FULL PAPER



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CuI/Fe₃O₄ NPs@Biimidazole IL-KCC-1 as a leach proof nanocatalyst for the synthesis of imidazo[1,2-*a*]pyridines in aqueous medium

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Nasrin Shadjou, Nanotechnology Research Group, Faculty of Science and Chemistry, Urmia University, Urmia, Iran. Email: n.shadjou@urmia.ac.ir In the present work, an innovative leach proof nanocatalyst based on dendritic fibrous nanosilica (DFNS) modified with ionic liquid loaded Fe₃O₄ NPs and CuI salts was designed and applied for the rapid synthesis of imidazo[1,2-a]pyridines from the reaction of phenyl acetylene, 2-aminopyridine, and aldehydes in aqueous medium. The structure of the synthesized nanocatalyst was studied by field emission scanning electron microscopy (FESEM), transmission electron microscopy (TEM), Fourier transform infrared (FT-IR), flame atomic absorption spectroscopy (FAAS), energy-dispersive X-ray (EDX), and X-ray diffraction (XRD), vapor-liquid-solid (VLS), and adsorption/desorption analysis (Brunauer-Emmett-Teller [BET] equation) instrumental techniques. CuI/Fe₃O₄NPs@IL-KCC-1 with high surface area $(225 \text{ m}^2 \text{ g}^{-1})$ and porous structure not only exhibited excellent catalytic activity in aqueous media but also, with its good stability, simply recovered by an external magnet and recycled for eight cycles without significant loss in its intrinsic activity. Higher catalytic activity of CuI/Fe₃O₄NPs@IL-KCC-1 is due to exceptional dendritic fibrous structure of KCC-1 and the ionic liquid groups that perform as strong anchors to the loaded magnetic nanoparticles (MNPs) and avoid leaching them from the pore of the nanocatalyst. Green reaction media, shorter reaction times, higher yields (71-97%), easy workup, and no need to use the chromatographic column are the advantages of the reported synthetic method.

K E Y W O R D S

advanced nanomaterials, dendritic fibrous nanosilica, imidazo[1,2-*a*]pyridines, magnetic nanocatalyst

1 | INTRODUCTION

Recently, porous silica materials due to its useful properties, such as high mechanical, thermal, and hydrothermal stability, low toxicity and density, cost-effectiveness, good biocompatibility, and easy of surface modification, have received a lot of attention.^[1-3] Dendritic fibrous nanosilica (DFNS), introduced by Polshettiwar and colleagues,^[4,5] shows excellent activities in various research areas such as catalysis and biomedical applications. KCC-1 with having dendritic fibrous morphology is an exceptional nanomaterial, which is in principle availability from totally sides in comparison with other mesoporous material such as MCM-41 and SBA-15 with tubular pores.^[6] Hence, various functional materials such as organic functional groups,

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organometallics, metal oxides, and some metal nanoparticles can be loaded in the pores of the KCC-1 without the blocking of its channels or the pores, and most importantly, accessibility of newly generated active sites was increased. Whereas the surface area of KCC-1 is lower than the MCM-41 and SBA-15, but the results show that its openness is affectedly suitable than previous conventional silica nanomaterials. Also, special morphology and structure allow better diffusion and loading of the agents and active sites in comparison with SBA-15 and MCM-41. Furthermore, DFNS with having thin silica walls possesses better thermal and mechanical stability, which is one of the serious concerns in conventional mesoporous materials.

On the other hand, literature review exhibits that loading of ionic liquids (ILs) on the structure of mesoporous silica materials leads to increasing of their catalytically behavior. Based on their significant properties such as high ionic conductivity, excellent thermal stability, ecofriendly, stability, and wide liquid temperature range window, ILs have been used for the organic synthesis.^[7,8] Various types of ILs that grafted to different supports not only can be used as reaction media and catalysis but also can be stabilized various nanoparticles because of their coordination and electrostatic interactions with ions and metal atoms.^[9] Also, during the reaction procedure, the supported ILs can provide appropriate hydrophobic media and enhance the catalytic activity of the catalyst. Therefore, ILs loaded nanocatalysts have been widely used for the heterocyclic compound synthesis.^[10]

One of the most important kinds of fused heterocyclic compounds with attractive biological and pharmacological properties is imidazopyridines. Antibacterial,^[11] varicella-zoster,^[12] antiviral,^[13-15] anti-cancer,^[16] and antifungal^[17,18] agents are the interesting properties of these compounds. Zolpidem,^[19,20] Alpidem,^[19] Zolimidine,^[21] and Olprinone^[22] are some of the synthetic drugs based on imidazo[1,2-*a*]pyridine framework (Scheme 1).

