

γ -Fe₂O₃@HAP-Fe²⁺ NPs: An Efficient and Eco-Friendly Catalyst for the Synthesis of Xanthene Derivatives in Water

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ABSTRACT: *Efficient and environmentally friendly syntheses of xanthenes derivatives by using γ -Fe₂O₃@HAP-Fe²⁺ NPs as a catalyst has been carried out. The catalyst can be readily isolated by using an external magnet and no obvious loss of activity was observed when the catalyst was reused in eight consecutive runs. The procedure has several advantages, such as economic availability of catalyst, simple procedure, ease of product isolation, no harmful byproducts, less reaction time and high yields.*

KEYWORDS: *Magnetic nanoparticles; Xanthenes; γ -Fe₂O₃@HAP-Fe²⁺ NPs; Green solvent.*

INTRODUCTION

Today, the most emphasis on chemical synthesis is on the development of green synthetic routes with heterogeneous catalysts and H₂O media. The “Green Chemistry” concept is an interesting approach to reduce the negative environmental impacts of organic synthesis. With the increasing environmental concerns and the regulatory constraints faced in the chemical and pharmaceutical industries, the development of environmentally benign organic reactions has become a crucial and demanding research area in modern organic chemical research. Therefore more chemist’s synthetic endeavors are devoted to ‘green synthesis’ which means the reagent, solvent, and catalyst are environmentally friendly. [1]

In the past decade, Magnetic NanoParticles (MNPs) have been considered as attractive and interesting materials because of their high surface area and unique

magnetic properties. They have a wide range of novel applications in various fields; such as catalysis [2], nanocomposite [3], magnetic fluids [4], drug delivery [5], Magnetic Resonance Imaging (MRI) [6], biomolecular sensors [7], environmental remediation [8] and data storage [9]. MNPs have recently been viewed as attractive materials either as supporters for immobilization of homogeneous and heterogeneous catalysts [10]. Moreover, they can be used in multi-component condensation reactions [11], Knoevenagel reaction [12], Suzuki coupling reactions, hydrogenation of alkynes [13], esterifications [14], CO₂ cycloaddition reactions [15], epoxidation of alkenes [16], nucleophilic substitution reactions of benzyl halides [17] and synthesis of α -amino nitriles [18].

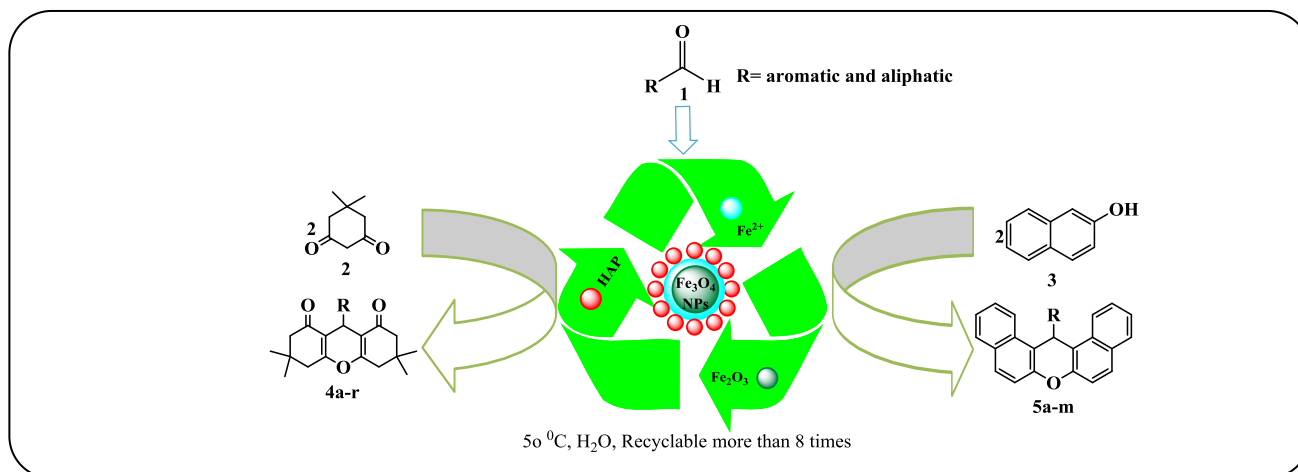
Xanthenes are common natural products in a variety of biologically active and useful compounds [19].

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Scheme 1: One pot synthesis of 1,8-dioxooctahydroxanthenes **4a-r** and aryl-14H-dibenzo [a,j] xanthenes **5a-m** in the presence of $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs.

Xanthenes act as anti-malarial [20], anti-microbial [21], anti-inflammatory activities [22], laser technologies [23], pH-sensitive fluorescent materials for visualization of biomolecules [24], photodynamic therapy [25] and dyes [26].

The most widely used approach to synthesize xanthenes involves a one-pot thermal condensation reaction in the presence of a number of catalysts in water solvent [27].

Although in many cases have convenient protocols with good to high yields most of these methods suffer from some disadvantages such as prolonged reaction time, anhydrous condition, high reaction temperature, tedious work-up procedure, the use of expensive catalysts or harmful solvents, strong conditions. Therefore, it seems that there is still a need for the development of novel methods that proceed under green and eco-friendly conditions. [27j].

Herein, $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs will be tested and analyzed as a heterogeneous catalyst for one-pot synthesis of 1,8-dioxooctahydroxanthenes **4a-r** and aryl-14H-dibenzo [a,j] xanthenes **5a-m** via three-component reactions of various aromatic and aliphatic aldehydes with dimedone or β -naphthol in H_2O at $50\text{ }^\circ\text{C}$ (Scheme 1).

