective to afford the desired product in 98% yield (Table 1).

To investigate the substituent effect, a wide variety of aromatic aldehydes containing electron-withdrawing or electron-donating groups were utilized. Aromatic aldehydes with both electron-donating and electron-withdrawing groups reacted under the selected conditions in short reaction times (Table 2). The yields were good to excellent without formation of any by-products such as oxidation products of aldehydes, etc., which are normally formed under strongly acidic conditions. In each case, the reaction profile was clean, and this one-pot three-component procedure revealed some advantages over existing methods. The other features of this new method are simple isolation and purification of the products, easy separation of the catalyst by an external magnet and its repeated use.

To show the merits of this procedure in comparison with the previously reported protocols, we compared the synthesis of 8-phenyl-7*H*-acenaphtho[1,2-*d*]imidazole (**4f**) under different conditions (Table 3). The advantages of our procedure are the use of Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ as heterogeneous, reusable, and magnetically separable catalyst, excellent yield, short reaction time, and mild reaction condition, which are very important for chemical industry.

A plausible mechanism for the formation of 8-aryl-7*H*-acenaphtho[1,2-*d*]imidazoles from aldehydes, acenaphthenequinone, and ammonium acetate is given in Scheme 3.

EXPERIMENTAL

The melting points were measured in capillary tubes with an Electrothermal 9200 apparatus. The IR spectra were recorded on a Perkin Elmer FT-IR spectrometer between 4000 and 400 cm^{-1}. The ^1H NMR spectra

Table 1. The effects of the catalyst amount, temperature, and solvent in the synthesis of 8-phenyl-7*H*-acenaphto[1,2-*d*]-imidazole (**4f**) in the presence of Fe_3O_4 NPs@GO@$C_4H_8SO_3H$[a]

Amount of the catalyst, g	Solvent	Temperature, °C	Reaction time, min	Yield, %
0.05	EtOH	Reflux	7	84
0.08	EtOH	Reflux	7	87
0.09	EtOH	Reflux	9	94
0.09	EtOH	70	5	94
0.1	THF	75	8	95
0.1	$CHCl_3$	80	10	80
0.1	EtOH	75	8	90
0.1	EtOH	Reflux	5	98
0.12	EtOH	Reflux	8	95
0.15	EtOH	Reflux	8	85
0.17	EtOH	Reflux	10	84
0.2	EtOH	Reflux	12	85

[a] Benzaldehyde (1 mmol), acenaphthenequinone (1 mmol), ammonium acetate (2 mmol) and Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ in a solvent (10 mL)

Table 2. Synthesis of 8-aryl-7*H*-acenaphto[1,2-*d*]imidazoles **4a**–**4j** using Fe_3O_4 NPs@GO@$C_4H_8SO_3H$

Compound no.	R	Reaction time, min	Yield, %
4a	3-NO_2	15	82
4b	3-OH	7	96
4c	4-Me	5	98
4d	4-Br	8	92
4e	4-F	10	94
4f	H	5	98
4g	2-OH	9	94
4h	2-OH-3-OMe	8	96
4i	2-OMe	12	94
4j	2,6-Cl_2	10	95

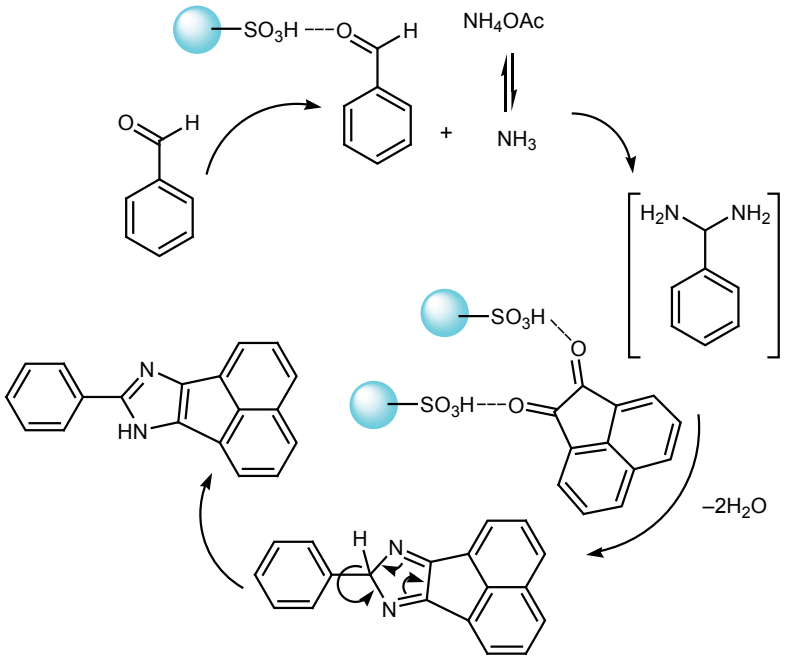
Table 3. Comparison of different reaction conditions for the synthesis of **4f**

