

CHEMISTRY A European Journal



Accepted Article

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This manuscript has been accepted after peer review and appears as an Accepted Article online prior to editing, proofing, and formal publication of the final Version of Record (VoR). This work is currently citable by using the Digital Object Identifier (DOI) given below. The VoR will be published online in Early View as soon as possible and may be different to this Accepted Article as a result of editing. Readers should obtain the VoR from the journal website shown below when it is published to ensure accuracy of information. The authors are responsible for the content of this Accepted Article.

To be cited as: Chem. Eur. J. 10.1002/chem.201801416

Link to VoR: http://dx.doi.org/10.1002/chem.201801416

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Compartmentalization of Incompatible Polymers within Metal-Organic Framework towards Homogenization of Heterogeneous Hybrid Catalysts for Tandem Reactions

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Abstract: New catalytic systems bearing incompatible catalytic sites can be designed via In situ polymerization of acidic and basic polymers into MOFs, resulting in highly porous, recyclable, and durable catalytic composites with excellent compartmentalization to spatially isolate opposing agents. These synthesized hybrid catalysts exhibit excellent catalytic activity for one-pot "wolf and lamb" reactions (deacetalization-Knoevenagel/Henry), which would be attributed to their unique characteristic of locally homogeneous but globally heterogeneous structure.

Introduction

Enzymatic catalysis is one of the most advanced synthetic processes.^[1] In addition to adaptive properties, enzymatic catalysis combines multiple incompatible catalytic sites that can effectively catalyze tandem reactions. The cascade process demonstrates superior performance to that of two-step conventional reaction.^[2] Work on developing catalysts that can act like enzymes has attracted intense attention; however, progress has been slowed because, in conventional catalytic systems, these incompatible catalysts can be quenched or deactivated during the reaction. The trade-off between isolation of active site and preservation of activity is still a challenging issue.^[3]

The concept of "wolf and lamb" reactions emerges as a powerful tool to probe site-isolation effects. To catalyze "wolf and lamb" reaction, the incompatible active sites are separately embedded in different heterogeneous solid supports. Various solid supports have been employed, such as resin,^[4] sol-gel colloids,^[5] Pickering emulsions,^[6] or polymeric micelles.^[7] In general, the precedent catalytic

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strategies involving solid supports can be classified into two types: 1) anchorage/encapsulation of catalytic groups with opposite properties onto insoluble solids to form heterogeneous catalyst; with this technique, the active sites, which can react with each other in solution, can be physically separated;^[4,5] 2) fabrication of soluble coreconfined star/bottlebrush polymers, where the incompatible reactive agents are located in the core and sterically isolated from each other by fully extended long hydrophobic brush.^[6,7] The first strategy renders relatively easy separation from the products and solution; however, the heterogeneous catalysts typically bear the drawbacks of insufficient contact with the organic reactants. The second strategy affords homogeneous multifunctional catalysts, which have demonstrated high activity, but whose recyclability is still a challenge. Therefore, a mechanistically distinct strategy needs to be developed for the rational design of multifunctional catalysts for cascade reactions.



Figure 1. Compartmentalization of incompatible polymers within MOF via *in situ* polymerization of hostile vinyl substrates for Tandem Reaction.

Metal-organic frameworks (MOFs) have become particularly attractive for a wide range of applications, such as gas storage,[8a,b] separation,[8c] drug delivery,[8d] and catalysis.[8e-g] Recently, Kitagawa, Uemura, and co-workers reported a series of MOF/polymer composites,^[9] providing a powerful tool for the integration of functional polymers and MOF.^[10] This new class of porous composites has the linear polymer threading throughout the nano-space of MOFs. In principle, although there may exist strong interaction between pore wall of MOF and polymers (e.g., hydrophobic interaction, electrostatic interaction), the solvent can significantly reduce net segment-segment forces (e.g., electrostatic, van der Waals force). Therefore, when in contact with appropriate solvents, the polymer in the polymer/MOF composite can detach from the wall of MOFs, but reside in the channel of MOFs due to the confinement effect, while the skeleton of MOFs remains unchanged. In this sense, the

composite has the characteristics of a locally homogeneous but globally heterogeneous structure. These features make polymer/MOF an ideal support to demonstrate the concept of "wolf and lamb" reactions.

