



ONE-POT FOUR COMPONENT SYNTHESIS OF 1H-pyrazolo [1,2-b]phthalazine-5,10-dione DERIVATIVES USING CALCINED MG-FE HYDROTALCITE CATALYST

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ABSTRACT

A simple, efficient and One-pot four component synthesis to afford the library of 1H-pyrazolo[1,2-b]phthalazine-5,10-dione derivatives using novel heterogeneous calcined Mg-Fe-CO₃ hydrotalcite at room temperature is described. The calcined hydrotalcite with a Mg/Fe ratio of 3:1 derived from calcinations at 500°C was found to be a suitable catalyst that gives best catalytic activity for this reaction. Hydrotalcites are non-toxic, easy to separate and the isolated catalyst was reused for a number of times without loss of catalytic activity. Hence, making this process green and benign.

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INTRODUCTION

Heterocyclic chemistry attracted considerable attention in organic synthesis and pharmaceutical chemistry¹. Among the various heterocyclic systems nitrogen containing heterocycles play a fundamental role in the view of both chemistry and biology and their application in biologically active pharmaceuticals, agrochemicals and functional materials are getting more and more important.²⁻⁴

In addition, heterocycles containing a phthalimide moiety has attracted extensive attention. Phthalazine derivative have been reported to possess antifungal⁵, anticonvulsant⁶, anti-inflammatory⁷, vasorelaxant⁸ and antimicrobial⁹. Moreover, 1H-pyrazolo [1,2-b]phthalazine-5,10-diones, were also found to have analgesic, antipyretic and antihypoxic activities¹⁰. Therefore, the development of new synthetic methodologies for the construction of 1H-pyrazolo [1, 2-b] phthalazine-5, 10-diones will be a beneficial and interesting challenge. Multicomponent reaction with high throughput generate structurally complex and diverse heterocyclic compounds by the reaction of three or more readily accessible starting materials via a one-pot methodology, have become the powerful tool in organic and medicinal chemistry.^{11,12,13} They offer significant advantages over traditional stepwise strategies, by reducing waste production, showing reaction periods, saving energy and avoiding protection-de protection of functional groups that resulting in both environmental and economical benefits.¹²

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The multicomponent synthesis of 1H-pyrazolo[1,2-b]phthalazine-5,10-diones derivatives have been reported via the three component reaction of phthalhydrazide, malononitrile and aldehyde in the presence of diverse catalyst including p-toluene sulphonic acid in ionic liquid, [Bmim]Br, as solvent at 100°C for 3 hrs¹⁴, InCl₃¹⁵, using triethylamine as a catalyst in ethanol at 60°C for 1 hr under ultrasound with a frequency of 50Khz¹⁶, NiCl₂.6H₂O as a catalyst in ethanol under reflux¹⁷, glycerol promoted catalyst free synthesis¹⁸, AL-KIT-6 in ethanol at 60°C for 4 hrs.¹⁹ However, the reported methods have more or less shortcoming. They largely suffer in practical exploitation either due to use of environmentally unfriendly reagents such as strong acid, ionic liquid, require long reaction time, high temperature and non-recyclability of the catalyst.

In recent year, many investigations drawn great demand on the development of low cost heterogeneous materials with basic characteristics that could be used in reactions. Layer double hydroxides, LDH's are anionic clays that are also referred to as hydrotalcite like compound.²⁰ They have received considerable attention in recent years because of their potential application.^{21,22} General formula is $[M^{2+}_{1-x} M^{3+}_x (OH)_2]^{x+} [A^{n-}_{x/n} \cdot mH_2O]^{x-}$ where M²⁺ and M³⁺ are metal cations, for example Mg²⁺ and Al³⁺, that occupy octahedral sites in the hydroxide layers, Aⁿ⁻ is an exchangeable anion and x is the ratio M³⁺/M²⁺+M³⁺ and layer charge will depend on the M²⁺/M³⁺ ratio²³. There is a need to evaluate environmentally benign catalytic system and hydrotalcite meet the needs. Hydrotalcite has been reported to be ion-exchanger²¹ and catalyst or catalyst support.^{24, 25} It is reusable and non-toxic catalyst system. Herein, we have used Mg/Fe- hydrotalcite as a solid base catalyst for synthesis of 1H-pyrazolo [1,2-b] phthalazine-5,10-diones at room

temperature resulted in high yields. After the reaction, the catalyst can be recycled, easily separable and robust catalyst.

