HETEROCYCLES, Vol. 87, No. 3, 2013, pp. 559 - 570. © 2013 The Japan Institute of Heterocyclic Chemistry
Received, 13th November, 2012, Accepted, 17th January, 2013, Published online, 30th January, 2013
DOI: 10.3987/COM-12-12626

# ONE-POT SYNTHESIS OF 1*H*-INDAZOLO[2,1-*b*]-PHTHALAZINETRIONE CATALAZED BY MAGNETIC ROOM TEMPERATURE DICATIONIC IONIC LIQUID UNDER SOLVENT-FREE CONDITIONS

**Bijan Mombani Godajdar,[1]* Ali Reza Kiasat,[2] and Mohammad Mahmoodi Hashemi[3]**

[1]Department of Chemistry, Islamic Azad University, Science and Research Branch, P. O. Box 19395-1775 Tehran, Iran

[2]Department of Chemistry, College of Science, Shahid Chamran University, Ahwaz, Iran

[3]Department of Chemistry, Sharif University of Technology, Tehran, Iran

Email: bmombini@gmail.com Fax: (+98) 611-3331746

**Abstract** - The efficient one-pot condensation of aldehyde, dimedone, and phthalhydrazide has been achieved in the presence of a catalytic amount of Fe(III)-based dicationic ionic liquid, $[C_4(mim)_2](FeCl_4)_2$, as a novel environmentally benign magnetic catalyst under solvent-free conditions. The catalyst was easily separated after completion of the reaction and was recycled four times without affecting the catalytic property.

## INTRODUCTION

Today, one of the major goals of synthetic organic chemistry lies in the research, discovery and exploitation of environmentally friendly methods. Recently, several techniques for the efficient use of solvent free reactions and multi-component reactions (MCRs) have been developed individually but when these two wings of green chemistry can be combined,an excellent green chemistry protocol is expected.[1,2] Room temperature ionic liquids (RTILs) are generally defined as salts that are liquid at or below room temperature. The combination of ammonium, pyridinium, phosphonium or imidazolium cations with various inorganic or organic anions led to a large amount of liquid salts with numerous possible applications e.g. in the field of organic synthesis, catalysis, biocatalysis, material science, chemical

engineering, electrochemistry or separation processes.[3] The increasing interest in RTILs is related to their possible exploitation as environmentally friendly neoteric solvents because of their vanishing vapour pressure, thermal and chemical stability, air and moisture stability, wide liquids range, solvent capability, etc.[4] However the large scale application of ionic liquids is still far from realization because of their high cost and difficult recovery.

In comparison to the common monocationic ionic liquids, dicationic ionic liquids are an important class of organic salts having two positive charges on the same or different cations. They have been proved to have a better performance in terms of thermal stability, wide liquids range, and unusual dissolution properties.[5]

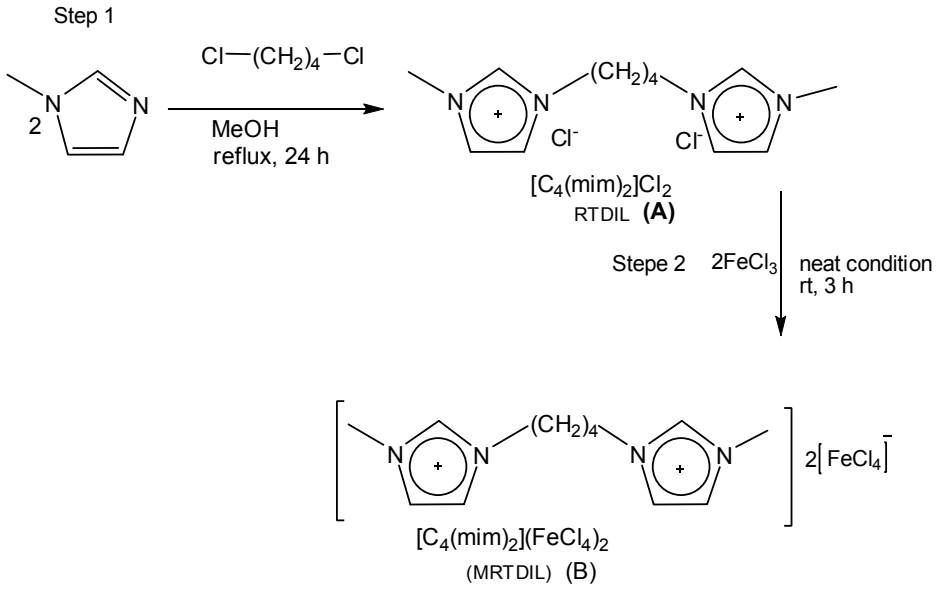
Magnetic ILs not only have the excellent properties of IL but also exhibit an unexpectedly strong response to an additional magnet.[6] These properties make magnetic ILs have more advantages and potential application prospects than conventional ILs in the fields of catalytic reactions, solvent effects and separation processes.[7] Magnetic room temperature dicationic ionic liquid, MRTDIL, not only has the properties listed above, but also has higher magnetic strength than the monocationic paramagnetic ionic liquid e.g. 1-butyl-3-methylimidazolium tetrachloroferrate (III), due to having two magnetic groups of $FeCl_4^-$.