EXPERIMENTAL SECTION

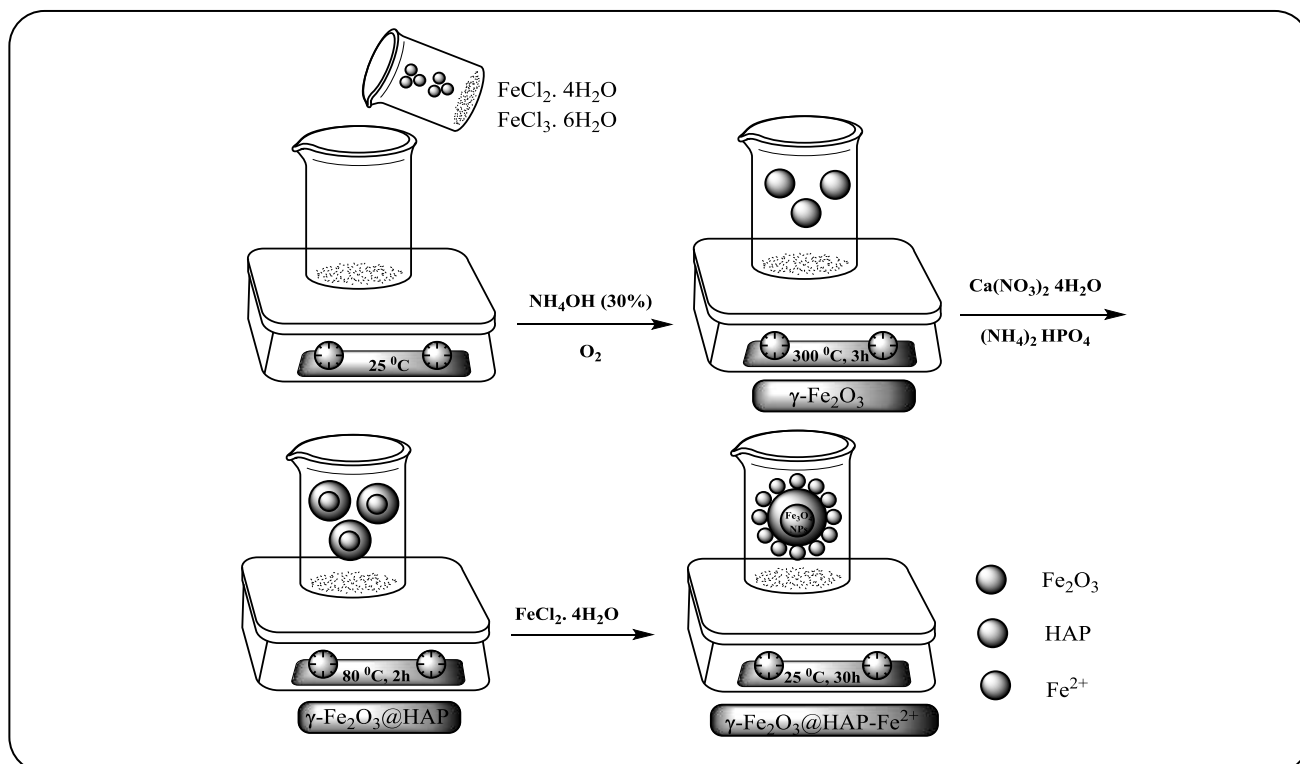
General

Products were characterized by comparison of physical properties with those reported in the literature [27d]. Morphological and structural of $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs were analyzed by TEM, SEM, XRD, and FT-IR techniques. The phases present in the magnetic materials

were analyzed using a powder X-ray diffractometer Philips (Holland), model X' Pert with $\text{CuK}\alpha 1$ radiation ($\lambda = 1.5406\text{ \AA}$), and the X-ray generator was operated at 40 KV and 30 mA. Diffraction patterns were collected from $2\theta = 20^\circ\text{--}70^\circ$. FT-IR spectra were recorded on a FT-IR spectrometer (Perkin Elmer) with a spectral resolution of 4 cm^{-1} in the wave number range of $400\text{--}4000\text{ cm}^{-1}$. Scanning electronic microscopy (SEM), the morphology of the surface of NPs was investigated using a scanning electron microscope of XL30 type (Netherlands).

Catalyst preparation

$\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs were synthesized according to a previously reported procedure [27d]. In this work, $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs was prepared in two steps. The Iron oxide magnetic particles (IOMP) were synthesized by chemical coprecipitation technique of ferrous and ferric chlorides in aqueous solution. Solutions of $\text{FeCl}_3\cdot 6\text{H}_2\text{O}$ (0.25 mol/L) and $\text{FeCl}_2\cdot 4\text{H}_2\text{O}$ (0.125 mol/L) were mixed and precipitated with NH_4OH solution (30 %) at pH12, while stirring vigorously. The black suspension, which formed immediately, was maintained at $80\text{ }^\circ\text{C}$ for approximately one hour and washed several times with ultra-pure water until the pH decreased to 7. Iron oxide magnetic particles were coated with hydroxyapatite (IOMP/HAP) was prepared by the impregnation method according to known procedures with some modifications. Then Hydroxyapatite-Encapsulated $\gamma\text{-Fe}_2\text{O}_3$ (0.60 g) was introduced into 100 mL of distilled water containing 6.40 mmol of $\text{FeCl}_2\cdot 4\text{H}_2\text{O}$. The mixture was stirred for 30 h, filtered, and washed several times with ethanol. The recovered solid was dried at $80\text{ }^\circ\text{C}$



Scheme 2: Synthesis of $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$.

overnight (Scheme 2). The mean size and the surface morphology of the $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs were characterized by TEM, SEM, XRD, and FT-IR techniques.

General procedures for the synthesis of 1, 8-dioxooctahydroxanthenes (4a-r) and aryl-14H-dibenzo [a,j] xanthenes (5a-m):

A mixture of aldehyde **1** (1.00 mmol), dimedone **2** (2.00 mmol) or β -naphthol **3** (2.00 mmol) and $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs (10 mg) was heated with stirring in H_2O (3.00 mL) at 50 °C. The completion of the reaction was monitored by TLC (*n*-hexane: ethyl acetate; 3:2). After cooling to room temperature, the reaction mixture was poured onto crushed ice (30.00 g) and stirred for 5-10 min. Then, the mixture was stirred at room temperature for 10 min. The separated solid was filtered under suction, washed with cold water (20.00 mL) and recrystallized from ethanol to afford the pure product. The catalyst can be readily isolated by using an external magnet. All the compounds were characterized by physical properties.

RESULTS AND DISCUSSION

The characterization of $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs

was further carried out by FT-IR (Fig. 1). The band at 3589 cm^{-1} was assigned to the stretching and bending modes of the OH groups in the hydroxyapatite structure [27d]. The bands at 1104, 1036 and 957 cm^{-1} were attributed to the asymmetric and symmetric stretching vibration of the phosphate group (PO_4^{3-}) and the bending modes of Fe–O were observed at 611, 570, and 469 cm^{-1} . In addition, the band at 868 cm^{-1} indicated that HPO_4^{2-} may also be present in the hydroxyapatite as an impurity. Also, Fig. 1 shows the XRD for $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs.

TEM micrographs provide more accurate information on the particle size, morphology, and loading of $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs. These nanoparticles consist of relatively small, nearly spherical particles, with the average size of 50 nm, much smaller than the sizes obtained from the XRD measurements (Fig 1). It should be noted that the characteristic peak in the XRD pattern is attributed to the crystalline structure of HAP and $\gamma\text{-Fe}_2\text{O}_3$ as follow 2 θ : 30 (220 $\gamma\text{-Fe}_2\text{O}_3$), 35 (311 $\gamma\text{-Fe}_2\text{O}_3$), 57 (422 $\gamma\text{-Fe}_2\text{O}_3$), 59 (511 $\gamma\text{-Fe}_2\text{O}_3$) and other peaks are related to the crystalline structure of HAP.

Thereupon, the catalytic efficiency and catalytic activity could be influenced by the catalyst amount.