Experimental

Materials

All chemicals of A.R. grade were purchased from S.D. Fine Chemicals Ltd., Mumbai, India and were used without any further purification.

Method of characterization

Melting points of all synthesized compounds were measured on electro thermal apparatus using open capillary tubes and are uncorrected. TLC for the purity of compounds was performed on silica gel coated aluminum plate as adsorbent and which are analyzed with U.V. light as a visualizing agent. FT-IR Spectra were recorded on Bruker Spectrometer in the region of 400-4000 cm^{-1} . ^1H and ^{13}C NMR spectra were recorded on Varian 500 MHz NMR spectrophotometer using TMS as an internal standard and $\text{CDCl}_3/\text{DMSO}-d_6$ as solvent (chemical shifts in δ ppm).

Powder X-ray diffraction pattern was collected with monochromatic $\text{Cu K}\alpha$ radiation ($\lambda = 1.54059 \text{ \AA}$) at 40 kV and 15 mA using Shimadzu 7000S diffractometer. Thermogravimetric analysis was performed with a RIGAKU Thermo Plus TG 8120 thermo balance with a heating rate of $10^\circ\text{C}/\text{min}$ from 25 to 900°C . The morphological information gathered using scanning electron microscope ZEISS Ultra FESEM.

Catalyst preparation

Mg-Fe-HTs with different Mg/Fe molar ratio (Mg/Fe = 2:1, 3:1, 4:1 and 5:1) were synthesized by co-precipitation method.²⁰ An aqueous solution of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ and $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ were prepared and mixed aqueous solution of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ and $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ was added drop wise using addition funnel to an aqueous solution containing NaOH and Na_2CO_3 under vigorous stirring. After complete addition the solution was heated at 80°C for 18 hr and maintain pH of the solution in the range of 10-11 during stirring. After complete stirring, the solution was allowed to cool to room temp and filtered. The obtained residue was washed with hot deionized water several times till filtrate was neutral. The solid was dried in an oven at 60°C in the air. Dry solid then calcined at 500°C for 5 hrs.

General procedure for synthesis of 1H-pyrazolo [1, 2-b] phthalazine-5, 10-dione

In round bottom flask Phthalimide (3mmol), hydrazine hydrate (3mmol) malononitrile (3mmol), benzaldehyde (3mmol) and 0.3 gm C-Mg-Fe-hydrotalcite in ethanol stirred at room temperature. The completion of the reaction was checked by T.L.C. After that, reaction mixture diluted with ethanol and heated to dissolved solid formed. The solid catalyst was recovered by filtration. The removal of solvent resulted in the recovery of solid product. The product was recrystallized using ethanol. Purified product characterized by N.M.R. and I.R.

RESULTS AND DISCUSSION

Characterization of hydrotalcite

XRD (X-ray diffractogram)

Powder XRD of calcined Mg/Fe = 3 hydrotalcite catalyst is in agreement in the standard hydrotalcite peaks, which indexes

are correlating with the reported hydrotalcites. After calcinations due to removal carbonate and water from the hydrotalcite structure mixed oxides of hydrotalcite precursors are formed. The powder X-ray diffraction pattern of LDH with Mg/Fe=3:1 molar ratio (fig. 2) shows peaks at $2\theta = 43.14^\circ, 62.60^\circ$ which are corresponding to MgO and at $2\theta = 30.14^\circ, 35.52^\circ, 43.14^\circ$ and 62.60° which can be attributed to MgFe_2O_4 spinel structure (JCPDS 17-0465) those peaks have been observed in literature.^{26,27}

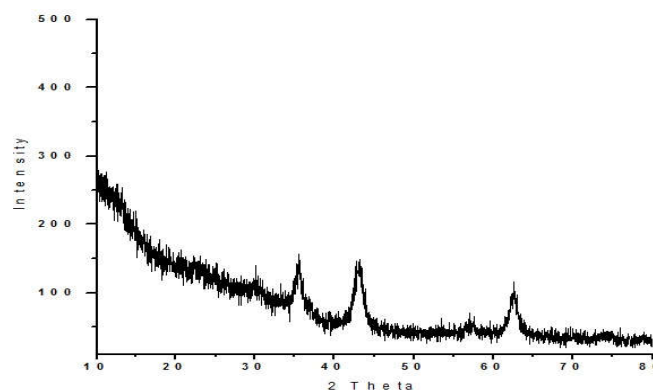


Fig 1 XRD spectrum for calcined hydrotalcite with Mg/Fe = 3:1

TGA (Thermo Gravimetric Analyses) and SEM (Scanning Electron Microscopy)