Catalyst	Reaction time, min	Yield, %	Solvent	Reference
Nano-SnO_2	150	86	EtOH	[28]
Nano-SiO_2	600	40	EtOH	[28]
Nano-ZrO_2	360	50	EtOH	[28]
Nano-ZnO	240	60	EtOH	[28]
Nano-Fe_2O_3	240	65	EtOH	[28]
NH_3/NH_4Cl	180	80	EtOH	[30]
Fe_3O_4 NPs@GO@$C_4H_8SO_3H$	5	98	EtOH	This work

were obtained on a Bruker DRX- 300 NMR instrument operating at 300 MHz. Analytical TLC of all reactions was performed on precoated silica gel plates (silica gel 60 F-254 on aluminum, Merck). Elemental analyses (EDS) and X-ray diffraction (XRD) analysis of the catalyst were carried out by a PW1840-Philips instrument with Cu K_α radiation.

Synthesis of 8-aryl-7*H*-acenaphtho[1,2-*d*]imidazoles 4a–4j using Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ (*general procedure*). A mixture of aldehyde **3a**–**3j**

Scheme 3.



(1 mmol), acenaphthenequinone (1 mmol), ammonium acetate (2 mmol), and Fe_3O_4 NPs@GO@$C_4H_8SO_3H$ (0.1 g) in EtOH (10 mL) was refluxed for a time indicated in Table 2. The progress of the reaction was monitored by TLC. After completion of the reaction, the catalyst was separated by an external magnet, the solvent was evaporated, and the residue was recrystallized from aqueous ethanol.

8-(3-Nitrophenyl)-7*H*-acenaphtho[1,2-*d*]imidazole (4a). Yield 82%, orange solid, mp 227–230°C [30]. IR spectrum (KBr), ν, cm^{-1}: 3433 (N–H), 3049 (C–H_{arom}), 1683 (C=N), 1525 (C=C), 1500 (NO_2), 1345 (C–N), 766 (δC–H, out-of-plane). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 7.63–7.5 m (7H, H_{arom}), 8.2 d (1H), 8.4 d (1H), 8.8 s (1H).

3-(7*H*-Acenaphtho[1,2-*d*]imidazol-8-yl)phenol (4b). Yield 96%, brown solid, mp 330–332°C [28]. IR spectrum (KBr), ν, cm^{-1}: 3392 (N–H, O–H), 3055 (C–H_{arom}), 1678 (C=N), 1590 (δN–H), 1480 (C=C), 1277 (C–N), 1227 (C–O), 770 (δC–H, out-of-plane). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 8.88 d.d (1H, J = 7.6, 1.2 Hz), 8.77 d.d (1H, J = 7.6, 1.2 Hz), 8.43 d (1H, J = 6.8 Hz), 8.33 d.d (1H, J = 8, 0.8 Hz), 8.04–8.10 m (2H), 7.83–7.89 m (3H), 7.79 s (1H), 7.63–7.70 m (2H).

8-(4-Methylphenyl)-7*H*-acenaphtho[1,2-*d*]imidazole (4c). Yield 98%, orange solid, mp. 230–232°C [30]. IR spectrum (KBr), ν, cm^{-1}: 3436 (N–H), 3041 (C–H_{arom}), 1687 (C=N), 1608 (δN–H), 1595 (C=C), 1384 (C–CH_3), 1108 (C–N), 775 (δC-H, out-of-plane). ^{1}H NMR spectrum (DMSO-d_6): 2.42 s (3H), 7.25 m (3H), 7.47 d (2H), 7.67 d (3H), 7.85 d (1H).