In juxtaposition to the abovementioned strategies, the use of polymer/MOF can combine heterogenous and homogenous properties in one single catalytic system, exploiting their respective advantages while effectively avoiding their shortcomings. Herein, we develop a novel "site-isolation" methodology *via* convenient *in situ* polymerization of hostile vinyl substrates within MOFs to compartmentalize incompatible polymers (Figure 1). The excellent catalytic performance of the so-prepared MOF/polymer composites was demonstrated in a sequential two-step reaction.

Results and Discussion

To validate the feasibility of the above proposed "site-isolation" strategy, we selected the Cr-MIL-101 as a host material due to its interconnected cage-type pore, sufficiently large pore size to allow monomer penetration (Figure 2) and reasonable stability against common solvents.[11,12] Benzene sulfonic acid (BSA) and methylaminopyridine (MAP) are chosen as agents to offer incompatible active sites. The preparation of the acidic PBSA/MIL-101 and basic PMAP/MIL-101 is accomplished in two steps via in situ polymerization strategy: (1) a solution of BSA- or MAP-containing vinyl derivative S1 (for the preparative protocol, see supporting information) and 2.2-azobisisobutyronitrile (AIBN) in DMF/H₂O is impregnated into the porous cavities of Cr-MIL-101; (2) in situ radical polymerization of the preloaded vinyl compounds is initiated by heating. Upon sufficient contact, the monomer-containing solution can be expected to penetrate into Cr-MIL-101; when polymerization occurs, the monomer units in different cages can polymerize together through neighboring cavities, so that the formed polymer can be physically interlocked inside MOFs. In situ polymerization is conducted to encapsulate BSA- or MAP-containing vinyl monomers onto polystyrene, leading to the formation of the desired MOF/acidic/basic polymer (Figure 1). The resulting polymeric chains can be isolated by ordered pores of the MOF.



Figure 2. The topological characteristic of (a) Cr-MIL-101, (b) the proposed model for encapsulated linear polymer PBSA and PMAP (six repetitive units).

To confirm the polymeric and chemical structure of the polymer inside the MOF, the linear polymers (PBSA and PMAP) within cavities of PBSA/MIL-101 and PMAP/MIL-101 are released and collected by digesting MIL-101 with strong alkaline. As shown in Figure 3a, proton chemical shifts match with those of bulk PBSA and PMAP prepared using solution approach (for the preparative protocol, see supporting information). The broad peaks around 7.5 ppm belong to the aromatic H of BSA, while the ones in the spectrum of PMAP/MIL-101 ~2.96, 4.40, 6.50, 6.80, and 8.10 ppm are associated to the N-methyl of pyridine, benzyl hydrogen protons, and aromatic H of polymeric styrene and pyridine, respectively. Furthermore, the released PBSA and PMAP polymers were characterized via gel permeation chromatography (GPC) to have a number-average molecular weight of ~Mn=3600 and 7000, respectively (Figure S1, supporting information). This is equivalent to ca. 27 and 34 repeat units of PBSA and PMAP, the length of which is enough to intertwine within the cavities of Cr-MIL-101. The existence of acidic and basic active sites is also confirmed via using solidstate Fourier transform infrared spectroscopy (FTIR). In FTIR spectra of polymer/MOF composites, characteristic bonds (e.g., S-O and C=N) of the included polymers are observed (Figure S2, supporting information). These NMR and FTIR results demonstrate the successful anchorage of BSA and MAP during the in-situ polymerization, respectively. Then, the loading amounts of polymers are quantified, showing that there are 1.01 mmol and 0.34 mmol of acidic and basic groups per gram of PBSA/MIL-101 and PMAP/MIL-101, respectively (Eqs. 1-2). Examination of the gas adsorption behavior indicates that all of the functionalized MOFs are porous (Figure 2b, Table 1). Their surface areas are still very large to ensure good contact with reactants. Furthermore, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) experiments revealed that most of the vinyl monomers were polymerized inside the microspore of MIL-101 without bulk polymer formation on the external surface (Figures S3 and S4, supporting information). Thermogravimetric analysis (TGA, Figure S5, supporting information) confirms the thermal stability of PBSA/MIL-101 and PMAP/MIL-101. The thermal decomposition temperature of the loaded polymer can be higher (e.g., PBSA is ~400 °C) than that of MIL-101 (~350 °C). Powder X-ray diffraction (PXRD, Figure 3c) confirms retention of the parent framework structure of octahedron-like morphology and the crystallinity of the resultant MOF-polymer composites.

