A Concise Review of Nanocomposites' Function in Organic Reactions to Synthesize Various Organic Nuclei

Doaa A. Elsayed Department of Chemistry, Faculty of Science, Zagazig University

A Abd-ElSattar Department of Chemistry, Faculty of Science, Zagazig University

Mohamed E.Abdu Department of Chemistry, Faculty of Science, Zagazig University

Wesam S. Shehab Department of Chemistry, Faculty of Science, Zagazig University

https://doi.org/10.5109/7323382

出版情報: Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.1005-1011, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences バージョン: 権利関係: Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International

A Concise Review of Nanocomposites' Function in Organic Reactions to Synthesize Various Organic Nuclei

Doaa A. Elsayed¹, A Abd-ElSattar¹, Mohamed E.Abdu ^{1,2}, Wesam S. Shehab^{1*}

^{1.} Department of Chemistry, Faculty of Science, Zagazig University, Zagazig 44519 Egypt.
^{2.}Kyushu University, 6-1 Kasuga-Koen Kasuga, Fukuoka,816-8580.Japan.

Corresponding author email: wsshehab@zu.edu.eg (W.S.S.), dr.wesamshehab@gmail.com

Abstract: Given the high aspect ratio and larger surface area of nanostructured materials, nanocomposites are essential catalysts in organic processes. The rate and yield of the product are enhanced during the reaction due to the significant interfacial contact of the reactant with the surface of nanocomposites. A critical investigation of the role of nanocomposites in chemical reactions (Reduction, oxidation, epoxidation, Knoevenagel Michael condensation and coupling reactions) to synthesize different organic nuclei is shown in the current review. Different transition metal-based nanocomposites track organic reaction selectivity as well as changes in yields, reaction time, atom economy, and solvent influence. Numerous recognized green one-pot synthesis methods for organic nuclei. These methods also include the use of different nano catalysts. Therefore, the current study investigates novel approaches to the replacement of conventional catalysts and reagents in organic synthesis with transition metal-based nanostructured catalysts, adhering to green chemistry principles.

Keywords: Nanocomposites; Organic Reactions; Organic Nuclei; oxidation, Knoevenagel Michael

1. INTRODUCTION

One of the main objectives of organic synthesis is the creation of straightforward synthesis methods for commonly used organic molecules using easily available reagents. Researchers are currently paying close attention to the production of new heterocyclic compounds with high biological activity through the use of highly efficient nanoparticles. Recently, there has been an increasing interest in the search for affordable and efficient solid nano catalysts [1, 2]. According to a number of recent research, magnetic nanoparticles can be used to synthesize novel chemicals utilizing simpler, more affordable, and environmentally friendly methods, such as nanocrystalline TiO₂-HClO₄ [3]. ZnCl₂ supported on nano Fe₃O₄@SiO₂ [4] , SO₃H-dendrimer (Fe₃O₄ @D-NH-(CH₂)₄-SO₃H), [5] nanostructured diphosphate $(Na_2CaP_2O_7)$, [6] and MMWCNTs-D- $(CH_2)_4$ -SO₃H. [7] Sulfonic acid nanoporous silica (SBA-Pr-SO₃H), [8] Fe₃O₄, [9] nano[2-bromophenylsalicylaldiminemethyl pyranopyrazole]Cl₂, [10] nickel NPs-N-doped TiO₂ [11] and MGO-D-NH-(CH₂)₄-SO₃H are further attempts at creating new, superior nanocatalysts [12]. Furthermore, the presence of effective and recyclable nano-catalysts like Mn₃O₄, Fe₃O₄, and ZnO enforced the field [13]. Nanocomposites based on transition metals are a novel class of materials that have unique properties and are better than conventional doped type systems. Some of the drawbacks of conventional catalysts include their costly synthesis techniques and laborious separation processes. In many different synthesis methods, catalysts based on nanocomposites have gained a great deal of interest. More stability and selectivity result from the substantial alteration of transition metal nano catalysts in terms of size, shape, and composition [14, 15]. However, good interpretation of the reaction mechanisms and analysis of potential by-products are crucial for the synthesis of novel chemicals, more advanced processes, and