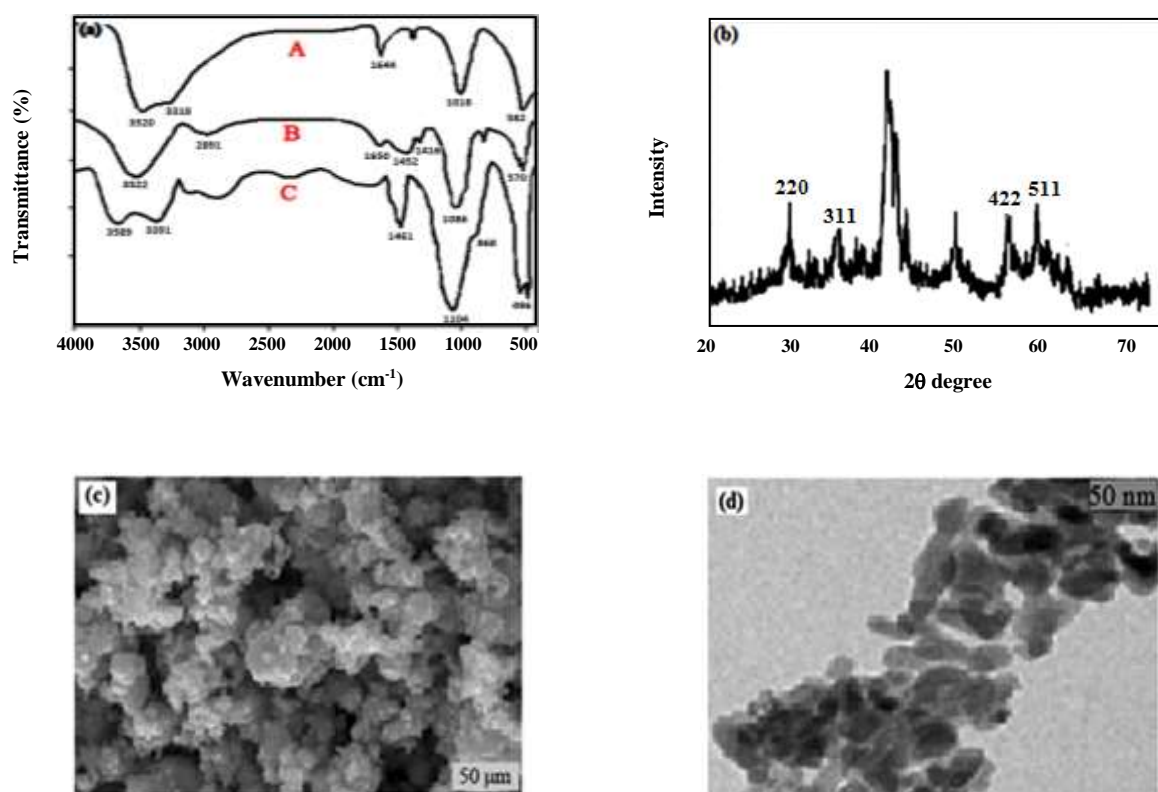


Fig. 1: FT-IR spectra (a) (A: $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$, B: $\gamma\text{-Fe}_2\text{O}_3\text{@HAP}$, C: HAP), XRD (b), SEM (c) and TEM (d) micrographs of $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs

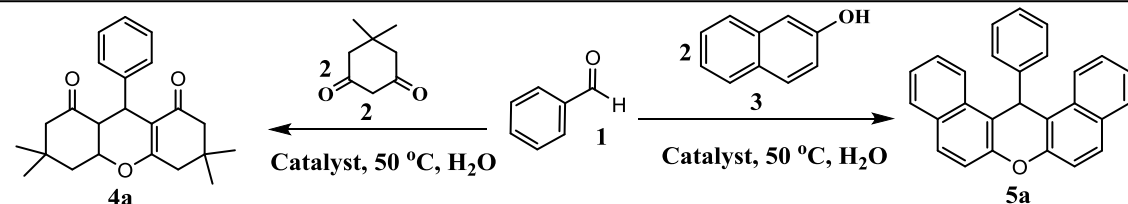
Therefore, a set of experiments using various amounts of catalyst was considered in the reaction of benzaldehyde (**1a**) with two equivalent of dimedone (**2**) or β -naphthol (**3**) were stirred in water at 50 °C (Table 1). Use of just 0.01 g $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs at 50 °C in water is sufficient to push the reaction forward. The optimum catalyst amount was examined as 0.01 g $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs to reach 93% and 95% yields of compounds **4a** and **5a**, respectively. The catalyst plays a crucial role in the success of the reaction in terms of the rate and the yields. Lower amounts of catalyst resulted in a decrease in the efficacy of the reaction, while higher amounts led to complete conversion in short reaction time. The catalytic activity was examined as $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs > $\gamma\text{-Fe}_2\text{O}_3\text{@HAP}$ NPs > $\gamma\text{-Fe}_2\text{O}_3$ NPs (Table 1).

We have also examined other solvents. In order to achieve the optimum conditions, the reaction of benzaldehyde and dimedone were selected as the model. The effects of the amount of catalyst (5-30 mg), different solvents (polar and nonpolar solvent) and different

temperatures (r.t., 50 °C and reflux) were examined. As shown in Table 2, it was found that 10 mg of $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs in H₂O at 50 °C is the best reaction conditions (Table 2, entry 2). It is important to note, whilst organic solvents such as MeOH and EtOH gave similar yields (Table 2, entries 7-12), but H₂O selected as the solvent due to accordance with the green chemistry principle. Using optimized conditions, the reaction of various aromatic and aliphatic aldehydes and dimedone were investigated (Scheme 1).

To evaluate the use of this interesting approach, a variety of aromatic and aliphatic aldehydes were examined which good library of 1,8-dioxooctahydroxanthenes **4a-r** and aryl-14*H*-dibenzo [a,j] xanthenes **5a-m** were obtained in high yields (Table 3). The analysis of products **4a-r** and **5a-m** have good accordance with the reports.

It was found that all the reactions proceeded smoothly to give the corresponding 1, 8-dioxooctahydroxanthenes and aryl-14*H*-dibenzo [a,j] xanthenes in high yields (Table 3). Both aromatic aldehydes bearing electron-donating

Table 1: Effect of catalyst amount and catalytic activity for the synthesis of 4a and 5a^[a].


Catalyst	Catalyst (mg)	Time (min) ^[b]	Time (min) ^[c]	Yields (%) ^[b]	Yields (%) ^[c]
$\gamma\text{-Fe}_2\text{O}_3$ NPs	5	30	25	22	23
$\gamma\text{-Fe}_2\text{O}_3$ NPs	10	30	25	31	34
$\gamma\text{-Fe}_2\text{O}_3$ NPs	20	30	25	41	44
$\gamma\text{-Fe}_2\text{O}_3$ NPs	30	30	25	51	53
$\gamma\text{-Fe}_2\text{O}_3\text{@HAP}$ NPs	5	30	25	42	46
$\gamma\text{-Fe}_2\text{O}_3\text{@HAP}$ NPs	10	30	25	65	69
$\gamma\text{-Fe}_2\text{O}_3\text{@HAP}$ NPs	20	30	25	69	72
$\gamma\text{-Fe}_2\text{O}_3\text{@HAP}$ NPs	30	30	25	71	72
$\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs	5	30	25	64	70
$\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs	10	30	25	93	95
$\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs	20	30	25	94	95
$\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs	30	30	25	95	96

[a] Reaction conditions: benzaldehyde 1a (1.00 mmol), dimesone 2 (2.00 mmol), β -naphthol 3 (2.00 mmol) and catalyst in H₂O as solvent at 50 °C. [b] Isolated yields from 4a. [c] Isolated yields from 5a.

Table 2 Effects of catalyst amount, solvent and temperature on the reaction yield^a

Entry	Catalyst amount (mg)	Solvent	Temp (°C)	Yield (%) ^b
1	5	H ₂ O	50	64
2	10	H ₂ O	50	93
3	20	H ₂ O	50	94
4	30	H ₂ O	50	95
5	10	H ₂ O	25	47
6	10	H ₂ O	reflux	94
7	10	EtOH	25	51
8	10	EtOH	50	95
9	10	EtOH	reflux	95
10	10	MeOH	25	54
11	10	MeOH	50	90
12	10	MeOH	reflux	91
13	10	CH ₃ CN	25	48
14	10	CH ₃ CN	reflux	74
15	10	CH ₂ Cl ₂	25	42
16	10	CH ₂ Cl ₂	reflux	55
17	10	PhCH ₃	25	25
18	10	PhCH ₃	reflux	36

[a] Reaction conditions: benzaldehyde (1a) (1.00 mmol), dimesone (2) (2.00 mmol), solvent (3.00 mL), $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs, 50 °C, 30 min. [b] Isolated yield

Table 3: Synthesis of 1, 8-dioxooctahydroxanthenes 4a-r and aryl-14H-dibenzo [a,j] xanthenes 5a-m^a.