Table 1.Texturacomposites.	I structure and	amount of	active site of	MOFs and its
Sample	BET surface area (m³/g)	Pore size ^[a]	Pore volume ^[b]	Amount of active site ^[c]
		(nm)	(mL/g)	(mmol/g)
MIL-101	3024	2.5	1.43	0
PMAP/MIL-101	564	2.3	0.27	0.34
PBSA/MIL-101	1107	2.3	0.52	1.01

[a] Pore size distribution is calculated based on BJH model and desorption branch; ^b Total pore volume; ^cActive site is defined as either acidic or basic groups on the polymer and the amount is determined based on the loadings of polymer in the composites (see below).

Besides, due to the nature of linear, relatively short, and isolated polymeric chains within MOF, the dissolution/swelling process would be facile due to the minimized polymer-polymer

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interaction. The dissolution process of the chiral polymeric chains is significantly easier than routine BSA-containing crosslinked PPBSA and MAP-containing cross-linked PPMAP resin (Figure S6, supporting information).



Figure 2 (a) ¹H-NMR spectra of encapsulated polymers of the digested PBSA/MIL-101, PMAP/MIL-101 and the bulk PP1 (MeOH-d₄) prepared in a solution approach; (b) N₂ isotherms for Cr-MIL-101, PBSA/MIL-101 and PMAP/MIL-101; (c) PXRD measurements of Cr-MIL-101, PBSA/MIL-101 and PMAP/MIL-101.

These functionalized acidic/basic polymers/MOF composites are used to catalyze one-pot tandem reactions (Table 2), involving two steps: a) deacetalization reaction by acid catalysis; b) Knoevenagel reaction by basic catalysis. It is notable that the linear PBSA and PMAP released from the alkaline digestion of MIL-101 framework are completely soluble in the reaction solvent (DMSO/H₂O: 40/1, v/v) with solubility more than 20 mg/mL (Figure S6, supporting information). This further supports the coexistence of global heterogeneous and local homogenous domains in our designed catalytic system. We examined the reaction of *p*-fluoro-benzaldehyde glycol acetal and ethyl cyanoacetate in the presence of various heterogeneous and homogeneous catalysts as a model reaction. A mixture of a catalytic amount (5 mol%) of PBSA/MIL-101 and PMAP/MIL-101 (PBSA~PMAP/MIL-101) efficiently catalyzes this reaction to give 4a in a quantitative yield after 12 h (Table 2, entry 1), whereas a mixture of *p*-toluene sulfonic acid (PTSA) and 4dimethylaminopyridine (MAP) as a homogeneous catalyst (5 mol%) shows no activity (Table 2, entry 2), maybe due to the fast acid-base neutralization. In contrast, the use of a mixture of routine cross-linked polystyrene resins PPBSA and PPMAP can only lead to the deacetalization product 2a in 33% yield; the desired product has, thus, not been formed, revealing that the exposure of incompatibly catalytic sites on the surface of solid materials can also remarkably interfere with each other when mixing them up. Moreover, the addition of excessive amounts of free acid (TPSA, 5 eq.) or base (MAP 5 eq.) to PBSA~PMAP/MIL-101 can entirely stop the catalytic activity (Table 2, entries 5 and 6), demonstrating that the opening channel filled with catalytic sites can be readily reached for reaction substrate/opposite agents. This contrasting experiment

can relate the catalytic performance to their structure features: the high porosity of PBSA/MIL-101 and PMAP/MIL-101 would provide sufficiently guest-accessible room for catalysis. In addition, the unique structures of the MOF/chiral polymer composites featuring with heterogeneous matrix and local homogeneous active domain would contribute to the efficient catalytic site-exposure of PBSA/MIL-101 and PMAP/MIL-101. The recyclability of the bifunctional catalyst PBSA~PMAP/MIL-101 is also excellent. The yield of the 4th run is about 83% of the value of the 1st run. After recycling, the crystallinity of the catalyst has been maintained as verified by PXRD (Figure S7, supporting information).

Table 2	2. One pot sequential deacetalizati Acid Catalyst DMSO/H ₂ O 1a	on-Knoevena CHO <u>base Cata</u> NC CC 3a	gel reaction. ^{[a}	J COOEt CN
Entry	Catalyst	Conv. of 1a (%) ^[b]	Yield of 2a (%) ^[c]	Yield of 4a (%) ^[c]
1	MIL-101/PBSA~PMAP	100	Trace	89
2	TPSA + DMAP	Trace	Trace	Trace
3	PPBSA+PPMAP	40	33	Trace
4	PBSA~PMAP/MIL-101 +MAP	Trace	Trace	Trace
5	PBSA~PMAP/MIL-101+ TPSA	100	91	9

[a] Reaction conditions: 1a (0.25 mmol), 3a (0.3 mmol), DMSO/H₂O (40/1, v/v), 70 °C, 12h. [b] Conversion of was determined from ¹H NMR of the crude reaction mixtures. [c] The yield was determined by isolated yield.