increased efficiency. The fundamental idea behind nano catalysis can be understood by examining the crucial role that intrinsic properties of nanomaterials play in catalytic activity. These properties can be directly related to (a) bond length, primarily atomic density, mean lattice constant, and binding energy; (b) cohesive energy per discrete atom, such as critical temperature for phase transformations, diffusion, nano-solid evaporation, and chemical reactions; and properties like (c) A Hamiltonian that aids in identifying the whole band structure, core level energy, band gap, photoemission, and photo absorption and is dependent on the binding energy density in the relaxed continuum region (d) mechanical strength, strain, stress, Young's modulus, surface energy, and magnetic behavior, all of which are influenced by the interaction of binding energy density and cohesive energy between atoms [16]. Because the precise mechanism underlying these catalytic activities is yet unknown, researchers are drawn to developing new approaches to the design and analysis of nanocatalysts. Catalysis is responsible for the production of almost 50% of all compounds used in most chemical processes [17]. Heterogeneous catalysts became an essential component of many industrialized processes, such as organic synthesis, pollution management, and oil refining [18, 19]. By monitoring the pore shape or changing views toward, say, nanotechnology and nanoscience, it was more likely to promote heterogeneous catalytic activity [20]. Several catalyst supports were used to constrain the particle in order to address the problem of catalyst recovery and separation from the reaction matrix on behalf of heterogeneous catalysis. gives the heterogeneous catalyst enough surface area [21] to prevent it from dissolving into the solution matrix [22-24]. Thus, heterogeneous catalysts, such as TiO₂, Al₂O₃, ZrO₂, and ZnO, were based on their broad availability and reasonably priced synthesis methods.

In this review, we aim to delve into the fundamentals and mechanisms of different transition metal-based nanocomposites track organic reaction selectivity as well as changes in yields, reaction time, atom economy, and solvent influence. Numerous recognized green one-pot synthesis methods for organic nuclei are examined, including diazenyl benzoic acid derivatives, 1H-3-Indolyl derivatives, 1H-benzo[d]imidazole derivatives, pyrano[2,3] pyrimidine derivatives, and pyrimidine-5carbonitrile.

This review critically examines the role of nanocomposites in various chemical reactions, including reduction, oxidation, epoxidation, Knoevenagel-Michael condensation, and coupling reactions, for synthesizing different organic compounds.

The review highlights how different transition metalbased nanocomposites affect organic reaction selectivity, as well as changes in yields, reaction times, atom economy, and solvent effects. It also covers established green one-pot synthesis methods for organic compounds, which often utilize various nano catalysts.

The study focuses on exploring innovative approaches to replace traditional catalysts and reagents with transition metal-based nanostructured catalysts, in line with green chemistry principles. The main objectives and novel aspects of this study should be emphasized clearly.

2. MECHANISM OF ROLE OF NANO CATALYST IN ORGANIC CHEMISTRY

Shehab et al. discussed mechanism of role of nano catalyst in organic chemistry, because of their higher surface area and high aspect ratio, nanostructured materials are essential catalysts in organic processes and play a significant role in nanocomposites. The rate and yield of the product are increased throughout the reaction due to the reactant's high interfacial contact with the nanocomposites' surface Fig 1 [25].



Fig. 1. The conceivable process for producing pyrano[2,3-d]pyrimidine-6–carbonitrile (1) [21]

3. APPLICATION OF TRANSITION METAL BASED NANOCOMPOSITE CATALYSTS FOR ORGANIC REACTIONS

The development of transition metal nanocomposites has been accelerated by their broad variety of synthesis techniques, flexibility in modifying their characteristics and compositions, and extensive use in catalysis. A large number of novel and important materials synthesis processes in the industrial domain rely on catalysts derived from transition metal nanocomposites. With the exact control over the location, quantity, and kind of active sites as well as the hydrophilic and porosity characteristics of the catalyst, nanocomposite materials allow for wide catalyst creation. Many techniques for modifying the physical and chemical features of these composites are available to improve their catalytic effectiveness Fig 2 [26].