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Until now, different copper containing catalysts such as Cu-MOFs, CuSO₄/glucose, CuCl/Cu (OTf)₂, CuI/NaHSO₄-SiO₂, Cu-MnO, CuI/Cu (OTf)₂, and CuSO₄/p-TsOH have been used for the efficient synthesis of imidazo[1,2-*a*]pyridine.^[23-29]

It is important to point out that iron oxide magnetic nanoparticles (MNPs) have been predicted to be a promising immobilization matrix due to its fast electrontransfer kinetics, robust adsorption capacity, high surface-to-volume ratio, biocompatibility, and nontoxic nature. Iron oxide MNPs can be proposed as suitable microenvironment for increment of the organic reactions kinetic based on their catalytically behavior.^[30–40]

Following previous research work,^[41] fibrous nanosilica modified with IL loaded Fe_3O_4 NPs and CuI salts is the best candidate as a magnetic nanocatalyst for the synthesis of imidazo[1,2-*a*]pyridines in aqueous solution. In the study, KCC-1 was functionalized with biimidazole. Then Fe_3O_4 NPs and CuI salts were anchored to the functionalized ILs. Finally, the new magnetic and green nanocatalyst has been applied for the efficient synthesis of imidazo[1,2-*a*]pyridine derivatives. Choosing this catalyst and its higher catalytic activity is due to the exceptional dendritic fibrous morphology of KCC-1 and its modification with the biimidazole IL functional groups that perform as strong anchors to the loaded MNPs and avoid leaching them from the pore of the nanocatalyst (Scheme 2).

2 | EXPERIMENTAL

2.1 | Materials

Tetraethyl orthosilicate (TEOS, 98%), (3-aminopropyl) triethoxysilane (APTES, 99%), and malachite green were purchased from Sigma-Aldrich Co, USA. The employed solvents during synthesis procedures were obtained from Merck, Germany. Some of the solvents used in the



SCHEME 1 Drugs structure with imidazo[1,2-*a*]pyridine framework



SCHEME 2 Synthesis of imidazo[1,2-a]pyridines in the presence of CuI/Fe₃O₄ NPs@IL-KCC-1 as a magnetic nanocatalyst

present study were toluene, hexanol, and dimethylsulfoxide (DMSO). Cetyltrimethylammonium bromide was also purchased from Merck, which was used as surfactant during the preparation of KCC-1. Deionized water in this study was produced in laboratory. No further purification was performed on materials and reagents, and they were used as purchased.

2.2 | Instrumentation

X-ray diffraction (XRD) was performed by Siemens D 5000 X-Ray diffractometer (Texas, USA). UV–Vis spectrophotometer analysis was achieved by Shimadzu UV-1800 with a resolution of 1 nm. Transmission electron microscopy (TEM) images were recorded by Carl Zeiss LEO 906 electron microscope operated at 100 kV (Oberkochen, Germany). Field emission scanning electron microscopy (FESEM) analysis was done by TESCAN system of FEG-SEM MIRA3 TESCAN (Brno, Czech Republic). Fourier transform infrared (FT-IR) spectra were recorded by using Shimadzu model FT-IR Prestige 21 spectrophotometer (Tokyo, Japan). Brunauer– Emmett–Teller (BET) was performed on a Micromeritics NOVA 2000 (Florida, USA).

2.3 | General procedure for the synthesis of imidazo[1,2-*a*]pyridine derivatives

Α mixture of benzaldehyde (1 mmol) and 2-aminopyridine (1 mmol) was added in a 25.0-cc roundbottomed flask and stirred for 20 min at room temperature. Then phenyl acetylene (1.1 mmol), (CuI/Fe₃O₄ NPs@IL-KCC-1) (0.034 mol %), CTAB (5 mg), and H_2O (4.0 ml) were included to the above solution and stir for specific period of time under reflux conditions. Thin-layer chromatography (TLC) was used for the monitoring of reaction process till completion. The catalyst was separated by an external magnet and washed several times with water and acetone to use in subsequent reactions. Then the obtained product was crystallized by ethanol to the further purification.