	Table	3. PBSA~PMAP/MIL-101	catalyzed one	pot deacetalization-
2	Knoeve	$\begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{c} \\ \\ \end{array} $	PBSA~PDMAP/MIL-101	R ¹ CN 4
	Entry	1	3	Yield of 4[%]
	1	1b : R ¹ =H	3a: R ² =COOEt	4b : 93
	2	1c: R ¹ =OCH ₃	3a: R ² =COOEt	4c : 90
/	3	1d : R ¹ =F	3c: R ² =COOMe	4e : 86
	4	1d : R ¹ =F	3d : R ² =COO <i>i</i> -Pr	4f : 88
	5	1d : R ¹ =F	3d:R ² =COO <i>i</i> -Bu	4g : 78
	6	1d : R ¹ =F	3d:R ² =COOt-Bu	4h : 75
	7		3a : R ² =COOEt	4i : trace

[a] Reaction conditions: compound 1 (0.25 mmol), 3 (0.3 mmol), PBSA~PMAP/MIL-101 (5 mmol%, 0.0125 mmol), DMSO/H2O (40/1, v/v), 70 °C. 12h.

To demonstrate the universality of these catalysts, we further extended the scope of this protocol to other aldehyde glycol acetals with cyanoacetate derivatives. As shown in Table 3, the electron-donating (OMe), electron-withdrawing groups (F), and neutral (R=H) on para position of the benzene ring of aldehyde glycol acetal are all well tolerated to produce the expected products in good yields (Table 3, entry 1-3). Besides, the size of ester group (iPr, i-Bu, and t-Bu) of cyanoacetate showed slightly influence on the reaction outcome (Table 3, entries 4-6), affording the desired products in moderate to good yields. Next, we turned our attention toward the bulk aldehyde glycol acetal 1e as a substrate for this reaction, which is even larger than the FULL PAPER

window size of Cr-MIL-101. Accordingly, the expected products **4i** were only obtained in trace (Table 3, entry 7), revealing that the catalytic reactions occur mostly in the cavities of the catalyst rather than on the external surface, and thus exhibiting reagent size selectivity for such heterogeneous catalyst.

Furthermore, PBSA~PMAP/MIL-101 has also been evaluated in a tandem reaction involving the hydrolysis of an acetal and a subsequent Henry reaction (Scheme 1). Remarkably, the bifunctional catalytic composites can convert benzaldehyde glycol acetal **5** into desired product **7** with a good yield of 94% without any aldehyde intermediate.



 $\label{eq:scheme1} \begin{array}{l} \mbox{Scheme 1. } \mbox{PMAP/MIL-101 catalyzed one pot deacetalization-henry reaction.} \end{array}$

Conclusions

We have demonstrated the "Wolf and Lamb" concept with bifunctionlized linear polymer/MOF composites. The acidic and basic polymers are separately accommodated into MOF via the steps of loading corresponding monomers and then polymerization. These two types of polymers/MOF catalysts bearing isolated active sites work together to catalyze one-pot tandem reactions. The tightly intertwined state of linear polymers and MOF architecture ensures this heterogeneous material to recyclability and provide have aood excellent compartmentalization to spatially isolate incompatible or opposing reagents. More importantly, by contrast to the previous strategies to realize site-isolated catalysts, the polymer/MOF composite can provide unique local homogeneous and global heterogeneous micro-domain.