Fig. 2. Use of catalysts for organic processes based on transition metal nanocomposite materials [22].

3.1. Reduction reactions

The reduction of 4-nitrophenol (4-NP) to 4-aminophenol (4-AP) using transition metal-based nanocomposites as catalysts involves several mechanisms and catalyst designs to achieve efficient conversion.

3.1.1. Catalyst Design and Mechanism:

Metallic Species and Active Sites: Transition metalbased nanocomposites are designed to have metallic species that provide active sites for adsorption of NaBH₄. NaBH₄ acts as the source of hydride ions (H⁻) necessary for the reduction reaction.

Formation of Metal-Hydride Complex: The catalyst facilitates the adsorption of NaBH₄, which forms a metalhydride complex on the catalyst surface. This complex is crucial as it generates active hydride species required for the reduction reaction.

3.1.2. Reduction Mechanism:

Interaction with 4-Nitrophenol (4-NP): 4-NP molecules diffuse onto the surface of the catalyst where they interact with the active hydrogen species generated from the NaBH4 reaction.

Formation of 4-Aminophenol (4-AP): The active hydrogen species from the metal-hydride complex react with the nitro group (-NO₂) of 4-NP, leading to the reduction of the nitro group to an amino group (-NH₂), thereby forming 4-aminophenol (4-AP).

3.1.3. Examples of Catalysts and Their Efficiency:

Mohamed et al. (NC)-1 Catalyst: This catalyst, RGO-ZnWO₄-Fe₃O₄, demonstrates high efficiency in reducing

4-NP to 4-AP, completing the reaction in just 40 seconds compared to conventional methods [27] Fig 3.



Fig. 3. Reduction of 4-Nitrophenol to 4-Aminophenol by RGO-ZnWO₄-Fe₃O₄ [32].

Sahu et al. L-cys-rGO/Ag Nanocomposite: This composite utilizes nano silver imprinted graphene oxide as a catalyst. L-cysteine present in the composite aids in stabilization and modification of the graphene oxide sheet, enhancing catalytic efficiency. This catalyst achieves rapid conversion of 4-NP to 4-AP within 6 to 7 minutes Fig 4a.

Das et al. Cu/HAP/ZnFe₂O₄ catalyst: The NaBH₄ acts as a source of hydrogen. NaBH₄ reacts with water and produces hydrogen gas according to the equation below.

$NaBH_4 + H_2O \rightarrow NaBO_2 + 4H_2$

BH4 - ions are adsorbed and reacted with the surface of Cu/HAP/ZnFe₂O₄ catalyst to produce active hydrogen species. At the same time, p-NP in the solution diffuses onto the surface of Cu/HAP/ZnFe₂O₄ and reacts with the active hydrogen species to form p-AP Fig 4b [26].



Fig. 4. (a) Reduction of 4-nitrophenol to 4-aminophenol by L-cys-rGO/Ag; (b) reduction of 4-nitrophenol to 4-aminophenol by Cu/HAP/ZnFe₂O₄ [22]. 3.2. Oxidation reactions

The oxidation mechanisms described by Shahriari et al. [26] and Mal et al. [28] illustrate different approaches in catalytic processes involving transition metal catalysts Fig 5.



Fig. 5. Oxidation of (a) benzyl alcohol to benzaldehyde by Fe₃O₄@CS-Agarose/Pd [22];(b) toluene to

benzaldehyde by MnWO₄ [24].

3.3. Knoevenagel Michael condensation

Shehab et al. used Mn₂O₃ as a nano- and green solid acid catalyst for the synthesis of 7-amino-4-oxo-5-(thiophen-2-yl)2*H*-pyrano[2,3-*d*] pyrimidine-6-carbonitrile derivatives via the Knoevenagel Michael condensation. The process involves combining thiophene-2carbaldehyde, barbituric acid derivatives, and malononitrile in ethanol. By examining how the amount of Mn₂O₃ nano catalyst affects the reaction yield, optimization methods for Mn₂O₃ catalysis and pyranopyrimidine heterocyclic synthesis have been established. It was discovered that 1 mmol of Mn₂O₃ generated around 80% of pyranopyrimidine in 30 minutes, which is the optimal length of time to finish the reaction Fig 6 [29].