Phthalazine derivatives are an important class of heterocyclic compounds due to their wide range of pharmaceutical and biological activities.[8] Phthalazine derivatives was reported to possess anticonvulsant; antifungal, anticancer, and vasorelaxant activities.[9-12] Therefore, considerable effort has been devoted toward finding an efficient synthesis of phthalazine derivatives. Several methods have been reported for synthesis 2*H*-indazolo[2,1-*b*]phthalazin**e**triones such as P-TSA, silica sulfuric acid, Mg $(HSO_4)_2$, $I_2$/EtOH, TCT, HPA/IL, PPA/$SiO_2$ and $Me_3SiCl$[13-20] as catalysts. However, most of these methods have limitations including use of expensive catalyst or solvent, strong acidic conditions and harsh reaction conditions. Thus, the development of an alternate milder and safe method is highly demanding for synthesis of phthalazine derivatives, which overcome those limitations.Herein, we wish to report a novel and green approach for the preparation of 2*H*-indazolo[2,1-*b*]phthalazin**e**triones catalyzed by magnetic room temperature dicationic ionic liquid, MRTDIL, under solvent free conditions.

## RESULTS AND DISCUSSION

1-Butyl-3-methylimidazolium tetrachloroferrate ([bmim]$FeCl_4$) with magnetism was synthesized and first reported by Hayashi et al. in 2004.[21] Since then, the syntheses of magnetic ILs have been focused on expanding synthesis with different alkyl chain length of imidazole cations or different magnetic metal anions.[22] To the best of our knowledge, there is no report for the preparation of Fe(III)-based dicationic ionic liquid as a magnetic room temperature dicationic ionic liquid (MRTDIL).

Scheme 1 illustrates the synthetic route for the preparation of MRTDIL synthesized and characterized in this study. As shown in Scheme1, the synthesis of 1,4'-(butane-1,4-diyl)bis(3-methylimidazolium)bis-[tetrachloroferrate(III)](B), $[C_4(mim)_2](FeCl_4)_2$, involves two steps. First, 1,4-dichlorobutane was reacted with two equivalents of *N*-methylimidazole in methanol and under reflux conditions to afford dicationic RTIL in quantitative yield.[23] In the second step, the anions of imidazolium based room temperature dicationic ionic liquid, $Cl^-$, were easily changed with $FeCl_4^-$ anions by the simple mixing with $FeCl_3$ under neat conditions.




**Scheme 1.** Synthesis of $[C_4(mim)_2](FeCl_4)_2$ as a magnetic room temperature dicationic ionic liuquid

Due to the paramagnetic nature of the $[C_4(mim)_2](FeCl_4)_2$, nuclear magnetic resonance technique could not be used to confirm its structure. Instead, UV spectra was used to characterize the $[C_4(mim)_2](FeCl_4)_2$ structure. The UV spectrum is shown in Figure 1. $[C_4(mim)_2](FeCl_4)_2$ spectra exhibited absorption bands in the visible region at 534, 620 and 680 nm which are characteristic for the $FeCl_4^-$ anion.[24]

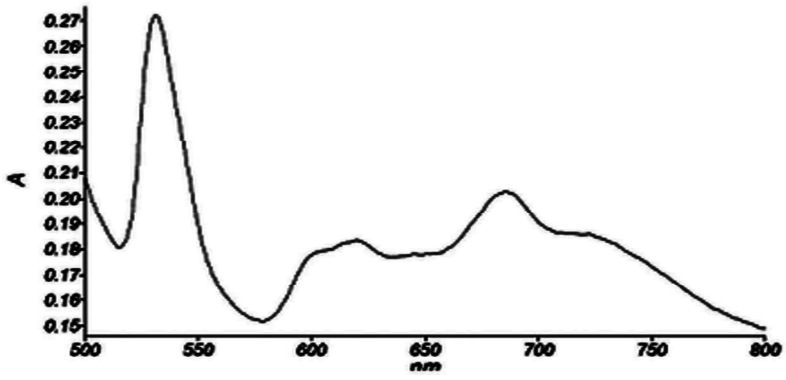



**Figure 1.** Visible absorption spectrum of MRTDIL

The magnetic properties of the MRTDIL and $FeCl_3$ were measured by vibrating sample magnetometer, VSM, at the room temperature. The paramagnetic linear response of MRTDIL is similar to iron (III) chloride. From M vs. H curves, the magnetization value for MRTDIL at the same field was found to be 0.4 emu Oe g-1, lower than of $FeCl_3$ (0.7 emu Oe g-1) at 8 kOe.

In order to be able to carry out preparation of 2*H*-indazolo[2,1-*b*]phthalazinetrione derivatives in a more efficient way minimizing the time, temperature and amount of catalyst, the reaction of benzaldehyde, 5,5-dimethylcyclohexane-1,3-dione (dimedone) and phthalhydrazide was selected as model system to the effects of the catalyst at different reaction temperatures (25, 60, 80, 100 and 120 °C and the different amount of catalyst (0, 10, 20, 30, and 40% mol) were investigated. The results are summarized in Table 1. As shown in Table 1, the reaction using 20% mol of MRTDIL at 100 °C proceeded in highest yield. Further increase in temperature to, 120 °C had little effect on the rate of reaction. Therefore, we kept the reaction temperature at 100 °C as optimal temperature. According to Table 1, this reaction was carried out without catalyst under solvent free conditions in order to establish the effectiveness of the catalyst. It was found that 2*H*-indazolo[2,1-*b*]phthalazinetrione was not made after 1h of heating. The best results were obtained with 1.2 : 1 : 1 ratio of benzaldehyde, dimedone, phthalhydrazide and 20% mol of MRTDIL after 10 min at 100 °C.