Experimental Section

Chemicals and instrument information. NMR spectra were recorded on a Brüker DPX-400/500 spectrometer at 400/500 MHz for ¹H-NMR and 100/125 MHz for ¹³C-NMR. Data for ¹H-NMR are recorded as follows: chemical shift (ppm), multiplicity (s, singlet; d, doublet; t, triplet; q, quarter; m, multiplet), coupling constant (Hz), integration. Data for ¹³C-NMR are reported in terms of chemical shift (δ, ppm). Mass spectra were determined on an Esquire-LC-00075 mass spectrometer. All infrared experiments were performed on a Brüker Alpha FT-IR spectrometer using ~1.0 mg of the solid sample at a 4 cm⁻¹ resolution. Powder X-ray diffraction (PXRD) data were collected at ambient temperature on a Bruker D8 Advance diffractometer at 40 kV, 40 mA for Cu Kα (λ= 1.5418 Å), with a scan speed of 1 sec/step, a step size of 0.02° and a 20 range of 5-40°. The Brunauer-Emmer-Teller (BET) surface areas were measured via Micromeritics ASAP 2020 analyzer at 77 K. Thermogravimetric Analysis (TGA) data were collected at Perkin Elmer TGA 7 running from 50 °C to 500 °C with a scan rate of 10 °C/min. Analyses of the morphology and chemical composition of the samples were conducted via a Hitachi S-4800 field-emission scanning electron microscope (FE-SEM). The computational modeling for the topological characteristic of the host, monomers, and linear polymers were archived by Discovery Studio 2.5 (Accelrys Software Inc., San Diego, CA). Gel permeation chromatography (GPC) analysis was performed on Waters 1525 with refractive index (RI) detector. Starting materials and solvents were purchased and used without further purification from commercial suppliers (Sigma-Aldrich, Alfa Aesar, TCI, and others).

The synthesis of the PBSA/MIL-101 composites. A solution of sodium 4-styrenesulfonate (300 mg, 1.46 mmol) and 2,2-azobisisobutyronitrile (AIBN, 45 mg, 0.27 mmol, as radical initiator) in 1.5 mL DMF/H₂O (5:1, v/v) was impregnated into Cr-MIL-101 (0.7 g). The mixture was ground in a mortar and then allowed to stand at 4 °C for 12 hours to reach distribution equilibrium of the monomers through the cavities of MIL-101. The polymerization was conducted under a nitrogen atmosphere at 80 °C for 5 days. The so-obtained powder was soaked in DMF for 3 days and intensively washed with DMF to completely remove all unreacted monomer and loosely attached polymers. The residue DMF was then removed by soaking and washing with acetone. Finally, the obtained composite was acidified by soaking in 12N HCl for 12 hours, filtered and further dried at 80 °C for overnight.

The synthesis of the PMAP/MIL-101 composites. A solution of compound S1 (300 mg, 1.34 mmol, see supporting information) and 2,2-azobisisobutyronitrile (AIBN, 45 mg0.27 mmol), as a radical initiator, in toluene (1.5 mL) was impregnated into Cr-MIL-101 (0.7 g). The mixture was ground finely in a mortar and then allowed to stand at 4 °C for 12 hours to reach distribution equilibrium of the monomers through the cavities of MIL-101. The polymerization was conducted under a nitrogen atmosphere at 80 °C for 5 days. The obtained powder was firstly soaked in DMF for 3 days and then washed with acetone to remove the residue DMF. Finally, the powder was repeatedly washed with 1N HCl to completely remove all unreacted monomer and loosely attached polymers between MIL-101 particles. After soaked in 5 % NaHCO₃ for 12 hours, the desired polymer composite PMAP/MIL-101 was obtained and further dried at 80 °C for overnight.

The extraction of the linear polymer PBSA (or PMAP) from the PBSA/MIL-101 (or PMAP/MIL-101) composites for NMR and GPC analyses. PBSA/MIL-101 (200 mg) was first fully digested by 10 wt.% NaOH at 120 °C for 10 min. The pH of the obtained solution was adjusted by 6 N HCl to slightly lower than 7. The NaPBSA together with terephthalic acid was precipitated out by adding an excessive amount of acetone. The precipitation was collected by filtration and washed with diethyl ether to remove the terephthalic acid; however, pure NaPBSA polymer cannot be obtained even though intensive washings was conducted. Then, the precipitation was dried and soaked in 2 mL H₂O. The insoluble solid was removed by filtration, and the filtrate was evaporated in vacuum. The resulting white solid was further dried by oil pump at 120 °C for 4 hours to afford encapsulated PBSA.¹H-NMR (500 MHz, D2O): 7.83 (d, J = 7.8 Hz, 2H), 6.78 (s, 2H), 2.68~1.04 (m, 3H). b) PMAP/MIL-101 (200 mg) was first fully digested by 10 wt.% NaOH at 120 °C for 10 min. The precipitation was collected by filtration and fully dried. Then, the precipitation was soaked in 10 mL CH₂Cl₂. The insoluble solid was removed by filtration, and the filtrate was evaporated in vacuum. The resulting solid was further dried by oil pump at 120 °C for 4 hours to afford encapsulated PMAP. ¹H-NMR (500 MHz, CDCl₃): 8.11 (s, 2H), 7.16~6.10 (m, 6H), 4.59~4.10 (m, 2H), 3.04 (m, 3H), 2.07~0.64 (m, 4H).