Entry	Aldehyde	Product/Time (min)/Yield(%) ^b	Melting point (°C)	
			found	Rep. [ref]
1	C ₆ H ₅	4a/30/93	203-206	203-205 (28a)
2	2,4-(OCH ₃) ₂ C ₆ H ₃	4b/40/92	209-211	209-211 (28b)
3	4-OCH ₃ C ₆ H ₄	4c/30/91	249-251	248-250 (28a)
4	2-OCH ₃ C ₆ H ₄	4d/35/89	185-187	184-185 (28b)
5	3-OCH ₃ C ₆ H ₄	4e/35/82	177-180	177-180 (28b)
6	4-OHC ₆ H ₄	4f/25/83	244-246	243-245 (28a)
7	2-OHC ₆ H ₄	4g/30/80	203-205	202-205 (28b)
8	4-CH ₃ C ₆ H ₄	4h/25/92	220-222	219-221 (28a)
9	3,5-(OCH ₃) ₂ -4-OHC ₆ H ₂	4i/40/89	205-206	204-206 (28e)
10	2-Naphthyl	4j/40/91	195-197	194-196 (28b)
11	Cinnamaldehyde	4k/35/89	177-179	176-178 (28a)
12	4-BrC ₆ H ₄	4l/25/92	230-232	231-233 (28b)
13	4-ClC ₆ H ₄	4m/25/93	231-233	231-233 (28a)
14	3-ClC ₆ H ₄	4n/35/90	193-195	192-194 (28e)
15	2,4-Cl ₂ C ₆ H ₄	4o/40/88	254-256	253-255 (28e)
16	4-FC ₆ H ₄	4p/25/94	223-225	224-225 (28a)
17	3-NO ₂ C ₆ H ₄	4q/25/91	170-172	168-170 (28a)
18	4-NO ₂ C ₆ H ₄	4r/30/94	229-231	228-230 (28a)
19	C ₆ H ₅	5a/25/95	180-183	181 (28c)
20	3-OHC ₆ H ₄	5b/35/90	262-264	261-263 (28e)
21	4-CH ₃ C ₆ H ₄	5c/30/92	239-241	238-240 (28a)
22	Propyl	5d/30/91	152-153	152 (28e)
23	Isopropyl	5e/35/90	155-157	155 (28e)
24	Benzyl	5f/35/94	177-179	178 (28e)
25	4-OCH ₃ C ₆ H ₄	5g/30/93	213-215	213-215 (28a)
26	2-ClC ₆ H ₄	5h/30/89	214-215	213-215 (28c)
27	4-ClC ₆ H ₄	5i/30/92	286-289	286-288 (28a)
28	2,4-Cl ₂ C ₆ H ₄	5j/40/94	251-253	252 (28a)
29	3-FC ₆ H ₄	5k/30/90	258-260	259 (28d)
30	3-CF ₃ C ₆ H ₄	5l/25/93	203-205	202-204 (28e)
31	2-NO ₂ C ₆ H ₄	5m/30/92	294-295	293 (28c)

[a] Reaction conditions: aldehyde 1 (1.00 mmol), dimedone 2 (2.00 mmol), β-naphthol 3 (2.00 mmol), γ-Fe₂O₃@HAP-Fe²⁺ NPs (10 mg), H₂O (3.00 mL), 50 °C, 20-40 min. [b] Isolated yield.

Table 4: Comparison of the efficiencies of various catalysts used in the synthesis of **4a** and **5a** in H_2O solvent.

Entry	catalyst	Condition	Yields (%) ^[a]	Yields (%) ^[b]	Ref.
1	Thiourea dioxide	50–60 °C, 45 min	96	----	(27c)
2	H_2SO_4	70–80 °C, 120 min	90	----	(27c)
3	$\text{BiVO}_4\text{-NPs}$	reflux, 60 min	0	----	(27c)
4	MCM-41- SO_3H	60 °C, 60 min	86	----	(27b)
5	DBSA	reflux, 6 h	89	----	(27h)
6	ZnO	reflux, 20 min	94	----	(27c)
7	Nano-ZMS-5	reflux, 120 min	76	----	(27a)
8	Nano- γ -alumina	reflux, 120 min	78	----	(27a)
9	Nano-SZ	reflux, 120 min	82	----	(27a)
10	$\text{In}(\text{OTf})_3$	100 °C, 15 h	----	82	(27e)
11	GO/ CuFe_2O_4	120 °C, 15 min	----	92	(27g)
12	$\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$	S.F, 90 °C, 10-35 min	----	95	(27d)
13	$\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$	50 °C, 30 min	93 ^c	95 ^c	Present Work

[a] Isolated yields from **4a**. [b] Isolated yields from **5a**. [c] Our manuscript.

groups and electron-withdrawing groups gave excellent yields. Sterically hindered aromatic aldehydes required longer reaction times. An acid-sensitive substrate such as cinnamaldehyde produced the desired condensation product in good yield. Another advantage of this method is its efficiency for the synthesis of alkyl-14H-dibenzo[*a,j*]xanthenes from the aliphatic aldehyde. The results are summarized in Table 3, which clearly indicate the generality and scope of the reaction with respect to various aromatic and aliphatic aldehydes.

To show the merit of the present work in comparison with the reported results in the literature, we compared results of $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs with the some reported catalytic methods in the synthesis of **4a** and **5a** derivatives in water solvent (Table 4). Thiourea dioxide (Table 4, entry 1), H_2SO_4 (Table 4, entry 2), $\text{BiVO}_4\text{-NPs}$ (Table 4, entry 3), MCM-41- SO_3H (Table 4, entry 4), DBSA (Table 4, entry 5), ZnO (Table 4, entry 6), Nano-ZMS-5 (Table 4, entry 7), Nano- γ -alumina (Table 4, entry 8), Nano-SZ (Table 4, entry 9), $\text{In}(\text{OTf})_3$ (Table 4, entry 10), GO/ CuFe_2O_4 (Table 4, entry 11), $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ (Table 4, entry 12), for the synthesis of **4a** and **5a** derivatives, which requires long reaction time, high temperature and requires harsh reaction conditions like use of reflux conditions to complete the reaction. As shown in (Table 4, entry 13), $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs

can act as an effective catalyst with respect to reaction times, the amount of the catalyst, and yields of the obtained products. In comparison with other reported methods of xanthenes synthesis, the use of $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs as a catalyst and water as a solvent is a very much versatile and efficient catalyst for obtaining dioxooctahydroxanthenes and aryl or alkyl-14H-dibenzo [*a,j*] xanthenes from different types of aldehydes. Thus, the present protocol with $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs catalysts is convincingly superior to the some reported catalytic methods.

The reusability of catalysts is of major importance in green chemistry and also is of major importance for large scale operations and from an industrial point of view. Thus, the recovery and reusability of $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs were investigated. The reusability of the catalyst was studied using benzaldehyde and dimedone as a model reaction (Fig. 2). Since the catalyst can be separated from the reaction mixture using an external magnetic field. Magnetically recovered $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs washed with water, dried in the oven (70 °C, 5 h), and was used again. The catalyst was consecutively reused eight times without any noticeable loss of its catalytic activity.