Fig. 6. synthesis of pyrano[2,3-d]pyrimidine Derivatives [25].

For the synthesis of 7-amino-5-(4-chlorophenyl)-4oxo-2-thioxo-2,3,4,5-tetrahydro-1H-pyrano[2,3-

d]pyrimidine-6-carbonitrile, AbdEl-Azim et al . used a one-pot multicomponent cyclocondensation process [25]. Refluxing conditions in ethanol facilitate the reaction of 4-chlorobenzaldehyde, thiobarbituric acid, and malononitrile with a catalytic quantity of Fe₃O₄ (or Mn₃O₄ or ZnO) nanoparticles as a catalyst. Various catalysts were employed to ascertain the ideal reaction conditions. First, this reaction using the methods mentioned in the literature [30] to determine the best kind of catalysts to utilize in this experiment: Fe₃O₄, ZnO, or Mn₃O₄. The use of Mn₃O₄ in the reaction produced the best outcomes. The outcomes showed that Fe₃O₄ had a low efficiency. The model reaction was conducted under refluxing conditions in ethanol in order to maximize the time. The findings show that after two hours, an 88% yield was achieved. On a carbon-coated copper grid, finely ground (Mn₃O₄, ZnO, and Fe₃O₄) nanocrystals were distributed in ethanol to produce high-resolution transmission electron microscopy pictures, as shown in Fig 7.



Fig. 7. synthesis of 7-amino-5-(4-chlorophenyl)-4-oxo 2-thioxo-2,3,4,5-tetrahydro 1H-pyrano[2,3-d]pyrimidine 6-carbonitrile [21].

Elsayed et al. used TiO_2 nanoparticles (TiO_2 -NPs) as a catalytic. It was discovered that when TiO_2 -NPs were added to the process, the greatest results were produced a 97% yield was reached after two hours Fig 8 [31].



Fig. 8. The synthesis of 2-amino-6-(1H-indol-3-yl)-4-(thiophen-2-yl)-4H-pyran-3-carbonitrile [27].

The generation of CuO-NPs and sodium acetate $(C_2H_3O_2Na)$ were connected in order to obtain the best sort of catalysts [32]. It became clear that when the CuO-NPs were elaborated in the reaction, the best characteristics were obtained. The model reaction was carried out in stirring conditions in order to adjust the time. Organized findings confirmed that 4 minutes after ingesting the CuO-NPs as a catalyst, 99% yield was

attained. The tabulated data demonstrated that CuO-NPs produced the best outcomes in terms of yield and time Fig 9.



Fig. 9. The synthesis of diazenyl benzoic acid Derivatives [28].

Shehab et al. was created different new heterocyclic compounds based on the pyrimidine moiety. The starting material4-(4-cyanophenyl)-6-oxo-2-

thioxohexahydropyrimidine-5-carbonitrile was synthesized using two different methods [33]. The traditional method involves reacting 4cyanobenzaldehyde with thiourea, also known as ethyl cyanoacetate, in ethanol under reflux circumstances while adding a small amount of triethylamine. The three components' reaction in the presence of Mn₃O₄ nanoparticles (Mn₃O₄-NPs) as a catalytic quantity in ethanol under reflux was recorded in order to create pyrimidine-5-carbonitrile with ideal reaction conditions Fig 10.



Fig. 10. The synthesis of 4-(4-cyanophenyl)-6-oxo-2-thioxohexahydropyrimidine-5-carbonitrile [29].

3.4. Epoxidation reactions

Mishra et al. [34] designed Ti–Co (NP)HT nano catalyst for oxidation of styrene-to-styrene oxide Fig. 11a.