Qualification for the PBSA loading amount with a unit of mmol/g in the PBSA/MIL-101 composite. CHNS element analysis gives the value of S weight ratio in PBSA/MIL-101. S can only derive from the PBSA within MOF. The molecular formula of PBSA are well defined (W_{PBSA} , -($C_8H_8O_3S$)_n-); therefore, if we know the S weight content (W_{s_1} %), the PBSA loading amount with a unit of mmol/g (C) in PBSA/MIL-101 composite can be calculated based on the following Eq. 1:

$$C = \frac{\frac{W_s}{32 * 100} * W_{PBSA} * 1000}{W_{PBSA}} \quad Eq. 1$$

Qualification for the PMAP loading amount with a unit of mmol/g in the PMAP/MIL-101 composite. PMAP/MIL-101 (2 g) was first fully digested by 10 wt.% NaOH at 120 °C for 10 min. The precipitation was collected by filtration and fully dried. Then, the precipitation was extracted FULL PAPER

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by CH₂Cl₂ (50 mL x 3). The organic layer was combined and evaporated in vacuum. The ¹H-NMR analysis was performed using dibromomethane (CH₂Br₂) as the internal standard (174 mg, 1 mmol). The molecular formula of PBSA are well defined (*W*_{PBSA}, -(C₁₅H₁₆N₂)n⁻), Indeed, NMR analysis gives the value of PMAP/CH₂Br₂ molar ratio, which can be calculated by the ratio of integral area between δ_{PMAP} (IA_{PMAP}, ~4.9 ppm) and δ_{CH2Br2} (IA_{CH2Br2}, ~5.5 ppm). Therefore, the PMAP loading amount with a unit of mmol/g (*C*) in can be calculated based on Eq. 2:

$$C = \frac{IA_{PMAP} / IA_{CH2Br2} * 1 * W_{PMAP}}{W_{PMAP} * 2} \quad Eq. 2$$

Typical reaction procedure for the deacetalization-Knoevenagel reaction in one pot. A suspension of PBSA/MIL-101 (12.3 mg, 0.0125 mmol) and PMAP/MIL-101 (36.7 mg, 0.0125 mmol) in 1 mL DMSO/H₂O (40/1, v/v) was stirred at room temperature for 1 h. Then, the corresponding benzaldehyde glycol acetal (0.25 mmol) and cyanoacetate derivatives (0.3 mmol) were added and then heated to 70 °C for 6 hours. Then, the mixture was filtered, and the filter cake was extracted by ethyl acetate. The organic layers were collected, dried over anhydrous Na₂SO₄, and concentrated in vacuum to obtain the crude product, which was then purified via chromatography (petroleum ether/ethyl acetate) to make the pure product.

The reaction procedure for the deacetalization-Henry reaction in a one pot. A suspension of PBSA/MIL-101 (37.1 mg, 0.0125 mmol) and PMAP/MIL-101 (110.3 mg, 0.0125 mmol) in 1 mL nitromethane/H₂O (40/1 v/v) was stirred at room temperature for 1 hour. Then, 2-(4-nitrophenyl)-1,3-dioxolane (0.25 mmol) was added and then heated to 70 °C for 6 hours. The mixture was then filtered and washed with methanol several times. The filtrates were combined and concentrated under then purified via chromatography (petroleum ether/ethyl acetate) to generate the pure product.

Acknowledgements

The authors gratefully acknowledge Prof. Chi-Ming Che at The Hong Kong University for their knowledge sharing and suggestions on Homogenization of Heterogeneous composites as catalytic system. Financial support from the National Natural Science Foundation of China (Nos. 21572096, 51603046), the National Key Basic Research Program of China (973 Program 2013CB834802), Shenzhen overseas high level talents innovation plan of technical innovation project (KQCX20150331101823702), Shenzhen special funds for the development of biomedicine, Internet, new energy, and new material industries (JCYJ20150430160022517) and South University of Science and Technology of China (FRG-SUSTC1501A-16) is greatly appreciated.

Keywords: Metal-organic Framework • Hybrid Catalysts • Tandem Reaction • *in situ* polymerization • Incompatible Polymers

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10.1002/chem.201801416

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FULL PAPER

New catalytic system

compartmentalizing incompatible catalytic sites is realized, exhibiting excellent catalytic activity for one-pot "wolf and lamb" reactions.

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Compartmentalization of Incompatible Polymers within Metal-Organic Framework towards Homogenization of Heterogeneous Hybrid Catalysts for Tandem Reactions