The TGA Plot of LDH having Mg/Fe molar ratio 3:1 shows three distinct phase loss in the range $50-200^\circ\text{C}$, $200-400^\circ\text{C}$ and $460-750^\circ\text{C}$ (fig. 3). The first weight loss in the temp range of $50-200^\circ\text{C}$ which was about 13%. This weight loss of hydrotalcite mainly due to interlayer and physisorbed water. Further, weight loss of 21% which occurs between $200-460^\circ\text{C}$ which is related to removal of carbonate ions from the interlayer of hydrotalcite and first step dehydroxylation. Final the third mass loss, that occurs further than 460°C can due to continuous dehydroxylation and decarbonation and formation of oxide metals as MgO which are detected in X-ray diffraction of calcined LDH and possibly MgFe_2O_4 , as reported in the literature.^{27,28} Beyond 600°C temp, there was no significant mass loss was observed.

Catalyst morphologies as indicated by the SEM image of C-Mg-Fe-HT-3 showed the materials to be clearly point out the homogeneity in shapes for the sample and high crystallinity (fig.4).

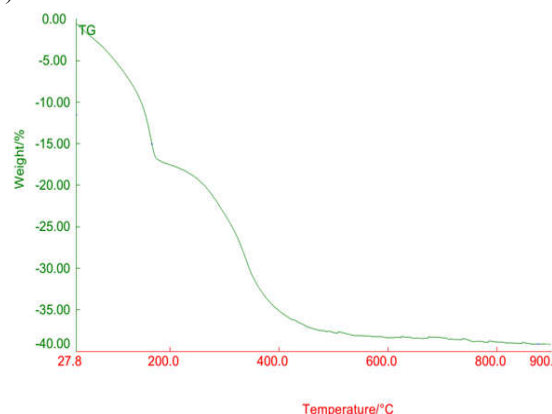


Fig 2 TGA Plot of hydrotalcite with Mg/Fe=3:1.

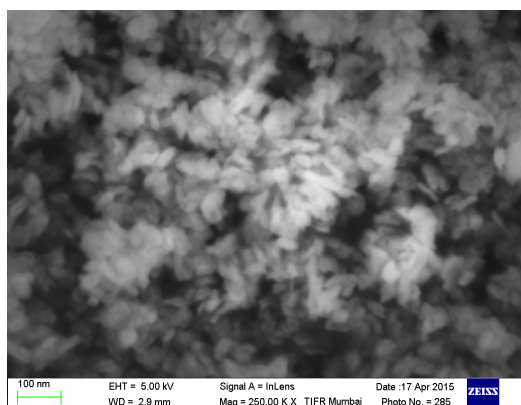
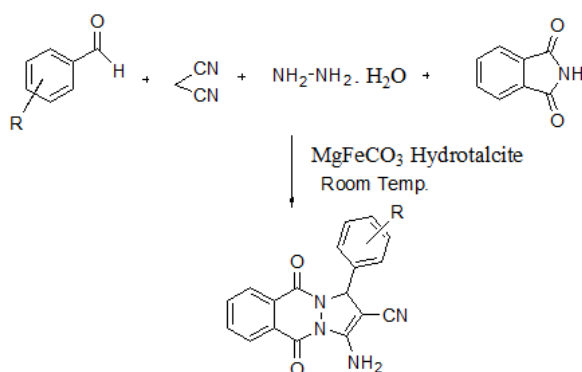


Fig 3 SEM image of hydrotalcite with Mg/Fe=3:1 calcined at 500°C

General reaction of phthalimide, hydrazine hydrate, malononitrile /ethyl acetoacetate and substituted aromatic aldehyde at room temperature were carried out in order to screen the various parameters in presence of Mg/Fe hydrotalcite (Scheme 1).



Scheme 1 Synthesis of 1H-pyrazolo [1, 2-b]phthalazine-5,10-dione as model reaction

In first step, the reaction was examined by carrying out this MCR in different protic and aprotic solvents such as water, ethanol, methanol, DMF and DMSO as tabulated in (Table1). From experimental studies of the solvent, ethanol found to be suitable solvent with an excellent yield of the product. In absence of solvent lower yield of product was observed. Along with solvent, the effect of catalyst and quantity of catalyst also evaluated for the model reaction.