According to Jiao et al. [35] there are two pathways to convert cyclohexene as given in Fig. 11b. Firstly, cyclohexene (1) is epoxidized to cyclohexene oxide (2), which can be hydrolysed to 1,2-cyclohexanediol (4) under acidic conditions. The other pathway is the allylic oxidation of cyclohexene to cyclohexen-1-one (3) and 2cyclohexen-1-ol(5). the TPAOH modified samples have a comparable selectivity to cyclohexene oxide, while the TPAOH modified samples have higher selectivity of 1,2cyclohexanediol and lower selectivity of cyclohexen-1one and 2-cyclohexen-1-ol. This implies that more cyclohexene is oxidized to cyclohexene oxide and 1,2cyclohexanediol via Pathway 1 over the TPAOH modified samples when compared to the as-prepared sample. These results clearly demonstrate the positive role of framework titanium in promoting Pathway 1 as the primary reaction route.



Fig. 11. Oxidation of styrene-to-styrene oxide by (a) Ti-Co (NP)HT [30]; (b) TS-1 zeolites [31].

3.5. Coupling reactions

Maity et al. synthesized a nanocomposite catalyst (*NC*)-**144**, XG-Pd (Pd nanoparticle/ calcium-cholate (CaCh) xerogel) for Suzuki crosscoupling reaction of iodobenzene (**35**) and phenylboronic acid (**36**) Fig 12 [36]. This catalyst can be used 4 times efficiently to provide high yield of products.



Fig. 12. Suzuki cross-coupling reaction of iodobenzene and phenylboronic acid by using XG-Pd nanocomposite catalys [32].

Veisi et al. [37, 38] developed a nanohybrid material called Fe₃O₄/DAG/Pd (Fe_3O_4) functionalized diaminoglyoxime nanocomposite supported bv palladium nanoparticles) to catalyze the Mizoroki-Heck reaction between styrene and aryl halides. Fig 13a, the coupling of styrene and bromobenzene is optimized for various parameters, including solvent effects, base presence, and catalyst concentrations. Et₃N has a higher effect than other bases, and DMF is the best solvent option. Optimized circumstances result in efficient reactions between electron-donating and electronwithdrawing groups and styrene, providing high yields of trans-stilbene.

Heidari al. [26] developed et а Fe₃O₄@SiO₂/isoniazide/Pd nanocatalyst for Suzuki coupling processes to produce biaryl compounds. Fig 13b illustrates the nanocatalyst's catalytic pathway. The first step involves the oxidative addition of an active palladium catalyst to an aryl halide to form Pd(II) intermediate (II). The second step involves exchanging the aryl moiety of phenyl boronic acid with halide on the catalyst's surface (III), followed by reductive elimination to produce the desired product. The magnetic catalyst is easily recovered and may be reused up to six times more efficiently.



Fig. 13. Heck coupling reaction by Fe₃O₄/DAG/Pd. [33]; (b) Suzuki coupling reaction by Fe₃O₄@SiO₂/isoniazide/Pd. [22].

4. CONCLUSION

This review comprehensively discusses the importance and advantages of nanocomposites in organic synthesis, emphasizing their role as catalysts. Nanocomposites, due to their high aspect ratio and large surface area, provide

enhanced interfacial contact between reactants and the catalyst surface, leading to increased reaction rates and yields. The review highlights several key points:

Enhanced Catalytic Efficiency: Nanocomposites improve the efficiency of organic reactions through their high surface area, which allows for greater interaction between reactants and the catalyst.

Transition Metal-Based Nanocomposites: These are particularly significant in tracking selectivity, yield, reaction time, atom economy, and solvent influence in organic reactions. They offer a promising alternative to traditional catalysts by providing better performance and adhering to green chemistry principles.

Green One-Pot Synthesis Methods: The review examines various green one-pot synthesis methods for organic nuclei such as diazenyl benzoic acid derivatives, 1H-3-Indolyl derivatives, 1H-benzo[d]imidazole derivatives, pyrano[2,3]pyrimidine derivatives, and pyrimidine-5carbonitrile. These methods utilize different nanocatalysts to streamline synthesis processes, making them more environmentally friendly and efficient.

Novel Approaches: The study explores innovative approaches to replacing conventional catalysts and reagents in organic synthesis with transition metal-based nanostructured catalysts. This aligns with green chemistry principles by minimizing waste and the use of hazardous substances.