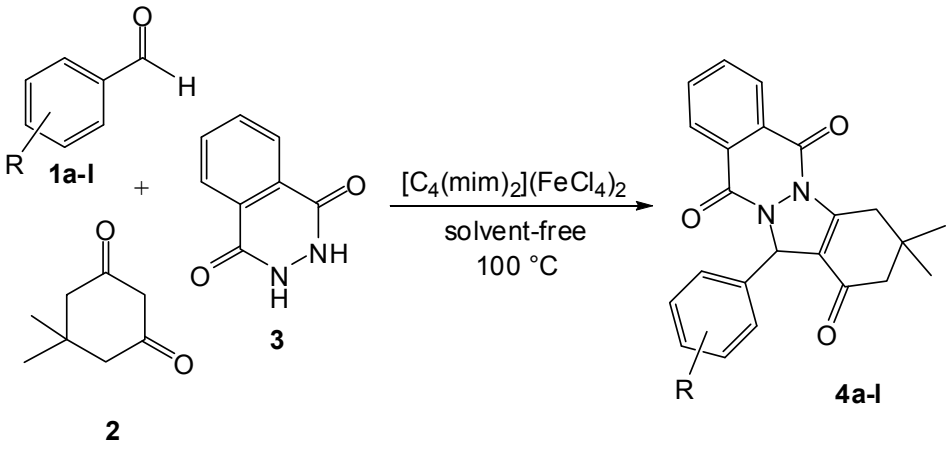
**Table 1.** Optimization of the amount MRTDIL and temperature for the synthesis of 2*H*-indazolo[2,1-*b*]phthalazinetrione **4a**[a]

| Temperature/°C | MRTDIL (mol %) | Time (min) | Yield (%) |
|---|---|---|---|
| 25 | 20 | 60 | 0 |
| 60 | 20 | 30 | 40 |
| 80 | 20 | 30 | 66 |
| 100 | 20 | 10 | 89 |
| 120 | 20 | 10 | 89 |
| 100 | 0 | 60 | 0 |
| 100 | 10 | 30 | 40 |
| 100 | 30 | 10 | 89 |
| 100 | 40 | 10 | 90 |

[a]Reaction conditions: benzaldehyde (1.2 mmol), dimedone (1 mmol), phthalhydrazide (1 mmol), X% mol of MRTDIL, solvent free, different temperature

Subsequently, with optimal conditions in hand, 1.2 : 1 : 1 molar ratios of benzaldehyde, dimedone and

phthalhydrazide and 20 mol% of MRTDIL at 100 °C under solvent-free conditions, the generality and synthetic scope of this coupling protocol were demonstrated by synthesizing a series of 2*H*-indazolo-[2,1-*b*]phthalazinetriones (Table 2, Scheme 2). Gratifyingly, a wide range of aromatic aldehydes




**Scheme 2**. Synthesis of 2*H*-indazolo[2,1-*b*]phthalazinetriones

**Table 2.** Synthesis of 2*H*-indazolo[2,1-*b*]phthalazinetrione derivatives[a]

| Product | R | Time (min) | Yield (%)[b] | Melting point (°C) Found | Reported[Ref] |
|---|---|---|---|---|---|
| 4a | H | 10 | 89 | 205-207 | 204-206[25] |
| 4b | 4-OMe | 15 | 90 | 220-222 | 218-220[19] |
| 4c | 4-Me | 10 | 90 | 228-230 | 226-231[25] |
| 4d | 2-Cl | 15 | 91 | 264-266 | 266-269[25] |
| 4e | 4-Cl | 15 | 87 | 262-265 | 262-264[25] |
| 4f | 3-$NO_2$ | 10 | 89 | 268-270 | 269-271[25] |
| 4g | 2,4-$Cl_2$ | 15 | 88 | 220-222 | 218-220[25] |
| 4h | 4-Br | 15 | 86 | 262-264 | 265-267[19] |
| 4i | 4-F | 15 | 89 | 221-224 | 220-224[25] |
| 4j | 2-Me | 10 | 91 | 242-244 | 243-245[19] |
| 4k | 4-$NO_2$ | 15 | 88 | 218-220 | 216-218[25] |
| 4l | 3-$CF_3$ | 10 | 89 | 211-213 | 213-215[26] |

[a]Reaction conditions: (1mmol); benzaldehyde (1.2 mmol); 5,5-dimethylcyclohexane-1,3-dione (1 mmol); phthalhydrazide (1 mmol); MRTDIL (20% mol), solvent free, 100 °C.
[b]Isolated yield

(carrying both electron releasing and electron withdrawing substituents in the ortho, meta, and para

positions) were well tolerated under the optimized reaction conditions. The time taken for complete conversion (monitored by TLC) and the isolated yields are recorded in Table 2. The desired pure products were characterized by comparison of their physical data (melting points, IR, $^{1}H$ and $^{13}C$ NMR) with those of known compounds.