Table 1 Influence of solvent selection in The reaction of benzaldehyde, malononitrile, Phthalimide and Hydrazine hydrate in the presence of C-Mg-Fe HT-3 in different solvents at ambient temperature 29°C

Entry	Solvent	Yield of product (%)
1	H ₂ O	40
2	EtOH	90
3	MeOH	78
4	DMF	55
5	DMSO	48
6	Without solvent	35

Reaction conditions: Benzaldehyde (3mmol), malononitrile (3mmol), Phthalimide (3mmol), Hydrazine hydrate (3mmol), solvent (5ml), C-Mg-Fe HT-3 (0.3g), ambient temperature (29°C).

To find out the most effective catalyst for this reaction calcined- Mg-Fe HT's with different Mg:Fe molar ratio i.e.

2:1,3:1,4:1,5:1. was tried (Table 2). However, the basicity of HT's mainly depend on Mg/Fe molar ratio and calcination temperature. The HT's were calcined in order to tune the basicity. On calcinations at a higher temperature, the Lewis basicity of hydrotalcite increases, while bronsted basicity decreases. It is reported that calcined hydrotalcite contain surface basicity due to OH⁻ group, (Mg-O) pairs and (O²⁻) species.²⁹ The basicity of hydrotalcite also sensitive to the Mg /Fe molar ratio and found to be maximum at Mg /Fe molar ratio 3:1 further increase in molar ratio decreases the basicity. Hence, Mg -Fe HT molar ratio of 3:1 was found to be the best catalyst for this reaction, and in absence of catalyst the yield of product was so poor.

Table 2 Influence of catalyst selection The reaction of benzaldehyde, malononitrile, Phthalimide and Hydrazine hydrate in the presence of different C- Mg-Fe HTs in EtOH at ambient temperature

Entry	Hydrotalcite	Yield of product (%)
1	C-Mg-Fe HT-2	65
2	C-Mg-Fe HT-3	90
3	C-Mg-Fe HT-4	18
4	C-Mg- Fe HT-5	58
5	Without HT	No Reaction

Reaction conditions: Benzaldehyde (3mmol), malononitrile (3mmol), Phthalimide (3mmol), Hydrazine hydrate (3mmol), Ethanol(5ml), C-Mg-Fe HT-3 (0.3g), ambient temperature (29°C).

In the heterogeneous catalyst, the optimization of catalyst quantity is very important in view of scale up of reaction and selectivity towards the expected product. The reaction was carried out with different quantity of hydrotalcite and 0.3gm of calcined- Mg -Fe-HT was found to be optimal quantity (Table 3).Further, any increase in the quantity of catalyst did not increase the yield of product.

Table 3 Influence of C-Mg-Fe-HT-3 catalyst loading in the reaction of benzaldehyde, malononitrile, Phthalimide and Hydrazine hydrate using different quantity of C-Mg-Fe- HT-3 in C₂H₅OH at ambient temperature.

Entry	Catalyst quantity (g)	Yield of product (%)
1	0.10	65
2	0.20	79
3	0.30	90
4	0.40	90
5	0.50	90

Reaction conditions: Benzaldehyde (3mmol), malononitrile (3mmol), Phthalimide (3mmol), Hydrazine hydrate (3mmol), Ethanol (5ml), C-Mg-Fe HT-3 (0.3g), ambient temperature (29°C). Increased with increase in molar ratio up to 3.0 and when this molar ratio exceeds 3.0 the catalytic activity decreases. Since Mg-Fe HT was a heterogeneous base, it was easily separated from the reaction mixture by simple filtration. After each reaction, the catalyst could be reused. However, the yield of product remains same even after reusing of catalyst number of times (Figure .4).