Then the internal structure of the $\gamma\text{-Fe}_2\text{O}_3\text{@HAP-Fe}^{2+}$ NPs nanoparticles, after recovery, was determined by the FT-IR spectrum methods. As can be seen in Fig. 3, the recycled catalyst structure does not change. Due to

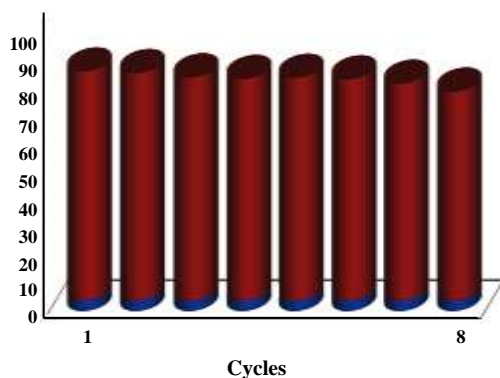
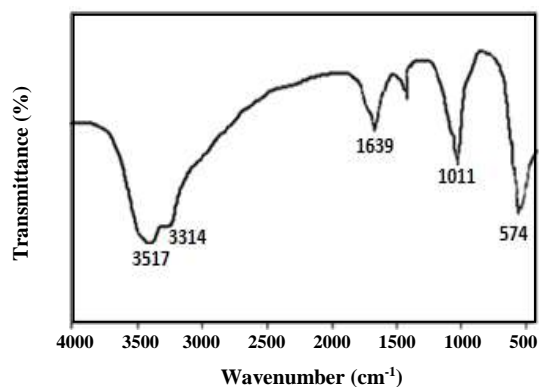
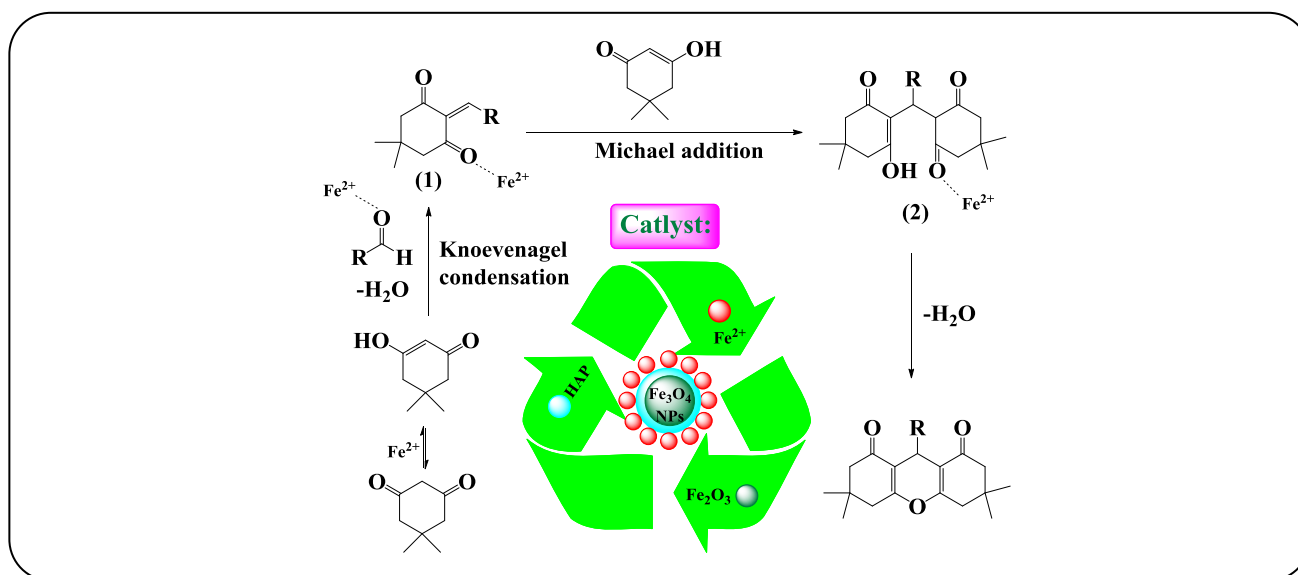


Fig. 2: Recycle of the catalyst.

Fig. 3: FT-IR spectrum of γ -Fe₂O₃@HAP-Fe²⁺ NPs.Scheme 3: Proposed mechanism for γ -Fe₂O₃@HAP-Fe²⁺ NPs catalyzed 1,8-dioxooctahydroxanthenes synthesis.

a slight decrease in the efficiency of the reaction, the catalyst surface can be covered by impurities in the reaction medium.

The mechanism of the reaction was proposed in Scheme 3. As can be seen, the reaction proceeds *via* one-pot Knoevenagel condensation, Michael addition, and cyclodehydration. According to the mechanism, γ -Fe₂O₃@HAP-Fe²⁺ NPs catalyzed the readily in-situ formation of the 1,8-dioxo-octa hydro xanthene product. This makes the γ -Fe₂O₃@HAP-Fe²⁺ NPs capable of bonding with the carbonyl oxygen, and increases the reactivities of the parent carbonyl compounds. Nucleophilic Addition of dimedone to the activated aldehyde followed by the loss of H₂O generates intermediate I, which is further activated by γ -Fe₂O₃@HAP-Fe²⁺ NPs. Then, the 1,4-nucleophilic addition of a second molecule of dimedone on the activated

intermediate I, in the Michael addition fashion, affords the intermediate II, which undergoes intramolecular cyclodehydration to give the 1,8-dioxo-octa hydro xanthene. The electron withdrawing groups present on the aromatic aldehyde in the intermediate I increase the rate of 1,4-nucleophilic addition reaction because the alkene LUMO is at a lower energy in their presence compared with the aldehydes possessing electron donating groups. According to the mechanism, γ -Fe₂O₃@HAP-Fe²⁺ NPs catalyst might promote the reaction by accelerating the formation of enol from the 1,3-dicarbonyls such as dimedone, in the rate determining step [29].

CONCLUSIONS

In conclusion, we have developed a mild, simple, cost-effective and remarkably method for the C-C and

C-O bond formation in order to the preparation of 1,8-dioxooctahydroxanthenes and aryl or alkyl -14*H*-dibenzo [*a,j*] xanthenes using reusable heterogeneous nanocatalyst conditions. Moreover, the mild reaction conditions, high yield of products, easy work-up, the ready availability of the catalyst, compatibility with various functional groups, ecologically clean procedure and recyclability of catalyst will make the present method a useful and important addition to the present methodologies for the synthesis of xanthenes as biologically interesting compounds. In addition, it is possible to apply the tenets of green chemistry to the generation of interesting products using aqueous media methods that are less expensive and less toxic than those with organic solvents. The catalyst was recyclable and has been reused for eight successive runs with little loss of the catalytic activities.