The success of the above reactions prompted us to investigate the recyclability of catalyst. We carried out our study by using the reaction benzaldehyde with dimedone and phthalhydrazide under optimal conditions as a model study. Hayashi and hamaguchi showed that the shape of two layers containing [bmim]$FeCl_4$ and water was highly distorted with 0.55T NdFeB permanent magnet.[21] However, it was observed in our experiment that at least 1.5T is needed to see the magnetic behavior of pure $[C_4(mim)_2](FeCl_4)_2$. The 20% (V/V) of $[C_4(mim)_2](FeCl_4)_2$ was fully miscible with water after vigorous shaking and 50% mixture of $[C_4(mim)_2](FeCl_4)_2$ and water formed two phase; then the surface of the mixture was attracted and moved towared the electromagnet and the surface of the mixture changed to be concave upward. It means that the mixture of $[C_4(mim)_2](FeCl_4)_2$ and water forming 2-phase can be successfully separated by a strong magnetic field of 1.5T.

With preliminary experimental, after completion of the reaction (the progress of the reaction was monitored by TLC), the mixture was cooled to room temperature and the precipitated product was separated by filtration; then washed with water and dried. The aqueous phase was concentrated; the catalyst was separated using an external magnetic field 1.5T. The residue catalyst was washed with diethyl ether dried in a vacuum oven at 60 °C for overnight and reused in the next run. The catalyst could be reused for fourth times without significant decrease in catalytic activity (Table 3).

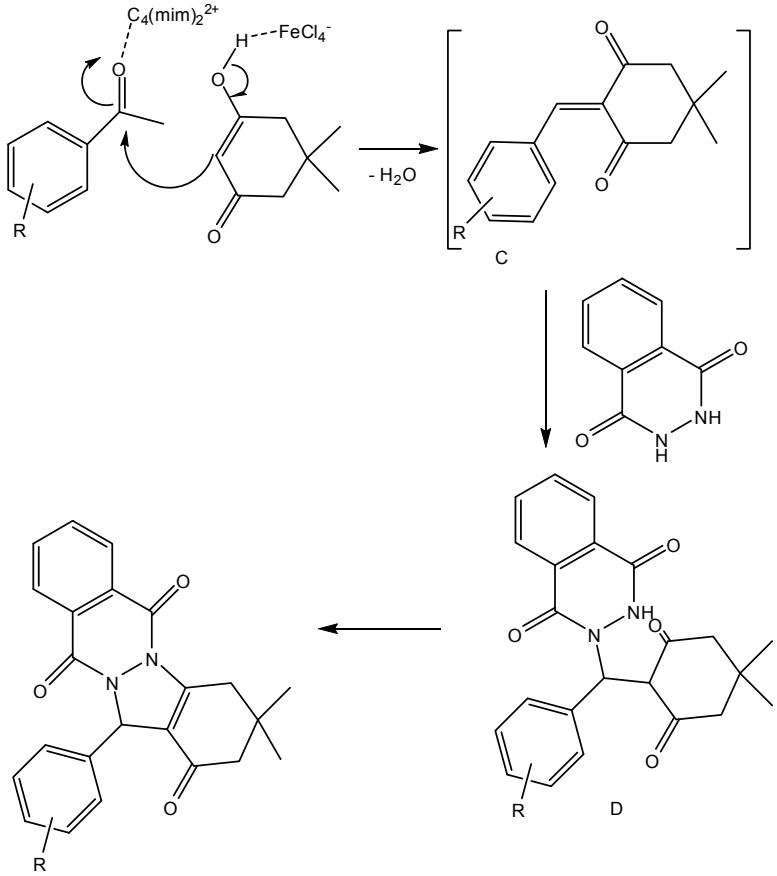
**Table 3**. The reusability of the catalyst

| Cycle | Fresh | First | Second | Third | Fourth |
|---|---|---|---|---|---|
| Yield (%) | 89 | 86 | 84 | 80 | 76 |

The suggested mechanism of MRTDIL catalyzed transformations is shown in Scheme 3. The first step is believed to be the $C_4(mim)_2^{2+}$ catalyzed Knoevenagel condensation between the aldehyde and dimedone to generate adduct **C**, which acts as Michael acceptor. The phthalhydrazide attacks to in adduct **C** in a Michael-type fashion to produce an open chain intermediate **D**. Intermediate **D** undergoes intra-molecular cyclization by the reaction of nucleophilic amino function to carbonyl group followed by dehydration to form 2*H*-indazolo[2,1-*b*]phthalazinetriones.

To compare the advantage of the use of MRTDIL over the reported catalysts, the model reaction of, dimedone, phthalhydrazide and benzaldehyde was considered as a representative example (Table 4). The yield of product in the presence of $[C_4(mim)_2](FeCl_4)_2$ is comparable with these catalysts. However, the

reported procedures required longer reaction times (entries **4**, **6**), strong acidic conditions (entries **1**, **4**), high catalyst loading (entries **1**, **6**), and expensive catalyst or toxic organic solvents (entries **3**, **4**, **6**). These results demonstrate that MRTDIL is an equally or more efficient catalyst for this three-component reaction.




**Scheme 3.** A plausible reaction mechanism

**Table 4.** Comparison of MRTDIL with reported catalysts in the reaction of dimedone, phthalhydrazide and benzaldehyde

| Entry | Reagent and conditions | Time (min) | Yield (%) | Ref. |
|---|---|---|---|---|
| 1 | *p*-toluenesulfonic acid, solvent-free, 80 °C, 30 mol% | 10 | 93 | 13 |
| 2 | polyphosphoric acid-$SiO_2$, solvent-free, 100 °C, 5 mol% | 6 | 93 | 19 |
| 3 | $Mg(HSO_4)_2$, solvent-free, 100 °C, 10 mol% | 4 | 88 | 15 |
| 4 | $H_2SO_4$, [bmim][$BF_4$], 80 °C, 15 mol% | 30 | 94 | 25 |
| 5 | silica sulfuric acid, solvent-free, 100 °C, 6.5 mol% | 7 | 91 | 14 |
| 6 | TMSCl, MeCN/DMF (8:2), 80 °C | 30 | 90 | 20 |
| 7 | $[C_4(mim)_2](FeCl_4)_2$, solvent-free, 100 °C, 20 mol% | 10 | 89 | this work |

## CONCLUSION

In conclusion, we have successfully developed a simple and green catalytic procedure for the efficient synthesis of 2*H*-indazolo[2,1-*b*]phthalazinetrione using MRTDIL and under solvent free conditions. MRTDIL can replace the ILs and other homogeneous catalysts with reasonable recovery and reusability and therefore ideal for industrial applications.