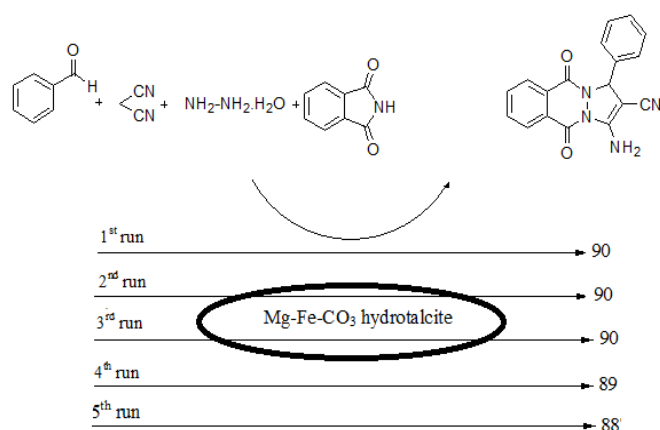
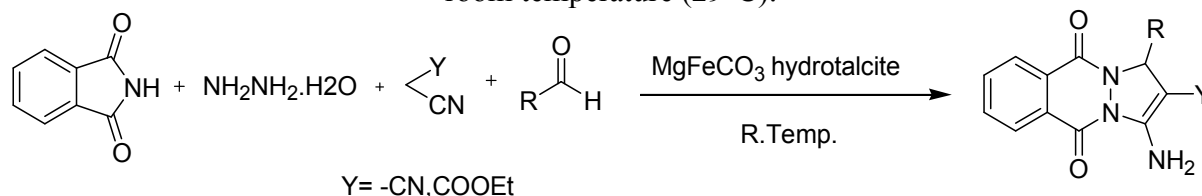


Fig 6 Reusability of the catalyst

Reaction conditions: Benzaldehyde (3mmol), malononitrile (3mmol), Phthalimide (3mmol), Hydrazine hydrate (3mmol), C₂H₅OH (5ml), C-Mg-Fe HT-3 (0.3g), ambient temperature (29°C).

The feasibility of this MCR process was further evaluated under optimized reaction conditions and results are shown in (Table 5). A variety of aromatic aldehyde carrying both electron withdrawing and electron donating groups were reacted with malononitrile and phthalhydrazide to generate 1H-pyrazolo [1, 2-b] phthalazine-5, 10-dione in good to excellent yields. In general aromatic aldehyde carrying electron withdrawing group reacted rapidly as compared to aromatic aldehyde carrying electron donating group. In addition, the four component reactions using ethyl acetoacetate instead of malononitrile generally gave good yields (Table 5).

Table 4 Synthesis of substituted 1H-pyrazolo [1, 2-b] phthalazine-5, 10-dione using C-Mg-Fe-HT-3 at room temperature (29°C).



Entry	R	Y	product	Yield (%)	Time(min.)	M.P°C	Lit. M.P.°C	References
1	C ₆ H ₅	-CN	1a	90	60	275-276	276-278	19
2	3-NO ₂ -C ₆ H ₄		1b	91	55	268-270	269-271	19
3	4-NO ₂ -C ₆ H ₄		1c	93	50	230-231	230-232	19
4	2-Cl- C ₆ H ₄		1d	91	65	259-261	251-261	19
5	3-Cl- C ₆ H ₄		1e	87	68	265-266	266-267	19
6	4-Cl- C ₆ H ₄		1f	92	60	269-270	270-272	19
7	4-OCH ₃ - C ₆ H ₄		1g	87	65	275-276	-
8	3-Furyl		1h	84	65	290-292	-
9	C ₆ H ₅	-COOEt	2a	92	65	345-347	-
10	3-NO ₂ - C ₆ H ₄		2b	94	55	332-334	-
11	4-Cl- C ₆ H ₄		2c	93	60	326-328	-
12	4-OCH ₃ -C ₆ H ₄		2d	89	70	308-310	-

Reaction conditions: Substituted benzaldehyde (3mmol), Phthalimide (3mmol), Hydrazine hydrate (3mmol), Malononitrile /cyano ethylacetoacetate (3mmol), EtOH (5ml), C-Mg-Fe HT-3 (0.3g), reaction temperature (29°C).

CONCLUSION

We have developed an operationally simple and mild process for the synthesis of 1H-pyrazolo [1, 2-b] phthalazine-5, 10-diones in presence of solid base catalyst Mg/Fe=3:1 hydrotalcite at room temperature. This solid base catalyst is a

practical alternative for application of this synthesis in the view of following advantages high catalytic activity, easy separation of catalyst by simple filtration, waste minimization, reusability of catalyst and environmentally benign processes.

Conflicts of interest

There are no conflicts of interest to declare.

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Spectral Data

3-Amino-5,10-dioxo-1-phenyl-5,10-dihydro-1H-pyrazolo[1,2-b]phthalazine-2-carbonitrile (5a): Yellow powder, Yield = 90%, M.P.= 275-276°C, IR (KBr) [cm⁻¹]: 3362 cm⁻¹ & 3261 (NH₂), 2198 (C≡N), 1661 (amido C=O). ¹H NMR (500 MHz, DMSO-*d*₆): δppm= 6.219 (s,1H,CH), 7.401-8.376(m,11H,Ar-H & NH₂) ¹³C NMR (500 MHz, DMSO-*d*₆): δppm= 61.8(CH),116.31 (CN), 127.18-154.09(C=C, ArC), 157.04 (C=O).