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REFERENCES

- [1] a) Min B.K., Friend C.M., [Heterogeneous Gold-Based Catalysis for Green Chemistry: Low-Temperature CO Oxidation and Propene Oxidation](#), *Chem. Rev.*, **107**: 2709-2724 (2007).
- b) Moghimi A., Hosseinzadeh-Khanmiri R., Shaabani A., Hamadani H., [A Green Synthesis of Nitrones from Diamino Glyoxime Using Aldehydes and Ketones](#), *J. Iran. Chem. Soc.*, **10**: 929-936 (2013).
- c) Moghimi A., Hosseinzadeh-Khanmiri R., Omrani I., Shaabani A., [A New Library of 4\(3*H*\)- and 4,4'\(3*H*,3*H'*\)-quinazolinones and 2-\(5-alkyl-1,2,4-oxadiazol-3-yl\)quinazolin-4\(3*H*\)-one Obtained from Diaminoglyoxime](#), *Tetrahedron Letters*, **54**: 3956-3959 (2013).
- d) Hassanpour A., Hosseinzadeh-Khanmiri R., Abolhasani J., [ZnO Nanoparticles as an Efficient, Heterogeneous, Reusable, and Ecofriendly Catalyst for One-Pot, Three-Component Synthesis of 3,4-Dihydropyrimidin-2\(1*H*\)-\(thio\)one Derivatives in Water](#), *Synthetic Communications*, **45**: 727-733 (2015).
- e) Hosseinzadeh-Khanmiri R., Moghimi A., Shaabani A., Valizadeh H., Ng S. W., [Diaminoglyoxime as a Versatile Reagent in the Synthesis of bis\(1,2,4-oxadiazoles\), 1,2,4-Oxadiazolyl-Quinazolines and 1,2,4-oxadiazolyl-benzothiazinones](#), *Mol. Divers.*, **18**: 769-776 (2014).
- f) Hosseinzadeh-Khanmiri R., Moghimi A., Shaabani A., Valizadeh H., [Synthesis of 2-\(1,2,4-oxadiazol-3-yl\)quinazolin-4\(3*H*\)-ones from Diaminoglyoxime-based Nitrones](#), Ng S.W., *Mol. Divers.*, **19**: 501-510 (2015).
- g) Hassanpour A., Hosseinzadeh-Khanmiri R., Babazadeh M., Edjlali L., [ZnO NPs: an Efficient and Reusable Nanocatalyst for the Synthesis of Nitrones from DAG Using H₂O as a Solvent at Room-Temperature](#), *Res Chem Intermed.*, **42**: 2221-2231 (2016).
- h) Edjlali L., Hosseinzadeh-Khanmiri R., [Titanium Dioxide Nanoparticles as Efficient Catalyst for the Synthesis of Pyran's Annulated Heterocyclic Systems via Three-Component Reaction](#), *Monatsh Chem.*, **147**: 1221-1225 (2016).
- i) Vessally E., Hosseinzadeh-Khanmiri R., Ghorbani-Kalhor E., Es'haghi M., Ejlali L., [Eco-Friendly Synthesis of 3,4-dihydroquinoxalin-2-Amine, Diazepine-Tetrazole and Benzodiazepine-2-Carboxamide Derivatives with the Aid of MCM-48/H₅PW₁₀V₂O₄₀](#), *Appl Organometal Chem.*, **31**: e3729- (2017).
- j) Babazadeh M., Hosseinzadeh-Khanmiri R., Zakhireh S., [Eco-Friendly Synthesis of Benzoxazepine and Malonamide Derivatives in Aqueous Media](#), *Appl. Organometal. Chem.*, **30**: 514- (2016).
- k) Mohammad Ziarani G., Saidian F., Gholamzadeh P., Badii A., Abolhasani Soorki A., [Green Synthesis of Pyrazol-chromeno\[2,3-*d*\]pyrimidinones using SBA-Pr-SO₃H as an Efficient](#), *Iran. J. Chem. Chem. Eng. (IJCCE)*, **36**(6): 39-48 (2017).
- l) Zhang J., Wang A., Wang Y., Wang H., Gui J., [Heterogeneous Oxidative Desulfurization of Diesel Oil by Hydrogen Peroxide: Catalysis of an Amphipathic Hybrid Material Supported on SiO₂](#), *Chem. Eng. J.*, **245**: 65-70 (2014).
- m) Vessally E., Hosseini A., Edjlali L., Babazadeh M., Hosseinzadeh-Khanmiri R., [New Strategy for the Synthesis of Morpholine Cores: Synthesis from N-Propargylamines](#), *Iran. J. Chem. Chem. Eng. (IJCCE)*, **36**(3): 1-13 (2017).

- [2] a) Tsang S.C., Caps V., Paraskevas I., Chadwick D., Thompsett D., [Magnetically Separable, Carbon-Supported Nanocatalysts for the Manufacture of Fine Chemicals](#), *Angew. Chem.*, **116**: 5763- (2004).
- b) Edjlali L., Hosseinzadeh-Khanmiri R., Abolhasani J., [Fe₃O₄ Nano-Particles Supported on Cellulose as an Efficient Catalyst for the Synthesis of Pyrimido\[4,5-b\]quinolines in Water](#), *Monatsh. Chem.*, **146**: 1339-1342 (2015).
- c) Ghorbani-Kalhor E., Behbahani M., Abolhasani J., Hosseinzadeh-Khanmiri R., [Synthesis and Characterization of Modified Multiwall Carbon Nanotubes With Poly \(N-Phenylethanolamine\) and Their Application for Removal and Trace Detection of Lead Ions in Food and Environmental Samples](#), *Food Anal. Method*, **8**: 1326-1334 (2015).
- d) Behbahani M., Abolhasani J., Amini M.M., Sadeghi O., Omidi F., Bagheri A., Salarian M., [Application of Mercapto Ordered Carbohydrate-Derived Porous Carbons for Trace Detection of Cadmium and Copper Ions in Agricultural Products](#), *Food Chemistry*, **173**: 1207-1212 (2015).
- e) Kalate Bojdi M., Behbahani M., Mashhadizadeh M.H., Bagheri A., Davarani S.S.H., Farahani A., [Mercapto-Ordered Carbohydrate-Derived Porous Carbon Electrode as a Novel Electrochemical Sensor for Simple and Sensitive Ultra-Trace Detection of Omeprazole in Biological Samples](#), *Materials Science and Engineering: C*, **48**: 213-219 (2015).
- f) Fouladian H.R., Behbahani M., [Solid Phase Extraction of Pb\(II\) and Cd\(II\) in Food, Soil, and Water Samples Based on 1-\(2-Pyridylazo\)-2-Naphthol-Functionalized Organic-Inorganic Mesoporous Material with the Aid of Experimental Design Methodology](#), *Food Anal. Methods*, **8**: 982-993 (2015).
- g) Mohammadi S., Musavi M., Abdollahzadeh F., Babadoust S., Hosseinian A., [Application of Nanocatalysts in C-Te Cross-Coupling Reactions: An Overview](#), *Chem. Rev. Lett.*, **1**: 49-55 (2018).
- h) Sarhandi S., Daghaheleh M., Vali M., Moghadami R., Vessally E., [New Insight in Hiyama Cross-coupling Reactions: Decarboxylative, Denitrogenative and Desulfidative Couplings: A Review](#), *Chem. Rev. Lett.*, **1**: 9-15 (2018).
- i) Daghaheleh M., Vali M., Rahmani Z., Sarhandi S., Vessally E., [A review on the CO₂ Incorporation Reactions Using Arynes](#), *Chem. Rev. Lett.*, **1**: 23-30 (2018).
- [3] a) Abolhasani J., Hosseinzadeh-Khanmiri R., Ghorbani-Kalhor E., Hassanpour A., Asgharinezhad A.A., Shekari N., Fathi A., [An Fe₃O₄@SiO₂@polypyrrole Magnetic Nanocomposite for the Extraction and Preconcentration of Cd\(II\) and Ni\(II\)](#), *Fathi, Anal. Methods*, **7**: 313- (2015).
- b) Ghorbani-Kalhor E., Hosseinzadeh-Khanmiri R., Babazadeh M., Abolhasani J., Hassanpour A., [Synthesis and Application of a Novel Magnetic Metal-Organic Framework Nanocomposite for Determination of Cd, Pb, and Zn in Baby Food Samples](#), *Can. J. Chem.*, **93**(5): 518-525 (2015).
- c) Hassanpour A., Hosseinzadeh-Khanmiri R., Babazadeh M., Abolhasani J., Ghorbani-Kalhor E., [Determination of Heavy Metal Ions in Vegetable Samples Using a Magnetic Metal–Organic Framework Nanocomposite Sorbent](#), *Food Addit. Contam. Part A*, **32**: 725-736 (2015).
- d) Ghorbani-Kalhor E., Hosseinzadeh-Khanmiri R., Abolhasani J., Babazadeh M., Hassanpour A., [Determination of Mercury\(II\) Ions in Seafood Samples After Extraction and Preconcentration by a Novel Functionalized Magnetic Metal–Organic Framework Nanocomposite](#), *J. Sep. Sci.*, **38**: 1179-1186 (2015).
- e) Babazadeh M., Hosseinzadeh-Khanmiri R., Abolhasani J., Ghorbani-Kalhor E., Hassanpour A., [Solid Phase Extraction of Heavy Metal Ions from Agricultural Samples with the Aid of a Novel Functionalized Magnetic Metal–Organic Framework](#), *RSC Adv.*, **5**: 19884- (2015).
- f) Vessally E., Ghasemisarabadeih M., Ekhteyari Z., Hosseinzadeh-Khanmiri R., Ghorbani-Kalhor E., Ejlali L., [Platinum Nanoparticles Supported on Polymeric Ionic Liquid Functionalized Magnetic Silica: Effective and Reusable Heterogeneous Catalysts for the Selective Oxidation of Alcohols in Water](#), *RSC Adv.*, **6**: 106769- (2016).
- j) Salami Kalajahi M., Moqadam S., Mahdavian M., [Synthesis and Characterization of Sunflower Oil-based Polysulfide Polymer/Cloisite 30B Nanocomposites](#), *Iranian Journal of Chemistry & Chemical Engineering (IJCCE)*, **38**(1): 185- 192 (2018).
- [4] Chikazumi S., Taketomi S., Ukita M., Mizukami M., Miyajima H., Setogawa M., Kurihara Y., [Physics of Magnetic Fluids](#), *J. Magn. Magn. Mater.*, **65**: 245-251 (1987).