2.4 | Synthesis of the Fe₃O₄ NPs@IL-KCC-1

After synthesis of DFNS (KCC-1) according to our previous report,^[41,42] it is modified by 1-methyl-3-(oxiran-2-ylmethyl)-1*H*-imidazol-3-ium chloride to generate a new functionalized nanocatalyst. For this purpose, KCC-1 (1 g), sodium methoxide (3.0 g), and 20 ml of

dimethylformamide (DMF) were included in a 100-ml round-bottomed flask and stirred for 60 min under nitrogen atmosphere at 60°C. At the next step, the generated methanol and DMF were separated by vacuum from the reaction mixture. After that, dry DMF (20 ml) and 1-methyl-3-(oxiran-2-yl-methyl)-1H-imidazolium chloride were added drop wisely into the reaction mixture and stirred at 60°C for 24 h. In the next step, the mixture was filtered and then washed with DW three times and dried. Finally, to replace the chloride ion with hydroxide ion in the IL, the solid potassium hydroxide and the dried solid from the previous step were added to the water (50 ml). After striating the mixture at room temperature, overnight the mixture was centrifuged and washed with aqueous and dried under reduced pressure. So IL-KCC-1 was synthesized. Then a blend of FeCl₂·4H₂O (1 g), FeCl₃·6H₂O (2.5 g), along with IL-KCC-1 (1.0 g), and aqueous ammonia was included to a 50-ml deionized water and stirred vigorously for 60 min at 80°C in pH = 12. Using this method, Fe_3O_4 NPs were doped on the substrate of IL-KCC-1, and the Fe₃O₄ NPs@IL-KCC-1 was produced.

2.5 | Synthesis of the CuI/Fe₃O₄ NPs@IL-KCC-1

The obtained precipitate in the previous step was separated using external magnet, washed by DW, and dried at 60° C for 6 h. In the next step, dried precipitate (1 g, Fe₃O₄ NPs@IL-KCC-1) was included to the solution of CuI (0.190 g in 50-ml methanol) and stirred at 30°C for 24 h. Then the obtained magnetic nanocatalyst was separated using external magnet, washed with acetone, ethanol, and DW, and dried in air. The schematic of the synthesized nanocatalyst is shown in Scheme 3.

3 | **RESULTS AND DISCUSSIONS**

3.1 | Characterization of the nanocatalyst

After synthesis and modification of the magnetic nanocatalyst, the morphology and structure of CuI/Fe₃O₄NPs@IL-KCC-1 were investigated by SEM, TEM, FT-IR, flame atomic absorption spectroscopy (FAAS), energy-dispersive X-ray (EDX), XRD, BET, and BJH analyses, and vapor–liquid–solid (VLS) methods. The amount of copper and iron that loaded on the fibrous dendritic silica was measured using FAAS, which the amount of iron and copper loaded in the CuI/Fe₃O₄NPs@IL-KCC-1 catalyst was 5.91 and 22.54 wt%, respectively.



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FIGURE 1 Fourier transform infrared spectra of the prepared CuI/Fe $_3O_4$ NPs@IL-KCC-1 nanocatalyst

In the FT-IR spectrum (Figure 1), the peaks related to the stretching vibrations of C=C and C=N in the imidazolium rings appear in 1428 and 1628 cm⁻¹, respectively. The peak at 593 cm⁻¹ belongs to the vibration of Fe–O in Fe₃O₄. Also, the weak peak at 670 cm⁻¹ can be attributed to copper iodide bond, and the sharp peak at

3426 cm^{-1} is assigned to O–H bonds of engineered magnetic nanocatalyst.

Furthermore, the FESEM and TEM analyses were applied for the study of the morphology and the structure of the synthesized CuI/Fe_3O_4 NPs@IL-KCC-1 nanocatalyst (Figure 2). Fibrous morphology and

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 $\begin{array}{ll} \textbf{FIGURE 2} & \mbox{Field emission scanning electron microscopy} \\ (a) and transmission electron microscopy (b) images of the $$CuI/Fe_3O_4$ NPs@IL-KCC-1$ in different magnification $$$



uniform spheres of KCC-1 were approved by these imaging methods.