## EXPERIMENTAL

Melting points were measured on an Electrothermal 9100 apparatus and are uncorrected. $^1$H NMR spectra were recorded on 300 MHz and 400 MHz. $^{13}$C NMR spectra were recorded on 75 and 100 MHz. Chemical shifts are expressed in δ units relative totetramethylsilane (TMS) signal as internal reference in $CDCl_3/D_2O$. Aldehydes, dimedone and phthalhydrazide were purchased from Merck Company. Products were characterized by comparison of their physical and spectroscopic data with those of known samples. The purity of products and reaction monitoring was accomplished by TLC on silica gel Poly Gram SILG/UV 254 plates.

**Procedure for the preparation of $[C_4(mim)_2]Cl_2$ (A).** 1,4-Dicholorobutane (1 mmol) was reacted with 1-methylimidazole (2 mmol), respectively, stirred in MeOH, refluxed for 24 h, and then precipitated from EtOAc to obtain the required product (white solid, yield 94%). $[C_4(mim)_2]Cl_2$ (**A**). $^1$H NMR (300 MHz, $D_2O$): δ 1.90 (4H, quint., $J$ = 3.6 Hz), 3.90 (6H, s), 4.25 (4H, t, $J$ = 6.7 Hz), 7.55 (2H, t, $J$ = 1.7 Hz), 7.64 (2H, t, $J$ = 1.7 Hz), 9.01 (2H, s). $^{13}$C NMR (75 MHz, $D_2O$): δ 27.8, 36.5, 50.0, 123.6, 125, 138.

**Procedure for the preparation of $[C_4(mim)_2](FeCl4)_2$ as a magnetic dicationic ionic liquid (B).** $[C_4(mim)_2](FeCl_4)_2$, MRTDIL, was prepared by mixing crystal powder of $[C_4(mim)_2]Cl_2$ (1 mmol) with anhydrous $FeCl_3$ (2 mmol) at room temperature for 3 h, a dark brown liquid was obtained. The obtained MRTDIL was extracted with small amount of EtOAc. The solvent was evaporated and resulting clear brown liquid was dried in vacuum oven at 60 °C for 24 h. **$[C_4(mim)_2](FeCl4)_2$** (B); mp 50-55 °C.

**General procedure for the preparation of 2*H*-indazolo[2,1-*b*]phthalazinetrione.** A mixture of dimedone (1 mmol), aldehyde (1.2 mmol), phthalhydrazide (1 mmol) and MRTDIL (20 mol%) was heated at 100 °C for an appropriate time (Table 3). After completion of the reaction (TLC), the mixture was cooled to room temperature and washed with water. The solid product was purified by crystallization from aqueous EtOH to afford products **4a-l** (Scheme 2). The aqueous phase was concentrated; the catalyst was separated using an external magnetic field 1.5T. The residue catalyst was washed with a mixed of $Et_2O$ and deionized water and dried in a vacuum oven at 60 °C for overnight. The catalyst could be reused for fourth times without significant decrease in catalytic activity.

**3,4-Dihydro-3,3-dimethyl-13-phenyl-2*H*-indazolo[2,1-*b*]phthalazine-1,6,11(13*H*)-trione (4a).** Yellow powder; IR (KBr, $cm^{-1}$) 2958, 1664, 1576; $^1H$ NMR (400 MHz, $CDCl_3$): δ (ppm) 1.24 (s, 6H), 2.45 (s, 2H), 3.23 and 3.45 (d, AB system, *J* = 18.0 Hz, 2H), 6.45 (s, 1H), 7.32-8.35 (m, 9H, Ph); $^{13}C$ NMR (100 MHz, $CDCl_3$): δ (ppm) 28.4, 28.6, 34.7, 38.2, 50.9, 64.8, 118.2, 127.1, 127.6, 127.8, 128.7, 128.9, 129.1, 133.6, 134.5, 136.4, 150.9, 154.3, 156.2, 192.3.

**3,4-Dihydro-3,3-dimethyl-13-(4-methoxyphenyl)-2*H*-indazolo[2,1-*b*]phthalazine-1,6,11(13*H*)-trione (4b).** Yellow powder; IR (KBr, $cm^{-1}$): 2957, 1666, 1623; $^1H$ NMR (400 MHz, $CDCl_3$): δ (ppm) 1.23 and 1.29 (s, 6H), 2.35 (s, 2H), 3.24 and 3.43 (d, AB system, *J* = 18.6 Hz, 2H), 3.77 (s, 3H) 6.43 (s, 1H), 6.86-8.36 (m, 8H, Ph); $^{13}C$ NMR (100 MHz, $CDCl_3$): δ (ppm) 28.5, 28.7, 34.5, 51.38, 55.2, 64.4, 114, 118.3, 127.8, 127.9, 128.2, 128.4, 128.8, 129, 133, 134.3, 150.3, 154.3, 156, 158.3, 192.1. Anal. Calcd for $C_{24}H_{22}N_2O_4$: C 71.63, H 5.51, N 6.96. Found: C 71.59, H 5.62, N 7.02.