8-(4-Bromophenyl)-7*H*-acenaphtho[1,2-*d*]imidazole (4d). Yield 92%, brown solid, mp 262–264°C [28]. IR spectrum (KBr), ν, cm^{-1}: 3436 (N–H), 3094 (C–H_{arom}), 1656 (C=N), 1607 (δN–H), 1484, 1417 (C=C), 1384 (C–N), 762 (δC–H, out-of-plane), 683 (C–Br). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 8.88 d (1H, J = 7.6 Hz), 8.77 d (1H, J = 8 Hz), 8.43 d (1H, J = 6.8 Hz), 8.35 s (1H), 8.31 d (1H, J = 7 Hz), 8.15 d (1H, J = 7 Hz), 8.08–8.10 m (2H), 7.90–7.83 m (4H), 7.79–7.81 m (1H), 7.64–7.70 m (2H).

8-(4-Fluorophenyl)-7*H*-acenaphtho[1,2-*d*]imidazole (4e). Yield 94%, light brown solid, mp 301–303°C [28]. IR spectrum (KBr), ν, cm^{-1}: 3480 (N–H), 3130 (C–H_{arom}), 1674 (C=N), 1607 (δN–H), 1511, 1417 (C=C), 1384 (C–N), 1236 (C–F), 762 (δC–H, out-of-plane). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 8.88 d.d (1H, J = 7.2, 1.2 Hz), 8.77 d.d (1H, J = 7.2, 1.2 Hz), 8.43 d (1H, J = 6.4 Hz), 8.33 d.d (1H, J = 8, 1.2 Hz), 8.08–8.10 m (2H), 7.81–7.89 m (2H), 7.79 s (1H), 7.63–7.70 m (2H).

8-Phenyl-7*H*-acenaphtho[1,2-*d*]imidazole (4f). Yield 91%, yellow solid, mp 270–272°C [30]. IR spectrum (KBr), cm^{-1}: 3434 (N–H), 1664 (C=N), 1603 (δN–H), 1590 (C=C), 1227 (C–N), 776 (δC–H, out-of-plane). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 12.91 s (1H), 7.26 m (2H), 7.46 m (1H), 7.53 m (2H), 7.62 m (2H), 8.18 m (2H).

2-(7*H*-Acenaphtho[1,2-*d*]imidazol-8-yl)phenol (4g). Yield 94%, brown solid, mp 294–297°C [28]. IR spectrum (KBr), cm^{-1}: 3435 (N–H, O–H), 3055 (C–H_{arom}), 1697 (C=N), 1657 (C=C), 1591 (δN–H), 1384 (C–N), 1287 (C–O), 760 (δC–H, out-of-plane). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 6.86–6.93 d (2H, J = 7.5 Hz), 6.97–7.01 d (2H, J = 7.8 Hz), 7.2–7.52 m (10H), 12.49 br.s (NH).

2-(7*H*-Acenaphtho[1,2-*d*]imidazol-8-yl)-6-methoxyphenol (4h). Yield 96%, brown solid, mp 102–105°C. IR spectrum (KBr), ν, cm^{-1}: 3436 (N–H, OH), 3098 (C–H_{arom}), 1653 (C=N), 1583 (N–H), 1619 (C=C), 1584 (C–N), 1253 (C–O), 719 (δC–H, out-of-plane). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 6.99–7.04 d (2H, J = 8 Hz), 7.51–7.86 m (10H), 7.87–7.90 d (2H, J = 8.5 Hz), 12.61 br.s (NH). Mass spectrum: m/z 314.10 (I_{rel} 21%) $[M + 1]^+$. Found, %: C 76.40; H 4.46; N 8.88. $C_{20}H_{14}N_2O_2$. Calculated, %: C 76.42; H 4.49; N 8.91.

