Journal of Molecular Catalysis A: Chemical 420 (2016) 294–302

Contents lists available at ScienceDirect

Journal of Molecular Catalysis A: Chemical

journal homepage: www.elsevier.com/locate/molcata

Tungstophosphoric acid supported on core-shell polystyrene-silica microspheres or hollow silica spheres catalyzed trisubstituted imidazole synthesis by multicomponent reaction

Marina Gorsd, Gabriel Sathicq, G. Romanelli, L. Pizzio*, M. Blanco

Centro de Investigación y Desarrollo en Ciencias Aplicadas "Dr. J.J Ronco" (CINDECA), Departamento de Química, Facultad de Ciencias Exactas, UNLP-CCT La Plata, CONICET, 47 N° 257, 1900 La Plata, Argentina

ARTICLE INFO

Article history:
Received 17 February 2016
Received in revised form 8 April 2016
Accepted 12 April 2016
Available online 5 May 2016

Keywords:
Hollow silica spheres
Polystyrene-silica spheres
Tungstophosphoric acid
Trisubstituted imidazoles

ABSTRACT

Materials based on tungstophosphoric acid supported on core-shell polystyrene-silica microspheres or hollow silica spheres were prepared, characterized and used as catalysts in the synthesis of trisubstituted imidazoles by a multicomponent reaction under solvent-free conditions.

For the preparation of the two different silica-based structures, silica was synthesized using tetraethylorthosilicate (TEOS) as precursor in an ethanol-ammonium solution and polystyrene spheres as template or core. The formation and growth of the silica layer to obtain the core-shell microspheres were followed by 24 h. Then, the hollow spheres were obtained by calcination of the core-shell material at 500 °C for 3 h. Both supports were impregnated with tungstophosphoric acid (TPA) solutions.

A smooth appearance of the spheres was observed by scanning electron microscopy (SEM). Mesoporous materials were obtained, without important microporosity, as determined from N_2 adsorption-desorption isotherms. The Fourier transform infrared (FT-IR) spectra confirmed that complete removal of the polystyrene core can directly be achieved by calcination at 500 °C, and also that Keggin undegraded TPA species are present in the impregnated solids. The acidic characteristics of the solids were evaluated by potentiometric titration, showing that they exhibit very strong acid sites. Moreover, peaks assigned to crystalline forms of TPA were observed by XRD.

The yields obtained in the solvent-free synthesis of 2,4,5-triphenyl-1*H*-imidazole and other eight trisubstituted imidazoles were high, without formation of by-products resulting from competitive reactions or decomposition products, so the prepared materials are highly selective catalysts.

1. Introduction

Recently, numerous important heterocyclic compounds have been synthesized under solvent-free conditions by a multicomponent reaction [1,2]. Compounds containing imidazole moiety have many pharmacological properties and play important roles in biochemical processes [3]. Various applications have been reported in the therapeutic area, including anti-inflammatory, antiviral, antibacterial, antiallergenic and antitumor activity [4–6]. Also, imidazole moiety acts as a central section of biological systems such as Losartan and Olmesartan, which are antihypertensive. A variety of heterocyclic derivatives of this system were used as inhibitor of heme 1-oxygenase, HMG-CoA reductase, P2X7 receptors [7], and p38 MAP kinase [8].

In addition, imidazole-containing compounds play a key role in green chemistry and catalysis. Many commercial ionic liquids are based on imidazoles, due to the easy functionalization of the imidazole ring and the ability to form cations. A variety of ionic liquids were prepared, and their activity was investigated in catalytic reactions [9,10].

In 1882, Radziszewski [11], and Japp and Robinson [12] reported the first synthesis of the highly substituted imidazoles from a 1,2-dicarbonyl compound, different aldehydes, and ammonia. The preparation of heterocyclic compounds typically involves a large number of processes that use toxic reagents and generate toxic waste. A conventional preparation of trisubstituted imidazoles is performed by condensing a 1,2-diketone, an aldehyde and ammonium acetate in the presence of strong acids, such as H_3PO_4, H_2SO_4 and CH_3COONH_4 [13]. Today, there are a variety of methods for

---

* Corresponding author.
E-mail addresses: lrpizzio@quimica.unlp.edu.ar, lrpizzio@hotmail.com (L. Pizzio).

http://dx.doi.org/10.1016/j.molcata.2016.04.010
1381-1169/

the synthesis of substituted imidazoles, but many of these methods have disadvantages, such as low yields, long reaction times, extreme reaction conditions, use of expensive and toxic catalysts, and they often require a further reaction step for the synthesis of the desired compound.

These factors result in the need to develop alternatives for the production of substituted imidazoles in order to remove hazardous solvents and catalysts. The use of multicomponent reactions, heterogeneous catalysts and solvent-free reaction conditions would be the methodology to overcome these limitations [14–16].

On the other hand, hollow spheres and core-shell mesoporous structures have attracted increasing attention in recent years because they have an important field of application in different scientific scopes, such as catalysis [17–19], delivery of drugs [20] and medicinal use [21].

The most common method of preparation of core-shell spheres is the deposition of the desired material on a template or the use of specific functional groups on the surface of the template employed as core to induce the formation of the shell, and thus obtain a core-shell shaped structure. Then, if the material to be obtained must be hollow, the core or template is removed by calcination and/or extraction with an organic solvent depending on the system composition, though the variety of methods to prepare hollow spherical materials is diverse. Hard polymers [22], carbon spheres [23,24], silica microspheres [25], colloidal nanoparticles [26], oil/water (O/W) or water/oil (W/O) emulsion drops [27,28], or gas bubbles [29] have been used as template for the preparation of these materials. The hollow inside these materials can be used as a "microreactor", in which the chemical reactions occur differently than at the macroscale due to the effects caused by the microenvironment [30]. They also have interesting properties, such as uniform pore size, high surface area, large void space, and good biocompatibility.