**3,4-Dihydro-3,3-dimethyl-13-(4-methylphenyl)-2*H*-indazolo[2,1-*b*]phthalazine-1,6,11(13*H*)-trione (4c).** Yellow powder; IR (KBr, $cm^{-1}$): 2958, 1663, 1621; $^1H$ NMR (400 MHz, $CDCl_3$): δ (ppm) 1.24 (s, 6H), 2.32 (s, 3H), 2.35 (s, 2H), 3.25 and 3.44 (d, AB system, *J* = 18.5 Hz, 2H), 6.45 (s, 1H), 7.13-8.39 (m, 8H, Ph); $^{13}C$ NMR (100 MHz, $CDCl_3$): δ (ppm) 21.4, 28.3, 28.7, 34.7, 38.1, 50.9, 64.9, 118.7, 127.2, 127.7, 127.8, 128.7, 129.1, 129.5, 133.4, 133.6, 134.5, 138.3, 150.4, 154.2, 156.0, 192.1.

**3,4-Dihydro-3,3-dimethyl-13-(2-chlorophenyl)-2*H*-indazolo[1,2-*b*]phthalazine-1,6,11(13*H*)-trione (4d).** Yellow powder; IR (KBr, $cm^{-1}$): 3058, 2957, 2894, and 1662. $^1H$ NMR (300 MHz, $CDCl_3$): δ (ppm) 1.21 (s, 3H), 1.23 (s, 3H), 2.34 (s, 2H), 3.26 and 3.45 (d, AB system, *J* = 19.1 Hz, 2H), 6.66 (s, 1H), 7.24-8.41 (m, 8H, Ph); $^{13}C$ NMR (100 MHz, $CDCl_3$): δ (ppm) 28.3, 28.7, 34.5, 37.9, 50.8, 63.9, 116.6, 127.1, 127.5, 127.9, 128.6, 129.0, 129.8, 130.4, 132.5, 133.0, 133.5, 134.4, 151.8, 154.1, 156.1, 192.0.

**3,4-Dihydro-3,3-dimethyl-13-(4-chlorophenyl)-2*H*-indazolo[2,1-*b*]phthalazine-1,6,11(13*H*)-trione (4e).** Yellow powder; IR (KBr, $cm^{-1}$): 2957, 1656, 1623; $^1H$ NMR (400 MHz, $CDCl_3$): δ (ppm) 1.22 (s, 3H), 1.24 (s, 3H), 2.36 (s, 2H), 3.24 and 3.45 (d, AB system, *J* = 19.0 Hz, 2H), 6.44 (s, 1H), 7.32-8.39 (m, 8H, ph); $^{13}C$ NMR (100 MHz, $CDCl_3$): δ (ppm) 28.3, 28.7, 34.7, 38.0, 50.6, 64.4, 118.0, 127.6, 128.2, 128.4, 128.7, 128.9, 129.0, 133.7, 134.5, 134.6, 134.9, 151.1, 154.3, 156.0, 192.2

**3,4-Dihydro-3,3-dimethyl-13-(3-nitrophenyl)-2*H*-indazolo[1,2-*b*]phthalazine-1,6,11(13*H*)-trione (4f).** Yellow powder; IR (KBr, $cm^{-1}$): 3075, 2956, 1671; $^1H$ NMR (400 MHz, $CDCl_3$): δ (ppm) 1.17(s, 6H), 2.28 (s, 2H), 3.29 and 3.44 (d, AB system, *J* = 19.6 Hz, 2H), 6.46 (s, 1H), 7.56-8.34 (m, 8H, Ph); $^{13}C$ NMR (100 MHz, $CDCl_3$): δ (ppm) 28.5, 28.8, 34.6, 38.3, 51.2, 64.2, 116.89, 127.4, 127.4, 128.3, 128.8, 129.1, 129.9, 131.2, 132.4, 133.0, 132.5, 133.4, 135.1, 151.7, 153.3, 156.5, 192.2.

**3,4-Dihydro-13-(2,4-dichlorophenyl)-3,3-dimethyl-2*H*-indazolo[1,2-*b*]phthalazine-1,6,11(13*H*)-trione (4g).** Yellow powder; IR (KBr, $cm^{-1}$): 2964, 1660, 1628; $^1H$ NMR (400 MHz, $CDCl_3$): δ (ppm) 1.20 (s, 3H), 1.23 (s, 3H), 2.33 (s, 2H), 3.26 and 3.44 (d, AB system, *J* = 19.1 Hz, 2H), 6.63 (s, 1H), 7.22-7.84 (m, 5H, Ph), 8.23 (dd, *J* = 3.2, 5.4 Hz, 1H), 8.38 (dd, *J* = 3.3, 5.6 Hz, 1H); $^{13}C$ NMR (100 MHz, $CDCl_3$): δ (ppm) 28.3, 28.7, 34.5, 38.0, 50.6, 63.1, 127.5, 127.6, 128.2, 128.7, 129.0, 130.3, 131.8, 133.3, 133.6, 134.6, 135.1, 152.1, 154.2, 156.1, 192.1.