3-amino-1-(3-nitro)phenyl-5,10-dioxo-5,10-dihydro-1H-pyrazolo[1,2-b]phthalazine-2- carbonitrile (5b): Yellow powder, Yield = 91%, M.P.= 268-270°C IR (KBr) [cm⁻¹]: 3433 & 3323 (NH₂), 2198 (C≡N), 1658 (amido C=O) 1493 & 1330 (NO₂). ¹H NMR (500 MHz, DMSO-*d*₆): δppm= 6.330 (s,1H,CH), 7.655-8.387 (m, 10H, Ar-H & NH₂).

¹³C NMR (500 MHz, DMSO-*d*₆): δppm= 60.67(CH), 116.10 (CN), 122.50-154.37(C=C, ArC), 157.15 (C=O).

References

- Jiang, B, Rajale, T, Wever, W, Tu, S.J. and Li, G.G., 2010. Multicomponent Reactions for the Synthesis of Heterocycles. *Chem.-Asian J.*, 5:2318-2335.
- Lichtenthaler, F.W. 2002, Unsaturated O- and N-Heterocycles from Carbohydrate Feedstocks *Acc.Chem.Res.* 35:728-737.

- Franklin, E.C. 1935. Heterocyclic Nitrogen Compounds. I. Pentacyclic Compounds. *Chem. Rev.*, 16:305-361.
- Bergstrom, F.W. 1944. Heterocyclic Nitrogen Compounds. Part IIA. Hexacyclic Compounds: Pyridine, Quinoline, and Isoquinoline. *Chem. Rev.*, 35: 77-277.
- Kim, J.S. Rhee, H.K. Park, H.J. Lee, S.K. Lee, C.O. and Park Choo, H.-Y. 2008. Synthesis of 1-/2-substituted-[1,2,3]triazolo[4,5-g]phthalazine-4,9-diones and evaluation of their cytotoxicity and topoisomerase II inhibition *Bioorg. Med Chem.*, 16:4545-4550.
- Grasso, S. DeSarro, G. Micale, N. Zappala, M. Puia, G. Baraldi, M. and Demicheli, C. 2000. Synthesis and Anticonvulsant Activity of Novel and Potent 6,7-Methylenedioxyphthalazin-1(2H)-ones *J. Med. Chem.*, 43:2851-2859.
- Ryu, C.K. Park, R.E. Ma, M.Y. and Nho, J.H. 2007. Synthesis and antifungal activity of 6-arylamino-phthalazine-5,8-diones and 6,7-bis(arylthio)-phthalazine-5,8-diones *Bioorg. Med. Chem. Lett.*, 17:2577-2580.
- Watanabe, N. Kabasawa, Y. Takase, Y. Matsukura, M. Miyazaki, K. Ishihara, H. Kodama, K. Adachi, H. J. 1998. 4-Benzylamino-1-chloro-6-substituted Phthalazines: Synthesis and Inhibitory Activity toward Phosphodiesterase 5 *J. Med. Chem.*, 41:3367-3372.
- Liu, J.N. Li, J. Zhang, L. Song, L.P. Zhang, M. Cao, W.G. Zhu, S.Z. Deng, H.G. and Shao, M. 2012. Facile one-pot three-component reaction to synthesize trifluoromethylated cyclopenta[b]pyran derivatives and their further transformation *Tetrahedron Lett.*, 53:2469-2472.
- Li, J. Zhao, Y.F. Yaun, X.Y. Xu, J.X. and Gong, P. 2006: Synthesis and Anticancer Activities of Novel 1,4-Disubstituted Phthalazines *Molecules*, 11:574-582.
- Ugi, I., Dömling, A. and Hörl, W., 1994. Multicomponent reactions in organic chemistry *Endeavour*, 18 :115-122.
- Jain, R.P. and Vederas, J.C., 2004. Structural variations in keto-glutamines for improved inhibition against hepatitis A virus 3C proteinase *Bioorg. Med. Chem. Lett.*, 14:3655-3658.
- Heravi, M.M., Baghernejad, B. and Oskooie, H.A., 2009. A novel three-component reaction for the synthesis of N-cyclohexyl-3-aryl-quinoxaline-2-amines *Tetrahedron Lett.*, 50:767-769.
- Ghahremanzadeh, R., Imani Shakibaei, G. and Bazgir, A., 2008. An efficient one-pot synthesis of 1H-pyrazolo[1,2-b]phthalazine-5,10-dione derivatives, *Synlett.*, 8:1129-1132.