Overall, the review underscores the critical role of nanocomposites in advancing organic synthesis, providing a more sustainable and efficient alternative to traditional methods. The focus on green chemistry principles and the development of novel catalytic approaches highlights the potential for significant advancements in the field.

REFERENCES

[1] N. Neogi, K.P. Choudhury, Utilization of Metal Based Nanoparticles in Biomedical Imaging Technologies. (2023).

[2] M.G. Sazid, A.I. Helal, T. Islam, S. Purkaystha, A Mini Review of Photocatalytic Effects of Nano TiO_2 and an Analysis of Their Effectiveness (2023).

[3] F. Shirini, S.V. Atghia, M.G. Jirdehi, Nanocrystalline TiO2–HClO4: a novel, efficient and recyclable catalyst for the chemoselective N-Boc protection of amines under solvent-free condition, Chinese Chemical Letters 24 (2013) 34.

[4] F. Adibian, A.R. Pourali, B. Maleki, M. Baghayeri, A. Amiri, One - pot synthesis of dihydro-1H-indeno [1, 2-*b*] pyridines and tetrahydrobenzo [*b*] pyran derivatives using a new and efficient nanocomposite catalyst based on N - butylsulfonate - functionalized MMWCNTs-D-NH₂, Polyhedron 175 (2020) 114179.

[5] B. Maleki, O. Reiser, E. Esmaeilnezhad, H.J. Choi, SO₃H-dendrimer functionalized magnetic nanoparticles (Fe₃O₄@DNH(CH₂) 4SO₃H): Synthesis, characterization and its application as a novel and heterogeneous catalyst for the one-pot synthesis of polyfunctionalized pyrans and polyhydroquinolines, Polyhedron 162 (2019) 129. [6] B. Maleki, N. Nasiri, R. Tayebee, A.

[6] B. Maleki, N. Nasiri, R. Tayebee, A. Khojastehnezhad, H.A. Akhlaghi, Green synthesis of tetrahydrobenzo [*b*] pyrans, pyrano [2, 3-*c*] pyrazoles and spiro [indoline-3, 4-pyrano [2, 3-*c*] pyrazoles catalyzed

by nano-structured diphosphate in water, RSC advances 6 (2016) 79128.

[7] B. Maleki, H. Alinezhad, H. Atharifar, R. Tayebee, A.V. Mofrad, One-pot synthesis of polyhydroquinolines catalyzed by $ZnCl_2$ supported on nano Fe₃O₄@ SiO₂, Organic Preparations and Procedures International 51 (2019) 301.

[8] G.M. Ziarani, S. Faramarzi, S. Asadi, A. Badiei, R. Bazl, M. Amanlou, Three-component synthesis of pyrano [2, 3-d]-pyrimidine dione derivatives facilitated by sulfonic acid nanoporous silica (SBA-Pr-SO₃H) and their docking and urease inhibitory activit, DARU Journal of Pharmaceutical Sciences 21 (2013) 1.

[9] M. Pirhayati, A. Kakanejadifard, H. Veisi, A new nano-Fe₃O₄-supported organocatalyst based on 3, 4-dihydroxypyridine: an efficient heterogeneous nanocatalyst for one-pot synthesis of pyrazolo [3, 4-b] pyridines and pyrano [2, 3-d] pyrimidines, Applied Organometallic Chemistry 30 (2016) 1004.

[10] A. Moosavi-Zare, H. Goudarziafshar, Z. Jalilian, Nano-Zn[2-

boromophenylsalicylaldiminemethylpyranopyrazole]

Cl₂ as a novel nanostructured Schiff base complex and catalyst for the synthesis of pyrano [2,3-d] pyrimidinedione derivatives, Applied Organometallic Chemistry 33 (2019) e4584.