**3,4-Dihydro-3,3-dimethyl-13-(4-bromophenyl)-2*H*-indazolo[1,2-*b*]phthalazine-1,6,11(13*H*)-trione (4h).** Yellow powder; IR (KBr, $cm^{-1}$): 2959, 1654, 1623, $^1H$ NMR (400 MHz, $CDCl_3$): δ (ppm) 1.21 (s, 3H), 1.22 (s, 3H), 2.31 (s, 2H), 3.24 and 3.44 (d, AB system, *J* = 19.1 Hz, 2H), 6.54 (s, 1H), 7.30-8.45 (m, 8H, Ph); $^{13}C$ NMR (100 MHz, $CDCl_3$): δ (ppm) 28.3, 28.7, 34.6, 38.1, 50.8, 64.5, 118.1, 122.8, 127.8, 128.2, 128.8, 128.9, 129.1, 131.8, 133.6, 134.8, 135.5, 151.2, 154.4, 156.1, 192.2.

**3,4-Dihydro-3,3-dimethyl-13-(4-fluorophenyl)-2*H*-indazolo[2,1-*b*]phthalazine-1,6,11(13*H*)-trione (4i).** $^1H$ NMR (400 MHz, $CDCl_3$): δ (ppm) 8.37-8.26 (m, 2H), 7.88-7.85 (m, 2H), 7.43-7.39 (m, 2H), 7.03 (t, 2H, *J* = 8.8 Hz), 6.44 (s, 1H), 3.42 (d, *J* = 18.8 Hz, 1H), 3.25 (dd, *J* = 2.4, 18.8 Hz, 1H), 2.35 (s, 2H), 1.27-1.22 (s, 6H); $^{13}C$ NMR(100 MHz, $CDCl_3$): δ (ppm) 192.1, 163.9, 161.5, 156.0, 154.4,151.0, 134.6, 133.6, 132.2, 129.0, 128.9, 128.0, 127.7,118.2, 115.8, 115.6, 64.3, 50.9, 38.0, 34.6, 28.7, 28.4. Anal. Calcd for $C_{23}H_{19}FN_2O_3$; C 70.76, H 4.91, N 7.18. Found: C 70.82, H 4.88, N 7.26.

**3,4-Dihydro-3,3-dimethyl-13-(4-nitrophenyl)-2*H*-indazolo[2,1-*b*]phthalazine-1,6,11(13*H*)-trione (4k)**. Yellow powder; IR (KBr, $cm^{-1}$) 2922, 1693, 1659, 1615; $^1H$ NMR (400 MHz, $CDCl_3$): δ (ppm) 1.22 (s, 3H), 1.23 (s, 3H), 2.32 and 2.37 (AB system, *J* = 16.0 Hz, 2H), 3.26 and 3.45 (d,AB system, *J* = 19.0 Hz, 2H), 6.53 (s, 1H), 7.62-8.42 (m, 8H, Ph); $^{13}C$ NMR (100 MHz, $CDCl_3$): δ (ppm) 28.3, 28.7, 34.7, 38.0, 50.6, 64.0, 117.1, 124.0, 127.6, 128.2, 128.2, 128.5, 128.8, 133.8, 134.8, 143.3, 147.8, 151.6, 154.5, 155.8, 192.2. Anal. Calcd for $C_{23}H_{19}ClN_2O_3$: C 67.90, H 4.71, N 6.89. Found: C67.95, H 4.82, N 6.79.

**3,4-Dihydro-3,3-dimethyl-13-(3-trifluoromethylphenyl)-2*H*-indazolo[2,1-*b*]phthalazine-1,6,11(13*H*)-trione (4l).** Yellow powder; IR (KBr, $cm^{-1}$) 2968, 1635, 1616; $^1H$ NMR (400 MHz, $CDCl_3$): δ (ppm) 1.23 (s, 3H), 1.24 (s, 3H), 2.34 (s, 2H), 3.25 and 3.43 (d, AB system, *J* = 18.0 Hz, 2H), 6.46 (s, 1H), 7.47 (t, J = 7.0 Hz, 1H), 7.54 (d, *J* = 7.0 Hz, 1H), 7.58 (s, 1H), 7.67 (d, *J* = 7.0 Hz, 1H), 7.84–7.88 (m, 2H), 8.24–8.27 (m, 1H), 8.35–8.38 (m, 1H); $^{13}C$ NMR (100 MHz, $CDCl_3$): δ (ppm) 28.3, 28.7, 34.6, 38.1, 50.9, 64.3, 118.1, 123.5, 123.6, 125.6, 126.4, 127.7, 128.1, 128.9, 129.0, 129.3, 131.1, 131.3, 133.7, 134.7, 137.3, 151.4, 154.5, 156.1, 192.2.

## ACKNOWLEDGEMENTS

We gratefully acknowledge financial support from the Research Council of Islamic Azad university, science and research branch Tehran.