Based on TEM images, dendritic structure of CuI/Fe_3O_4 NPs@IL-KCC-1 is obvious. Also, average size of particle was obtained as 30 nm. Interestingly, spongy morphology of the synthesized nanocomposite is noticeable. It is important to point out that ILs lead to cross-link of whole nanomaterial, which lead to strong interaction. In addition, using TEM images, existence of MNPs on the structure of nanocatalyst was approved.

To demonstrate the coated Fe_3O_4 and CuI in the CuI/Fe₃O₄NPs@IL-KCC-1 nanocatalyst structure, EDX was utilized (Figure 3a). The EDX analysis proved the presence of O, Si, C, N, and Cu characteristic peaks. Also, all of these results were confirmed by map analysis (Figure 3b).

In the next step, to evaluate the crystal structure of the CuI/Fe₃O₄ NPs@IL-KCC-1 nanocatalyst, XRD analysis was applied (Figure 4). Results show that the peaks at $2\theta = 12.46^{\circ}$, 25.20° , 29.33° , 42.01° , 49.85° , 52.60° , 61.76° , 67.24° , 69.30° , 77.49° , 79.30° , and 89.21° for cubic CuI and peaks at 30.39° , 35.24° , 43.53° , 54.14° , 58.09° , and 63.08° for cubic Fe₃O₄. Also, a wide peak in the range of $2\theta = 19-30^{\circ}$ is related to the amorphous silica (Figure 4).

The porous nature of CuI/Fe₃O₄NPs@IL-KCC-1 and bare KCC-1-NH₂ was evaluated by BET and BJH analyses (Figure 5). Using these methods, porosity and surface area of the nanocatalyst were measured. In addition, using BJH analysis, the pore volume of the CuI/Fe₃O₄ NPs@IL-KCC-1 and KCC-1 was calculated and summarized in Table 1. According to these data, the pore volumes altered from 1.52 in 0.77 cm³ g⁻¹ for KCC-1 (bare material) and CuI/Fe₃O₄ NPs@IL-KCC-1. Also, surface area was obtained as 225 and 617 m² g⁻¹ for CuI/Fe₃O₄ NPs@IL-KCC-1 and bare materials (KCC-1), respectively. Also, the mean pore diameter of CuI/Fe₃O₄ NPs@IL-KCC-1 and KCC-1 was obtained as 13.76 and 9.9 nm, respectively.

The VLS magnetization curve of prepared nanocatalyst is shown in Figure 6, which exposed the super-paramagnetic properties of the prepared nanocatalyst. The saturation magnetization CuI/Fe₃O₄ NPs@IL-KCC-1 nanocatalyst is 22.47 emu g⁻¹.

3.2 | Application of CuI/Fe₃O₄ NPs@IL-KCC-1 nanocatalyst for the synthesis of imidazo[1,2-*a*]pyridines derivatives

At first, to find the optimum reaction conditions for the synthesis of imidazo[1,2-a] pyridines derivatives, a mixture of 4-chloro benzaldehyde (1 mmol), 2-aminopyridine

(1 mmol), and phenyl acetylene (1.1 mmol) under reflux conditions was selected as a model reaction (Scheme 4).

At first, the model reaction was investigated in the presence of different amounts of CuI/Fe₃O₄ NPs@IL-KCC-1 as a nanocatalyst in EtOH under reflux condition. Obtained results are shown in Table 2. It was observed that no product was obtained without catalyst after 180 min (Table 2, entry 1). In continuation, by adding and increasing the amount of the catalyst from 0.003 to 0.034 mol %, the yield of the reaction was increased (Table 2, entries 2–6). But with an increase in the amount of catalyst more than 0.034 mol %, the efficiency of the reaction was not changed. Hence, 0.034 mol % of the catalyst was selected as an optimized amount of nanocatalyst for the reaction (Table 2, entries 7–9).

As the table results show, when the model reaction is done in the absence of catalyst in water under reflux and solvent-free conditions, no desired product obtains after 30 h (Table 3, entries **1–3**). In the following, to show the impact of new magnetic nanocatalyst (CuI/Fe₃O₄ NPs@IL-KCC-1), the model reaction was investigated in the existence of the CTAB (in solvent-free conditions and in the presence of H₂O as solvent) and Fe₃O₄ NPs. No product was formed in the presence of these catalysts, and in the presence of CuI as a catalyst, the yield of the reaction was only 10% after 30 h (Table 3, entries **2–5**).