- Jiang, Y., Gao, S.Y., Li, Z.D., Jia, X.X. and Chen, Y.L., 2011. Cauliflower-like CuI nanostructures: green synthesis and applications as catalyst and adsorbent *Mater. Sci. Eng. B.*, 176:1021-1027.
- Nabid, M.R., Tabatabaei Rezaei, S.J., Ghahremanzadeh, R. and Bazgir, A., 2010. Ultrasound-assisted one-pot, three-component synthesis of 1H-pyrazolo[1,2-b]phthalazine-5,10-diones *Ultrason. Sonochem.*, 17: 159-161.
- Song, S.H., Zhong, J., He, Y.H., and Guan, Z., 2012. One-pot four-component synthesis of 1H-pyrazolo[1,2-b]phthalazine-5,10-dione derivatives *Tetrahedron Lett.*, 53: 7075-7077.
- Mulik, A., Deshmukh, M., Chandam, D., Patil, P., Jagdale, S., Patil, D., and Sankpal, S., 2013. Glycerol-promoted catalyst-free one-pot three component synthesis of 1H-pyrazolo[1,2-b]phthalazinediones *Der Pharma Chemica*, 5(2):19-23.
- Karthikeyan, G., and Pandurangan, A., 2012. Post synthesis alumination of KIT-6 materials with Ia3d symmetry and their catalytic efficiency towards multicomponent synthesis of 1H-pyrazolo [1,2b]phthalazine-5,10-dione carbonitriles and carboxylates *J. Mol. Catal. A: Chem.*, 361-362:58-67.
- Cavani, F., Trifiro, F., Vaccari, A., 1991. Hydrotalcite-type anionic clays: Preparation, properties and applications. *Catal. Today*, 11: 173-301.
- Vaccari, A., 1999: Clays and catalysis: a promising future *Appl. Clay Sci.*, 14, 161-198
- Rives, V., and Ulibarri, M.A., 1999: Layered double hydroxides (LDH) intercalated with metal coordination compounds and oxometalates *Coordination Chemistry Reviews*, 181:61.
- Wei, M., Shi, S., Wang, J., Li, Y., and Duan, X., 2004. Studies on the intercalation of naproxen into layered double hydroxide and its thermal decomposition by in situ FT-IR and in situ HT-XRD *Journal of Solid State Chemistry*, 177:2534.
- Costantino, U., Ambrogi, V., Nocchetti, M. and Perioli, L., 2008. Hydrotalcite-like compounds: Versatile layered hosts of molecular anions with biological activity *Microporous. Microporous Mesoporous Mater.*, 107:149-160.
- I. Carpani, M. Berrettoni, B. Ballarin, M. Giorgetti, E. Scavetta and D. Tonelli, 2004. Study on the intercalation of hexacyanoferrate (II) in a Ni, Al based hydrotalcite *Solid State Ionics*, 168:167-175.
- Zhang, H., Qi, R., Evans, D.G. and Due, X., 2004, Synthesis and characterization of a novel nano-scale magnetic solid base catalyst involving a layered double hydroxide supported on a ferrite core *J. Solid State Chem.*, 177:772-780.
- Ferreira, O.P., Alves, O.L., Gouveia, D.X., Souza Filho, A.G., de Paiva, J.A.C. and Mendes Filho, J., 2004. Thermal decomposition and structural reconstruction effect on Mg-Fe-based hydrotalcite compounds *J. Solid State Chem.*, 177:3058-3069.
- Kovanda, F., Balek, V., Dornieák, V., Martinec, P., Maslão, M., Bílková, L., Koloušek, D., and Bountsewa, I.M., 2003. Thermal behaviour of synthetic pyroaurite-like anionic clay *J. Therm. Anal. Calorim.*, 2003:727-737.
- Xie, W., Peng, H., Chen, L., 2006. Calcined Mg-Al hydrotalcites as solid base catalysts for methanolysis of soybean oil. *J. Mol. Catal. A: Chem.*, 24:246.