8-(2-Methoxyphenyl)-7*H*-acenaphtho[1,2-*d*]-imidazole (4i). Yield 94%, orange solid, mp 220–225°C. IR spectrum (KBr), ν, cm^{-1}: 3435 (N–H), 1603 (C=N), 1583 (δN–H), 1478 (C=C), 1384 (C–N) 1243 (C–O), 767 (δC–H, out-of-plane). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 3.07 s (3H, OMe), 7.80–7.82 m (5H, H_{arom}), 8.05 d (4H, H_{arom}, J = 7.0 Hz), 8.26 d (4H, H_{arom}, J = 8.3 Hz), 8.40 d (1H, H_{arom}, J = 8.0 Hz). Mass spectrum: m/z 298.11 (I_{rel} 20%) $[M + 1]^+$. Found, %: C 80.50; H 4.71; N 9.36. $C_{20}H_{14}N_2O$. Calculated, %: C 80.52; H 4.73; N 9.39.

8-(2,6-Dichlorophenyl)-7*H*-acenaphtho[1,2-*d*]-imidazole (4j). Yield 95%, yellow solid, mp 250–258°C. IR spectrum (KBr), cm^{-1}: 3413 (N–H), 3055 (C–H_{arom}), 1678 (C=N), 1591 (δN–H), 1480 (C=C), 1227 (C–N) 819 (δC–H, out-of-plane), 770 (C–Cl). ^{1}H NMR spectrum (DMSO-d_6): 7.82–7.90 m (4H, H_{arom}), 8.12 d (3H, H_{arom}, J = 7.0 Hz), 7.29–8.36 m (4H, H_{arom}), 8.36 d (1H, H_{arom}, J = 7.3 Hz). Mass spectrum: m/z 336.02 (I_{rel} 20%) $[M + 1]^+$. Found, %: C 67.60; H 2.95; Cl 21.00; N 8.29. $C_{19}H_{10}C_{l2}N_2$. Calculated, %: C 67.68; H 2.99; Cl 21.03; N 8.31.

CONFLICT OF INTEREST

The authors declare the absence of conflict of interest.