[11] Y. Rajinder, M. Gupta, J. Kour, Nickel NPs@ N-doped titania: an efficient and recyclable heterogeneous nanocatalytic system for one-pot synthesis of pyrano [2, 3-d] pyrimidines and 1, 8-dioxo-octahydroxanthenes, Journal of the Iranian Chemical Society 16 (2019) 1977.
[12] H. Alinezhad, M. Tarahomi, B. Maleki, A. Amiri, SO₃H-functionalized nano-MGO-D-NH₂: synthesis, characterization and application for one - pot synthesis of pyrano [2, 3-d] pyrimidinone and tetrahydrobenzo [b] pyran derivatives in aqueous media, Applied Organometallic Chemistry 33 (2019) e4661.

[13] W.S. Shehab, A.F. EL-Farargy, A.O. Abdelhamid, M.A. Aziz, Synthesis and biological application of pyranopyrimidine derivatives catalyzed by efficient nanoparticles and their nucleoside analogues, Synthetic Communications 49 (2019) 3560.

[14] X. Yu, V. De Waele, A. Löfberg, V. Ordomsky, A.Y. Khodakov, Selective photocatalytic conversion of methane into carbon monoxide over zinc-heteropolyacid-titania nanocomposites, Nature Communications 10 (2019) 700.

[15] D. Dang, Y. Chen, X. Chen, K. Feng, B. Yan, Y. Cheng, Phase-pureM1MoVNbTeOx/TiO₂

nanocomposite catalysts: high catalytic performance for oxidative dehydrogenation of ethane, Catalysis Science & Technology 12 (2022) 1211.

[16] S.B. Singh, P.K. Tandon, Catalysis: a brief review on nano-catalyst, J. Energy Chem. Eng 2 (2014) 106.

[17] D.J. Pollard, J.M. Woodley, Biocatalysis for pharmaceutical intermediates: the future is now, TRENDS in Biotechnology 25 (2007) 66.

[18] R. Liu, R. Jin, J. An, Q. Zhao, T. Cheng, G. Liu, Hollow-Shell-Structured Nanospheres: A Recoverable Heterogeneous Catalyst for Rhodium-Catalyzed Tandem Reduction/Lactonization of Ethyl 2-Acylarylcarboxylates to Chiral Phthalides, Chemistry– An Asian Journal 9 (2014) 1388.

[19] M.M. Amer, M.H. Abdellattif, S.M. Mouneir, W.A. Zordok, W.S. Shehab, Synthesis, DFT calculation,

pharmacological evaluation, and catalytic application in the synthesis of diverse pyrano [2, 3-c] pyrazole derivatives, Bioorganic Chemistry 114 (2021) 105136. [20] B. Uysal, B.S. Oksal, New heterogeneous B (OEt) 3-MCM-41 catalyst for preparation of α , β -unsaturated alcohols, Research on Chemical Intermediates 41 (2015) 3893.

[21] R.M.D. da Cruz, F.J.B. Mendonça-Junior, N.B. de Mélo, L. Scotti, R.S.A. de Araújo, R.N. de Almeida, R.O. de Moura, Thiophene-based compounds with potential anti-inflammatory activity, Pharmaceuticals 14 (2021) 692.

[22] K. Yamaguchi, C. Yoshida, S. Uchida, N. Mizuno, Peroxotungstate immobilized on ionic liquid-modified silica as a heterogeneous epoxidation catalyst with hydrogen peroxide, Journal of the American Chemical Society 127 (2005) 530.

[23] M.Z. Basyouni, M.E. Abdu, M.F. Radwan, A.M. Spring, From monomer to polymer: Controlled synthesis and comprehensive analysis of poly (p-phenylene vinylene) via ROMP, Journal of Molecular Structure 1310 (2024) 138001.

[24] A.A. El - Shehawy, M.E. Abdu, M.M. El -Hendawy, M. El - Khouly, M.H. Sherif, H.Y. Moustafa, Synthesis, photophysical, and theoretical studies on π conjugated copolymers based on benzothiadiazole and cyanopyridine acceptor moieties along with other π bridge units. Journal of Physical Organic Chemistry 34 (2021) e4158.

[25] M.H. AbdEl-Azim, M.A. Aziz, S.M. Mouneir, A.F. EL-Farargy, W.S. Shehab, Ecofriendly synthesis of pyrano [2, 3-d] pyrimidine derivatives and related heterocycles with anti-inflammatory activities, Archiv der Pharmazie 353 (2020) 2000084.