## REFERENCES

1. K. Tanaka and F. Toda, *Chem. Rev.*, 2000, **100**, 1025.
2. N. Shajari, A. R. Kazemizadeh, and A. Ramazani, *J. Serb. Chem. Soc.*, 2011, **10**, 2298.
3. D. Kogelniga, A. Stojanovica, F. Kammerb, P. Terzieffc, M. Galanskia, F. Jirsaa, R. Krachlera, T. Hofmannb, and B. K. Kepplera, *Inorg. Chem. Commun*., 2010, **13**, 1485.
4. H. Vallette, S. Pican, C. Boudou, J. Levillainb, J. C. Plaqueventa, and A. C. Gaumont, *Tetrahedron Lett*., 2006, **47**, 5191.
5. J. L. Anderson, R. Ding, A. Ellern, and D. W. Armstrong, *J. Am. Chem. Soc.*, 2005, **127**, 593.
6. I. de Pedro, D. P. Rojas, J. A. Blanco, and J. R. Fernández, *J. Magn. Magn. Mater.*, 2011, **323**, 1254.
7. J. Wang, H. Yao, Y. Nie, X. Zhang, and J. Li, *J. Mol. Liq.*, 2012, **169**, 152.
8. (a) F. Al´-Assar, K. Y. Zelenin, E. E. Lesiovskaya, I. P. Bezhan, and B. A. Chakchir, *Pharm. Chem. J.*, 2002, **36**, 598; (b) R. P. Jain and J. C. Vederas, *Bioorg. Med. Chem. Lett.*, 2004, **14**, 3655; (c) R. W. Carling, K. W. Moore, L. J. Street, D. Wild, C. Isted, P. D. Leeson, S. Thomas, D. O'Conner, R. M. McKernan, K. Quirk, S. M. Cook, J. R. Atack, K. A. Waftord, S. A. Thompson, G. R. Dawson, P. Ferris, and J. L. Castro, *J. Med. Chem.*, 2004, **47**, 1807.
9. S. Grasso, G. DeSarro, N. Micale, M. Zappala, G. Puia, M. Baraldi, and C. Demicheli, *J. Med. Chem*., 2000, **43**, 2851.
10. C. K. Ryu, R. E. Park, M. Y. Ma, and J. H. Nho, *Bioorg. Med. Chem. Lett*., 2007, **17**, 2577.
11. J. Li, Y. F. Zhao, X. Y. Yuan, J. X. Xu, and P. Gong, *Molecules*, 2006, **11**, 574.
12. N. Watanabe, Y. Kabasawa, Y. Takase, M. Matsukura, K. Miyazaki, H. Ishihara, K. Kodama, and H. Adachi, *J. Med. Chem.*, 1998, **41**, 3367.
13. M. Sayyafi, M. Seyyedhamzeh, H. R. Khavasi, and A. Bazger, *Tetrahedron*, 2008, **64**, 2357.
14. H. R. Shaterian, A. Hosseinian, and M. Feyzi, *App. Catal., A: General*, 2008, **345**, 128.
15. H. R. Shaterian, F. Khorami, A. Amirzadeh, R. Doostmohammadian, and M. Ghashang, *J. Iran. Chem. Res.*, 2009, **2**, 57.
16. X. Wang, G. Lu, W. Ma, and L. Wu, *E-J. Chem*., 2011, **8**, 100.
17. X. Wang, W. Ma, L. Wu, and F. Yan, *J. Chin. Chem. Soc*., 2010, **57**, 1341.
18. R. Fazaeli, H. Aliyan, and N. Fazaeli, *Catal. J*., 2010, **3**, 14.
19. H. R. Shaterian, A. Hosseinian, and M. Ghashang, *ARKIVOC*, 2009, **ii**, 59.
20. L. Nagarapu, R. Bantu, and H. B. Mereyala, *J. Heterocycl. Chem*., 2009, **46**, 728.

21. S. Hayashi and H. Hamagachi, *Chem. Lett*., 2004, **33**, 1590.
22. (a) M. H. Valkenberg, C. deCastro, and W. F. Hölderich, *Appl. Catal., A*, 2001, **215**, 185; (b) Y. Katayama, I. Konishiike, T.Miura, and T. Kishi, *Journal Power Sources*, 2002, **109**, 327; (c) F. Shi, J. Peng, and Y. Deng, *J. Catal*., 2003, **219**, 372; (d) J.-Z. Yang, W.-G. Xu, Q.-G. Zhang, Y. Jin, and Z.-H. Zhang, *J. Chem. Thermodyn*., 2003, **35**, 1855; (e) P. Kolle and R. Dronskowski, *Inorg. Chem*., 2004, **43**, 2803; (f) Q.-G. Zhang, J.-Z. Yang, X.-M. Lu, J.-S. Gui, and M. Huang, *Fluid Phase Equilib*., 2004, **226**, 207; (g) Y. Yoshida, A. Otsuka, G. Saito, S. Natsume, E. Nishibori, M. Takata, M. Sakata, M. Takahashi, and T. Yoko, *Bull. Chem. Soc. Jpn*., 2005, **78**, 1921.
23. J.-C. Chang, W.-Y. Ho, I.-W. Sun, Y.-K. Chou, H.-H. Hsieh, T.-Y. Wu, and S.-S. Liang, *Polyhedron*, 2010, **29**, 2976.
24. (a) X. Pel, Y. H. Yan, L. Yan, P. Yang, J. Wang, R. Xu, and M. B. Chan-Park, *Carbon*, 2010, **8**, 2501; (b) B. D. Bird and P. Day, *J. Chem. Phys*., 1968, **49**, 392; (c) A. P. Ginsberg and M. B. Robin, *Inorg. Chem.*, 1963, **2**, 817.
25. J. M. Khurana and D. Magoo, *Tetrahedron Lett*., 2009, **50**, 7300.
26. H. J. Wang, X. N. Zhang, and Z. H. Zhang, *Monatsh. Chem.*, 2010, **141**, 425.