As can be seen in Table 3, different solvents like water, ethanol, methanol, acetonitrile, and also solvent-free conditions, in the presence of CuI/Fe₃O₄ NPs@IL-KCC-1 (0.034 mol %), were used as a solvent for the model reaction (Table 3, entries **7–10**). In these conditions, the yields of the reaction in 4 h were 86%, 60%, 45%, and 40%, respectively. Hence, the highest yield of the product is obtained in the presence of 0.034 mol % of CuI/Fe₃O₄ NPs@IL-KCC-1 in water, compared with other solvents. Hence, water was selected as an optimum solvent. Therefore, all of the reactions were performed in aqueous solution.

Also, the obtained results show that when the solvent-free conditions were considered for the reaction in the presence and the absence of CTAB and CuI/Fe_3O_4 NPs@IL-KCC-1 as a catalyst, the yields of the reaction were 80% and 76%, respectively. As the results show, the yield of the reaction decreases in these conditions in comparison with aqueous media (Table 3, entries **10** and **11**).

It is necessary to mention that, for the increasing of the solubility of the reactants and the reaction kinetic in the aqueous media, CTAB as a cationic surfactant has been used. It should be noted that in the presence of surfactant and with increasing the time till 6 h, the yield of the reaction did not change (Table 3, entries **12** and **13**). It should be noted that when the reaction is done at room





TABLE 1 Porosity evaluation of CuI/Fe₃O₄ NPs@IL-KCC-1 and its comparison with KCC-1 as bare material

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 r_p/nm

Material type	Pore size (nm) ^[a]	Pore volume $(cm^3 g^{-1})^{[b]}$	Surface area $(m^2 g^{-1})$
KCC-1	9.9	1.5	617
CuI/Fe ₃ O ₄ NPs@IL-KCC-1	13.76	0.77	225

100

^aPore size was calculated by Brunauer-Emmett-Teller method.

 dV_p/dr_p

0.03

0 1

^bPore volume determined from nitrogen physicosorption isotherm.



FIGURE 6 Magnetic hysteresis as a function of field of CuI/Fe₃O₄ NPs@IL-KCC-1



SCHEME 4 The model reaction to optimize the reaction condition

temperature, the efficiency of the reaction decreases (Table 3, entry 14).

The results of Table 4 obviously show that CuI/Fe₃O₄ NPs@IL-KCC-1 (0.034 mol %) is an effective nanocatalyst for the reaction of the 4-chloro benzaldehyde (1 mmol), 2-aminopyridine (1 mmol), phenyl acetylene (1.1 mmol), and CTAB (5 mg) in water (4.0 ml), under reflux conditions to generate imidazo [1,2-a] pyridines derivatives (Table 4, 4a-m) in great yields. Finally, the products were obtained by an easy workup process. Also, turnover

Entry	Amount of the catalyst (mol %)	Yield (%)	Time (min)
1	0	0	180
2	0.003	19	180
3	0.006	46	180
4	0.013	64	180
5	0.027	85	180
6	0.034	96	180
7	0.04	96	180
8	0.047	96	180
9	0.054	96	180

TABLE 2 Optimization of the amount of the catalyst for the model reaction

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number (TON) was obtained as 2941 after optimization of nanocatalyst.

In order to evaluate the applicability of CuI/Fe₃O₄ NPs@IL-KCC-1 as advanced nanocatalyst, various types of aromatic aldehydes were used to react with phenyl acetylene and 2-aminopyridine under reflux conditions, and obtained results are summarized in Table 4. The obtained results show that the aromatic aldehydes with withdrawing groups (Cl, Br, CN, F, CF₃) have better yields and shorter reaction time in comparison with aldehydes with electron donation groups (Me, OMe).

Based on the obtained results, the proposed mechanism for the synthesis of imidazo [1,2-a] pyridines in the presence of CuI@Fe₃O₄ NPs-IL-KCC-1 is shown in Scheme 5. As can be seen, in the presence of nanocatalyst with IL that loaded Fe₃O₄ NPs and CuI salts, the imine as an intermediate (i) was formed. In the next step, the phenyl acetylene is converted to phenyl acetylene copper(I), and the intermediate (ii) is formed in the presence of magnetic nanocatalyst, which by its attacking to the imine bond, intermediate (iii) is produced. Finally, by cyclization of the mentioned intermediate, the major product was obtained with high yields.