REFERENCES

1. Zang, H., Su, Q., Mo, Y., Cheng, B. W., and Jun, S., *Ultrason. Sonochem*., 2010, vol. 17, p. 749. https://doi.org/10.1016/j.ultsonch.2010.01.015
2. Wan, Y., Liu, G., Zhao, L., Wang, H., Hung, S., Chen, L., and Wu, H., *J. Heterocycl. Chem*., 2014, vol. 51, p. 713. https://doi.org/10.1002/jhet.1751
3. Nasr-Esfahani, M., Montazerozohori, M., and Abdizadeh, T., *Chem. Pap*., 2015, vol. 69, p. 1491. https://doi.org/10.1515/chempap-2015-0156
4. Shingalapur, R.V., Hosamani, K.M., and Keri, R.S., *Eur. J. Med. Chem*., 2009, vol. 44, p. 4244. https://doi.org/10.1016/j.ejmech.2009.05.021
5. Ozkay, Y., Iskar, I., Incesu, Z., and Alkalin, G.E., *Eur. J. Med. Chem*., 2010, vol. 45, p. 3320. https://doi.org/10.1016/j.ejmech.2010.04.015
6. Tonelli, M., Simone, M., Tasso, B., Novelli, F., and Biodo, V., *Bioorg. Med. Chem*., 2010, vol. 18, p. 2937. https://doi.org/10.1016/j.bmc.2010.02.037
7. Mukherjee, A., Kumar, S., Seth, M., and Bhaduri, A.P., *Indian J. Chem., Sect. B*, 1989, vol. 28, p. 496. https://doi.org/10.1002/chin.198943134
8. Hadizadeh, F., Hosseinzadeh, H., Motamed-Shariaty, V.S., Seifi, M., and Kazemi, S.H., *Iran. J. Pharm. Res*., 2008, vol. 7, p. 29. https://doi.org/10.22037/IJPR.2010.741
9. Bhandari, K., Srinivas, N., and Marrapu, V.K., *Bioorg. Med. Chem. Lett*., 2010, vol. 20, p. 291. https://doi.org/10.1016/j.bmcl.2009.10.117
10. Bhragual, D.D., Kumar, N., and Drabu, S., *J. Chem. Pharm. Res*., 2010, vol. 2, p. 345.
11. Chawla, A., Sharma, A., and Kumar Sharma, A., *Pharma Chem*., 2012, vol. 4, p.116.
12. Padhy, A.K., Chetica, B., Mishara, S., Pati, A., and Iyer, P.K., *Tetrahedron Lett*., 2010, vol. 51, p. 2751. https://doi.org/10.1016/j.tetlet.2010.03.058
13. Sadeghi, B., Mirjalili, B.B.F., and Hashemi, M.M., *Tetrahedron Lett*., 2008, vol. 49, p. 2575. https://doi.org/10.1016/j.tetlet.2008.02.100
14. Karimi, A.R., Alimohammadi, Z., Azizian, J., Mohammadi, A.A., and Mohammadizadeh, M.R., *Catal. Commun*., 2006, vol. 7, p. 728. https://doi.org/10.1016/j.catcom.2006.04.004
15. Heravi, H.H., Derikvand, F., and Bamoharram, F.F., *J. Mol. Catal. A: Chem*., 2007, vol. 263, p. 112. https://doi.org/10.1016/j.molcata.2006.08.048
16. Samai, S., Nandi, G.C., Singh, P., and Singh, M.S., *Tetrahedron*, 2009, vol. 65, p. 10155. https://doi.org/10.1016/j.tet.2009.10.019
17. Nagarapu, L., Apuri, S., and Kantevari, S., *J. Mol. Catal. A: Chem*., 2007, vol. 266, p. 104. https://doi.org/10.1016/j.molcata.2006.10.056
18. Sivakumar, K. Kathirvel, A., and Lalitha, A., *Tetrahedron Lett*., 2010, vol. 51, p. 3018. https://doi.org/10.1016/j.tetlet.2010.04.013
19. Davidson, D., Weiss, M., and Jelling, M., *J. Org. Chem*., 1937, vol. 2, p. 319. https://doi.org/10.1021/jo01227a004
20. Wang, B., Gu, Y.L., Luo, C., Yang, T., Yang, L.M., and Suo, J.S., *Tetrahedron Lett*., 2004, vol. 45, p. 3417. https://doi.org/10.1016/j.tetlet.2004.03.012

21. Chen, M.-N., Mo, L.-P., Cui, Z.-S., and Zhang, Z.-H., *Curr. Opin. Green Sustainable Chem*., 2019, vol. 15, p. 27. https://doi.org/10.1016/j.cogsc.2018.08.009
22. Arabpourian, K. and Behbahani, F.K., *Russ. J. Org. Chem*., 2019, vol. 55, p. 682. https://doi.org/10.1134/S1070428019050166
23. Heravi, M.M., Behbahani, F.K., Daraie, M., and Oskooie, H.A., *Mol. Diversity*, 2009, vol. 13, p. 375. https://doi.org/10.1007/s11030-009-9118-z
24. Mirzaei, Z. and Behbahani, F.K., *Heterocycl. Lett*., 2018, vol. 8, p. 755.
25. Behbahani, F.K. and Ziaei, P., *Chin. J. Chem*., 2012, vol. 30, p. 65. https://doi.org/10.1002/cjoc.201180461
26. Behbahani, F.K. and Yektanezhad, T., *Monatsh. Chem*., 2012, vol. 143, p. 1529. https://doi.org/10.1007/s00706-012-0724-6
27. Fallah, N.S. and Mokhtary, M., *J. Taibah Univ. Sci*., 2015, vol. 9, p. 531. https://doi.org/10.1016/j.jtusci.2014.12.004
28. Wang, Y., Sang, R., Zheng, Y., Guo, L., and Guan, M., *Catal. Commun*., 2017, vol. 89, p. 138. https://doi.org/10.1016/j.catcom.2016.09.027
29. Nejadshafiee, V. and Islami, M.R., *Mat. Sci. Eng. C*., 2019, vol. 101, p. 42. https://doi.org/10.1016/j.msec.2019.03.081
30. Derisavi, A. and Mohammadi, M.K., *Int. J. Heterocycl. Chem*., 2017, vol. 7, no. 2, p. 7.