[26] S. Patra, S. Mishra, B. Parhi, H. Mishra, S.K. Swain, Role of transition metal nanocomposites in organic reactions: A state of art as an alternative to conventional catalysts, Results in Chemistry 6 (2023) 101172.

[27] M.J. Sadiq Mohamed, K. Bhat Denthaje, Novel RGO-ZnWO4-Fe3O4 nanocomposite as an efficient catalyst for rapid reduction of 4-nitrophenol to 4-aminophenol, Industrial & Engineering Chemistry Research 55 (2016) 7267.

[28] D.D. Mal, S. Khilari, D. Pradhan, Efficient and selective oxidation of toluene to benzaldehyde on manganese tungstate nanobars: a noble metal-free approach, Green Chemistry 20 (2018) 2279.

[29] W.S. Shehab, W.H. El-Shwiniy, Nanoparticles of manganese oxides as efficient catalyst for the synthesis of pyrano [2, 3-d] pyrimidine derivatives and their complexes as potent protease inhibitors, Journal of the Iranian Chemical Society 15 (2018) 431.

[30] A.V. Chate, R.M. Dongre, M.K. Khaire, G.M. Bondle, J.N. Sangshetti, M. Damale, β -CD-catalyzed multicomponent domino reaction: synthesis, characterization, in silico molecular docking and biological evaluation of pyrano [2, 3-d]-pyrimidinone derivatives, Research on Chemical Intermediates 44 (2018) 6119.

[31] D.A. Elsayed, M.G. Assy, S.M. Mousa, G.T. El-Bassyouni, S.M. Mouneir, W.S. Shehab, TiO2 nanoparticle as catalyst for an efficient green one-pot synthesis of 1H-3-Indolyl Derivatives as significant antiviral activity, Bioorganic Chemistry 124 (2022) 105805. [32] W.S. Shehab, D.A. Elsayed, A.M. Abdel Hamid, M.G. Assy, S.M. Mouneir, E.O. Hamed, S.M. Mousa, G.T. El-Bassyouni, CuO nanoparticles for green synthesis of significant anti-Helicobacter pylori compounds with in silico studies, Scientific Reports 14 (2024) 1608.

[33] W.S. Shehab, H.A. Haikal, D.A. Elsayed, A.F. El-Farargy, A.-R.B. El-Gazzar, G.T. El-Bassyouni, S.M. Mousa, Pharmacokinetic and molecular docking studies to pyrimidine drug using Mn3O4 nanoparticles to explore potential anti-Alzheimer activity, Scientific Reports 14 (2024) 15436.

[34] S. Mishra, S.W. Sangma, M.K. Poddar, R. Bal, G. Singh, R.K. Dey, TiO 2 supported cobalt oxide for olefin epoxidation reaction–characterization, catalytic activities and mechanism–using a DFT model, Dalton Transactions 51 (2022) 10486.

[35] Y. Jiao, A.-L. Adedigba, Q. He, P. Miedziak, G. Brett, N.F. Dummer, M. Perdjon, J. Liu, G.J. Hutchings, Inter-connected and open pore hierarchical TS-1 with controlled framework titanium for catalytic cyclohexene epoxidation, Catalysis Science & Technology 8 (2018) 2211.

[36] M. Maity, U. Maitra, An easily prepared palladiumhydrogel nanocomposite catalyst for C–C coupling reactions, Journal of Materials Chemistry A 2 (2014) 18952.

[37] H. Veisi, A. Sedrpoushan, S. Hemmati, Palladium supported on diaminoglyoxime-functionalized Fe_3O_4 nanoparticles as a magnetically separable nanocatalyst in Heck coupling reaction, Applied Organometallic Chemistry 29 (2015) 825.

[38] M.Z. Basyouni, M.F. Radwan, M.E. Abdu, A.M. Synthesis, Characterization, and Optical Properties of Carbazole-Functionalized Poly (norbornenedicarboximide) by ROMP Spring, (2024).