- [5] Christe Sonia Mary M., Sasikumar S., Sodium Alginate/Starch Blends Loaded with Ciprofloxacin Hydrochloride as a Floating Drug Delivery System - In Vitro Evaluation, *Iranian Journal of Chemistry & Chemical Engineering (IJCCCE)*, **34**(2): 25-31 (2015).
- [6] Mornet S., Vasseur S., Grasset F., Verveka P., Goglio G., Demourgues A., Portier J., Pollert E., Duguet E., Magnetic Nanoparticle Design for Medical Applications, *Prog. Solid State Chem.*, **34**: 237-247 (2006).
- [7] Graham D.L., Ferreira H.A., Freitas P.P., Magnetoresistive-Based Biosensors and Biochips, *Trends. Biotechnol.*, **22**(9): 455-462 (2004).
- [8] Takafuji M., Ide S., Ihara H., Xu Z., Preparation of Poly(1-vinylimidazole)-Grafted Magnetic Nanoparticles and Their Application for Removal of Metal, *Ions. Chem. Mater.*, **16**: 1977-1983 (1977).
- [9] Hyeon T., Chemical Synthesis of Magnetic Nanoparticles, *Chem. Commun.*, 927 (2003).
- [10] Senapati K.K., Borgohain C., Phukan P., Synthesis of Highly Stable CoFe₂O₄ Nanoparticles and Their Use as Magnetically Separable Catalyst for Knoevenagel Reaction in Aqueous Medium, *J. Mol. Catal. A: Chem.*, **339**: 24-31 (2011).
- [11] Zhang Q., Su H., Luo J., Wei Y.Y., A Magnetic Nanoparticle Supported Dual Acidic Ionic Liquid: A "Quasi-Homogeneous" Catalyst for the One-Pot Synthesis of Benzoxanthenes, *Green Chem.*, **14**: 201-208 (2012).
- [12] Karaoğlu E., Baykal A., Senel M., Sözeri H., Toprak M.S., Synthesis and Characterization of Piperidine-4-Carboxylic Acid Functionalized Fe₃O₄ Nanoparticles as a Magnetic Catalyst for Knoevenagel Reaction, *Mater. Res. Bull.*, **47**: 2480- (2012).
- [13] Abu-Reziq R., Wang D., Post M., Alper H., Platinum Nanoparticles Supported on Ionic Liquid-Modified Magnetic Nanoparticles: Selective Hydrogenation Catalysts, *Adv. Synth. Catal.*, **349**: 2145- (2007).
- [14] Jiang Y.Y., Guo C., Xia H.S., Mahmood I., Liu C.Z., Liu H.Z., Magnetic Nanoparticles Supported Ionic Liquids for Lipase Immobilization: Enzyme Activity in Catalyzing Esterification, *J. Mol. Catal. B: Enzym.*, **58**: 103-109 (2009).
- [15] Zheng X.X., Luo S.Z., Zhang L., Cheng J.P., Magnetic Nanoparticle Supported Ionic Liquid Catalysts for CO₂ Cycloaddition Reactions, *Green Chem.*, **11**: 455- (2009).
- [16] Kooti M., Afshari M., Phosphotungstic Acid Supported on Magnetic Nanoparticles as an Efficient Reusable Catalyst for Epoxidation of Alkenes, *Mater. Res. Bull.*, **47**: 3473-3478 (2012).
- [17] Kiasat A.R., Nazari S., Magnetic Nanoparticles Grafted with β -cyclodextrin-polyurethane Polymer as a Novel Nanomagnetic Polymer Brush Catalyst for Nucleophilic Substitution Reactions of Benzyl Halides in Water, *J. Mol. Catal. A: Chem.*, **365**: 80-86 (2012).
- [18] a) Kassae M.Z., Masrouri H., Movahedi F., Sulfamic Acid-Functionalized Magnetic Fe₃O₄ Nanoparticles as an Efficient and Reusable Catalyst for One-Pot Synthesis of α -Amino Nitriles in Water, *Appl. Catal. A: General*, **395**: 28-33 (2011).
b) Shahidi S., Farajzadeh P., Ojaghloo P., Karbakhshzadeh A., Hosseinian A., Nanocatalysts for Conversion of Aldehydes/Alcohols/Amines to Nitriles: A Review, *Chem. Rev. Lett.* **1**: 37-44 (2018).
- [19] Antony L.A.P., Slanina T., Sebej P., Šolomek T., Klan P., Fluorescein Analogue Xanthene-9-Carboxylic Acid: A Transition-Metal-Free CO Releasing Molecule Activated by Green Light, *Org. Lett.*, **15**: 4552-4555 (2013).
- [20] Horrobina, D.F. Manku M.S., Roles of Prostaglandins Suggested by the Prostaglandin Agonist/Antagonist Actions of Local Anaesthetic, Anti-Arhythmic, Anti-Malarial, Tricyclic Antidepressant and Methyl Xanthine Compounds. Effects on Membranes and on Nucleic Acid Function, *Medical Hypotheses*, **3**: 71-86 (1977).
- [21] Wang H., Lu L., Zhu S., Li Y., Cai W., The Phototoxicity of Xanthene Derivatives Against *Escherichia Coli*, *Staphylococcus Aureus*, and *Saccharomyces Cerevisiae*, *Curr. Microbiol.*, **52**: 21-26 (2006).
- [22] Chibale K., Visser M., Schalkwyk D.V., Smith P.J., Saravanamuthu A., Fairlamb A.H., Exploring the Potential of Xanthene Derivatives as Trypanothione Reductase Inhibitors and Chloroquine Potentiating Agents, *Tetrahedron*, **59**: 2289-2296 (2003).
- [23] Knight C.G., Stephens T., Xanthene-Dye-Labelled Phosphatidylethanolamines as Probes of Interfacial pH. Studies in Phospholipid Vesicles, *Biochem. J.*, **258**: 683-687 (1989).
- [24] Bright G.R., Fisher G.W., Rogowska J., Taylor L., Fluorescence Ratio Imaging Microscopy: Temporal and Spatial Measurements of Cytoplasmic Ph, *J. Cell Biol.*, **104**: 1019-1033 (1987).