In the present work, the catalytic activity of a catalyst with Keggin structure, which was confined both in silica microspheres with core-shell structure and hollow silica microspheres, was evaluated in the synthesis of imidazole. The method used to obtain the catalytic materials gave good results. Polystyrene spheres were used as core or template. On this polymer, a silica layer was deposited to form a shell by the Stöber approach. This is a well-known and efficient process to obtain uniform spherical colloidal silica particles via the hydrolysis and condensation of tetraethoxysilane (TEOS) in ethanol aqueous solution [31] by the sol-gel technique. In addition, in order to obtain the hollow microspheres, the template was removed by thermally treating the solids at high temperatures or by extraction with suitable solvents, as reported in the literature [32,33]. After the physicochemical characterization of the solids, their catalytic behavior in 2,4,5-triphenyl-1*H*-imidazole synthesis was firstly evaluated, and then the best catalyst was used to perform the synthesis of 2-(4-nitrophenyl)-4,5-diphenyl-1*H*-imidazole, 2-(4-methoxyphenyl)-4,5-diphenyl-1*H*-imidazole, and 2-(4-chlorophenyl)-4,5-diphenyl-1*H*-imidazole, which was carried out under solvent-free conditions in a multicomponent reaction, in order to achieve a method with low environmental impact.

2. Experimental

2.1. Preparation of polystyrene/silica spheres with core-shell structure

Monodisperse polystyrene (PS) spheres were synthesized employing the best conditions found in previous work [34]. They were prepared from 10 g of styrene (Aldrich, >99%) using 4,4′ azo-bis 4-cyanovaleric acid (ACVA) (Aldrich, >98%) as polymerization initiators, in the presence of 0.3 g of polyvinyl pyrrolidone (PVP) (Aldrich, PM = 29000) as surfactant agent.

To obtain the silica coating, PS templates in a quantity of 60% w/w with respect to the silica quantity to be prepared were weighed and placed in 40 cm^3 of ethanol, and then were sonicated for 10 min, in order to obtain a homogeneous dispersion. The modified Stöber method [35] was used for silica synthesis, which proceeds via hydrolysis/condensation of tetraethylorthosilicate (TEOS) in an alcohol/ammonium hydroxide reaction medium. Seven cm^3 of TEOS as silica precursor and 1 cm^3 of ammonium hydroxide (28% w/w) as catalyst of the sol-gel reaction were employed. The condensation reaction was performed at 50 °C with constant stirring for 20 h.

After this time, the coated spheres were separated by centrifugation and repeatedly washed with distilled water to remove the catalyst remains. Finally, they were dried at room temperature and then placed in a stove at 60 °C for 24 h, thus obtaining the solids that will be named PS@Si.

2.2. Preparation of hollow silica spheres

Part of the core-shell spheres reported in the previous section were calcined at 500 °C using a heating rate of 50 °C every 25 min in order to obtain the hollow silica spheres; the sample will be named @SiT500.

2.3. Impregnation of core-shell spheres and hollow silica spheres with tungstophosphoric acid

By employing the incipient wetness impregnation technique and using a solution of tungstophosphoric acid ($H_3PW_{12}O_{40}{\cdot}23H_2O$) (TPA) in ethanol-water (1:1 (v/v)), the following materials were impregnated: polystyrene spheres coated with silica (PS@Si) and hollow silica spheres (@SiT500). The quantity of TPA solution was fixed in order to obtain 30% and 60% of TPA (w/w) in the final material. The system was kept at room temperature till entire dryness. Afterward, the obtained solids (PS@SiTPA30, PS@SiTPA60, @SiT500TPA30 and @SiT500TPA60) were weighed. Then, the solids with core-shell structure were calcined at 200 °C to obtain the materials PS@SiTPA30T200 and PS@SiTPA60T200.

2.4. Characterization of supports and catalysts

The morphological study of the solids was performed by means of scanning electron microscopy (SEM), using Philips equipment, model 505, at a working potential of 15 kV. The samples were supported on graphite and metallized with a sputtered gold film before the measurement.

The Fourier transform infrared (FT-IR) spectra of the solids were recorded with Bruker IFS 66 equipment. Pellets of ca. 1% (w/w) of the sample in KBr were prepared in a self-made device. A wavenumber range of 400–4000 cm^{-1} was studied, the resolution being 2 cm^{-1}.

The specific surface area, the pore volume and the mean pore diameter of the solids were determined from the N_2 adsorption-desorption isotherms at liquid-nitrogen temperature, obtained by employing Micromeritics Accusorb 2100E equipment. The solids were previously degassed at 100 °C for 2 h.

Potentiometric titration was used to evaluate the acidic characteristics of the solids. To this end, 50 mg of solid suspended in 45 cm^3 of acetonitrile was stirred for 3 h. Then, the titration was carried out with a solution of *n*-butylamine in acetonitrile (0.05 N) at a flow rate of 0.05 cm^3/min. The electrode potential variation was measured in a Hanna 211 digital pH meter with a double-junction electrode.

The X-ray diffraction (XRD) patterns were obtained by the Debye-Scherrer method (powder method). The patterns were