3.3 | Reusability of the catalyst

industrial applications, the reusability of For nanocatalysts is so essential. Hence, the recyclability of the nanocatalyst was evaluated for the one-pot synthesis of imidazo[1,2-*a*]pyridines, using the reaction of aromatic benzaldehydes, 2-aminopyridine, and phenyl acetylene in aqueous solution. In this method, external magnet was used for easy removal of the CuI@Fe₃O₄ NPs-IL-KCC-1 from the reaction mixture and then washed with water and acetone. So the separated nanocatalyst was air dried carefully before being used in subsequent runs. As can be 10 of 13 WILEY ______ Organometallic Chemistry

Entry	Catalyst	Surfactant	Solvent	Reaction condition	Time (h)	Yield (%)
1	-	-	H_2O	Reflux	30	NR
2	-	CTAB	-	Solvent free	30	NR
3	-	CTAB	H_2O	Reflux	30	NR
4	Fe ₃ O ₄	CTAB	H_2O	Reflux	30	NR
5	CuI	CTAB	H_2O	Reflux	30	10
6	CuI/Fe ₃ O ₄ NPs@IL-KCC-1	-	H_2O	Reflux	4	86
7	CuI/Fe ₃ O ₄ NPs@IL-KCC-1	-	EtOH	Reflux	4	60
8	CuI/Fe ₃ O ₄ NPs@IL-KCC-1	-	МеОН	Reflux	4	45
9	CuI/Fe ₃ O ₄ NPs@IL-KCC-1	-	CH ₃ CN	Reflux	4	40
10	CuI/Fe ₃ O ₄ NPs@IL-KCC-1	-	-	Solvent free	4	76
11	CuI/Fe ₃ O ₄ NPs@IL-KCC-1	CTAB	-	Solvent free	4	80
12	CuI/Fe ₃ O ₄ NPs@IL-KCC-1	CTAB	H_2O	Reflux	3	88
13	CuI/Fe ₃ O ₄ NPs@IL-KCC-1	CTAB	H_2O	Reflux	6	88
14	CuI/Fe ₃ O ₄ NPs@IL-KCC-1	СТАВ	H_2O	Room temperature	4	60

Abbreviation: NR, not reported.

TABLE 4 Comparison of the time and yield of imidazo[1,2-a]pyridines derivatives synthesis in the presence of CuI/Fe₃O₄ NPs@IL-KCC-1

Entry	Product	Time (h)	Yield ^[a] (%)	M.P.
4a		3	90	117–119 ^[25]
4b		3	88	144–145 ^[32]
4c	Br	3	87	161–163 ^[43]
4d		3	97	134–135 ^[43]
4e		3	96	81-83 ^[26]



TABLE 4 (Continued)

Entry	Product	Time (h)	Yield ^[a] (%)	M.P.
4f		3	92	140-142 ^[43]
4g		3	90	117–118 ^[44]
4h		4	71	158–159 ^[45]
4i		3	90	131-133 ^[44]
4j		3	86	155 ^[25]
4k		4	72	Semisolid ^[26]
41		3	90	117–118 ^[45]
4m		3	85	140–141 ^[46]

^aIsolated yields.



SCHEME 5 Proposed mechanism for the synthesis of imidazo [1,2-a] pyridines in the presence of CuI@Fe₃O₄ NPs-IL-KCC-1

seen in Figure 7, it was established that under mild reaction conditions, this green nanocatalyst indicated recyclable behavior eight times with minor reduction in its catalytic activity.

4 | CONCLUSION

In summary, the results indicated that CuI/Fe₃O₄ NPs@IL-KCC-1 magnetic leaching as а free nanocatalyst is an efficient and green nanoreactor for the synthesis of imidazo [1,2-a] pyridines from the onepot reaction of 2-aminoprydine, phenyl acetylene, and aromatic aldehydes in water under reflux conditions. Exceptional catalytic behavior in aqueous media with high surface area and porous structure, shorter reaction times in comparison with previous reported methods, excellent yields, easy workup, no use of chromatographic columns and toxic solvents, and magnetically recoverable of the nanocatalyst are advantages of this work.





FIGURE 7 Effective separation of nanocatalyst (CuI/Fe₃O₄ NPs@IL-KCC-1) from the reaction mixture by means of external magnet and showing its reusability

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

Sajjad Azizi: Formal analysis. **Nasrin Shadjou:** Conceptualization; methodology. **Jafar Soleymani:** Investigation; methodology.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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