- [25] Mirjalili B.B.F., Bamoniri A., Akbari A., BF_3SiO_2 : an Efficient Alternative for the Synthesis of 14-aryl or Alkyl-14H-dibenzo[a,j]xanthenes, *Tetrahedron*, **49**: 6454-6456 (2008).
- [26] Bhowmik B.B., Ganguly P., Photophysics of Xanthene Dyes in Surfactant Solution, *Spectrochim. Acta A.*, **61**: 1997-2003 (2005).
- [27] a) Teimouri A., Najafi Chermahini A., Ghorbanian L., The Green Synthesis of New Azo Dyes Derived from Salicylic Acid Derivatives Catalyzed via Baker's Yeast and Solid Acid Catalysis, *Chemija.*, **24**(3): 59-66 (2013).
- b) Shoja A., Shirini F., Abedini M., Zanjanchi M.A., BiVO_4 -NPs as a New and Efficient Nano-Catalyst for the Synthesis of 1,8-Dioxo-Octahydro Xanthenes, *J Nanostruct Chem.*, **4**: 110- (2014).
- c) Haeri H. S., Rezayati S., Rezaee Nezhad E., Darvishi H., Three-Component Synthesis of Pyrano[2,3-d]pyrimidinone Derivatives Catalyzed by Ni^{2+} Supported on Hydroxyapatite-Core-Shell- γ - Fe_2O_3 Nanoparticles in Aqueous Medium, *Res Chem Intermed.*, **42**(5): 7594-7609 (2016).
- d) Urinda S., Kundu D., Majee A., Hajra A., Indium Triflate-Catalyzed One-Pot Synthesis of 14-Alkyl or Aryl-14H-Dibenzo[a, j]Xanthenes in Water, *Heteroatom Chemistry*, **20**: 232-234 (2009).
- e) Zhang Q., Su H., Luo J., Wei Y. Y., A Magnetic Nanoparticle Supported Dual Acidic Ionic Liquid: A "Quasi-Homogeneous" Catalyst for the One-Pot Synthesis of Benzoxanthenes, *Green Chem.*, **14**: 201-208 (2012).
- f) Jin T.-S., Zhang J.-S., Xiao J.-C., Wang A.-Q., Li T.-S., Clean Synthesis of 1,8-Dioxo-Octahydroxanthene Derivatives Catalyzed by p-Dodecylbenzenesulfonic Acid in Aqueous Media, *SYNLETT*, **5**: 0866-0870 (2004).
- j) Mokhtary M., Refahati S., Polyvinylpyrrolidone-Supported Boron Trifluoride (PVPP- BF_3): Mild and Efficient Catalyst for the Synthesis of 14-Aryl-14H-Dibenzo [a,j] Xanthenes and Bis(naphthalen-2-yl-sulfane) Derivatives, *Dyes Pigments*, **99**: 378-381 (2013).
- [28] a) Rad-Moghadam K., Azimi S.C., $\text{Mg}(\text{BF}_4)_2$ Doped in [BMIm][BF_4]: A Homogeneous Ionic Liquid-Catalyst for Efficient Synthesis of 1,8-dioxo-Octahydroxanthenes, Decahydroacridines and 14-Aryl-14H-dibenzo[a,j]xanthenes, *J. Mol. Catal. A: Chem.*, **363**: 465-469 (2012).
- b) Mahdavinia G.H., Ghanbari M., Sepehrian M., Kooti H.F., MCM-41 Functionalized Sulfonic Acid Catalyzed One-Pot Synthesis of 1,8- Dioxo-Octahydroxanthenes, *J. Iran. Chem. Res.*, **3**: 117-120 (2010).
- c) Amini M., Seyyedhamzeh M.M., Bazgir A., Heteropolyacid: An Efficient and Eco-Friendly Catalyst for the Synthesis of 14-aryl-14H-dibenzo[a,j] xanthene, *Appl. Catal., A.*, **323**: 242-245 (2007).
- d) Su W., Yang D., Jin C., Zhang B., $\text{Yb}(\text{OTf})_3$ Catalyzed Condensation Reaction of β -Naphthol and Aldehyde in Ionic Liquids: a Green Synthesis of Aryl-14H-dibenzo[a,j]xanthenes, *Tetrahedron Letters*, **49**: 3391-3394 (2008).
- e) Kumar A., Sharma S., Awatar Maurya R., Sarkar J., Diversity Oriented Synthesis of Benzoxanthene and Benzochromene Libraries via One-Pot, Three-Component Reactions and Their Anti-proliferative Activity, *J. Comb. Chem.*, **12**: 20-24 (2010).
- [29] a) Kokkiralala S., Sabbavarapu N.M., Yadavalli V.D.N., β -Cyclodextrin Mediated Synthesis of 1,8-Dioxooctahydroxanthenes in Water, *European Journal of Chemistry*, **2**(2): 272-275 (2011).
- b) Khosropour A.R., Khodaei M.M., Moghannian H., A Facile, Simple and Convenient Method for the Synthesis of 14-Alkyl or Aryl-14-H-Dibenzo[a,j]xanthenes Catalyzed by p-TSA in Solution and Solvent-Free Conditions, *Synlett*, **2005**(6): 0955-0958 (2005).
- c) Jin T.S., Zhang J.S., Wang A.Q., Li T.S., Ultrasound-Assisted Synthesis of 1,8-dioxo-octahydroxanthene Derivatives Catalyzed by p-Dodecylbenzenesulfonic Acid in Aqueous Media, *Ultrasonics Sonochemistry*, **13**(3): 220-224 (2006).
- d) Boroujeni K.P., Heidari Z., Khalifeh R., Carbon Nanotube-Supported Butyl 1-Sulfonic Acid Groups as a Novel and Environmentally Compatible Catalyst for the Synthesis of 1,8-Dioxo-octahydroxanthenes, *Acta Chim. Slov.*, **63**: 602- (2016).