



SUPRAMOLECULAR THERANOSTIC PLATFORMS GOES GREEN

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ABSTRACT

World Health Organization projected the number of deaths due to cancer alone to be ~13.1 million by 2030. To a certain extent conventional chemotherapy has been successful, but poor bioavailability, high-dose requirements, adverse side effects, low therapeutic indices, development of multiple drug resistance, and non-specific targeting have been severe limitations to its success. These limitations can be overcome via “theranostics” as it is precision medicine providing simultaneous diagnosis, targeted treatment and monitoring. Here the major actor is the drug –the therapeutic compound. It is importance to develop new green chemistries and technologies to produce supramolecular nanomedicines by employing appropriate inorganic and organic structures as theranostic platforms. SrMoO₄:Eu³⁺- MCM-41-γ-Fe₂O₃ composite was synthesized and characterized via FT-IR and XRD techniques. XRD pattern of SrMoO₄:Eu³⁺- MCM-41-γ-Fe₂O₃ composite shows the presence of SrMoO₄ (PDF card No: 01-075-4312), γ-Fe₂O₃ (PDF card no: 00-013-0458) and amorphous SiO₂ structures. The drug loading was investigated via TG systems. The amount of Ibuprofen loaded in the drug loaded SrMoO₄:Eu³⁺-MCM-41-γ-Fe₂O₃ microstructures, which were calculated from the TG curves, was found to be 14%. The release behavior of ibuprofen from SrMoO₄:Eu³⁺- MCM-41-γ-Fe₂O₃-Ibu was investigated in the PBS solution at pH = 7.4 and at 37 °C for 66 h. In the first 8 h, Ibuprofen is released on the surface absorbed and clinging to weak interactions. After than, Slow release of ibuprofen attached to the pores was observed.

Keywords: Theranostics, mesoporous γ-Fe₂O₃, Drug release

1. INTRODUCTION

The urgent need for targeted, safe, and efficient treatment of diseases gave birth to the rise of a new approach combining diagnosis and therapeutics with focus on patient-centered care. This new approach –theranostics- is concerned with providing unique predictive, preventive and successful personalized treatment protocol where the right drug would be offered to the right locality in the body of a given patient [1]. For this purpose, systems, which can selectively be “switched on” in the diseased locality, need to be designed and developed. These systems capable of avoiding problems that may arise due to cytotoxic effects of the drug on healthy cells and tissues mostly created by noncovalent interactions are called supramolecular systems [2]. These systems relying on weak and reversible forces (i.e., hydrogen bonds, hydrophobic forces, van der Waals forces, and metal–ligand coordination) play a key role in understanding biological processes, self-assembling systems as well as for constructing complex molecular machinery [3]. Although much effort is devoted to exploiting supramolecular metal-based structures such as supramolecular coordination complexes in the biomedical field still much effort is needed for using them as effective and efficient theranostic tools. The robustness and modular composition of supramolecular metal-based structures allows these systems to be modified with different functionalities that would enable imaging in cells *via* different modalities besides active targeting and stimuli-responsiveness [4]. However, these systems should not load a toxic burden on the body and should also be eco-friendly for their preferable availability. Therefore, supramolecular theranostics has to go green. In this respect, in this study SrMoO₄: Eu-

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MCM-41- γ -Fe₂O₃ composite were synthesized. The composite was characterized via FT-IR and XRD techniques and their thermal properties were determined via DTA-TG. Drug releasing studies were carried out in PBS buffer solution.

2. EXPERIMENTAL

2.1. Materials and Methods

2.1.1. Synthesis of MCM-41

Typically, 0.6 g of n-cetyltrimethylammonium bromide (CTAB) was first dissolved in 400 mL of deionized water. Then 3.5 mL of 2 mol/L NaOH was added to the solution, followed by adjusting the solution temperature to 80 °C. Subsequently, 2.5 mL of TEOS was added dropwise to the above solution with vigorous stirring. The mixture was stirred for another 2 h to give rise to white precipitates. The obtained solid product was filtered, washed with deionized water and ethanol, and then dried in air. The dried sample was calcined at 550 °C for 1 h.

2.1.2. Synthesis of mesoporous γ -Fe₂O₃ (MCM-41- γ -Fe₂O₃)

Fe(NO₃)₃ was dissolved in ethanol and MCM-41 was added to solution and stirred in the sonic bath for 2 h. After the filtration, the powder was dried at 100 °C and fired at 600-650 °C for 3 h. The obtained MCM-41- γ -Fe₂O₃ was added to 10 M NaOH and heated to dissolve MCM-41 phase. The obtained mesoporous γ -Fe₂O₃ was washed and dried.

2.1.3. Preparation of SrMoO₄:Eu³⁺-MCM-41- γ -Fe₂O₃ microstructures

0.38 g of SrCO₃ and 0.066 g of Eu₂O₃ were dissolved with 3 mL of HNO₃ and the solution was heated to 1 mL to remove HNO₃ and 2 mL of water was added each time and reheated. Addition of water and heating continued until the pH reached 2-3. To the prepared mixture of Sr(NO₃)₂ and Eu(NO₃)₃, 0.5494 g of sodium molybdate dihydrate and 0.846 g of citric acid dissolved in a mixture of 20 mL of water-ethanol (15: 5) as chelating agent were added and the molar ratio of metal: citric acid was adjusted to 1:2. 0.2 g/mL Polyethyleneglycol (PEG, molecular weight: 300 g/mol) was added to this mixture as crosslinker. After stirring the solution for 1 h, the sol was obtained and stirring was continued by adding the previously prepared MCM-41- γ -Fe₂O₃ powders. The suspension was stirred for 3 hours and centrifuged to separate the liquid and solid phase. The resulting precipitate was dried at 100 °C for 1 h. Then, the nanostructures of SrMoO₄:Eu³⁺-MCM-41- γ -Fe₂O₃ were prepared by firing at 700 °C for 6-10 hours.

2.1.4. Drug Loading Studies

Drug loading studies were carried out with supercritical carbon dioxide (scCO₂). 1 g of SrMoO₄:Eu³⁺-MCM-41- γ -Fe₂O₃ and 0.8 g ibuprofen were dissolved in 10mL of ethanol and they were placed in the vessel and were reacted with scCO₂ at 200 bar, 40 °C for 90 minutes. Then the vessel was allowed to cool to room temperature and the gas was released from the reactor from the valve on the vessel. Thus, the drug loaded microstructures were obtained.

2.1.5. In vitro drug releasing studies

In vitro drug release study was carried out at 37 °C with Ibuprofen loaded SrMoO₄:Eu³⁺-MCM-41- γ -Fe₂O₃ microparticles in phosphate buffered saline (PBS) with molar composition Na⁺/K⁺/Ca²⁺/Mg²⁺/Cl⁻/HCO₃⁻ /HPO₄²⁻/SO₄²⁻ (pH = 7.4) at ratio of 142.0/5.0/2.5/1.5/147.8/4.2/1.0/0.5. 3.5 mL. For each 3.5 mL volume of aliquot removed from the medium 3.5 mL PBS was added. The release profile of drug from the microparticles was monitored via UV-Vis spectrophotometric analysis at 273 nm.

3. RESULTS AND DISCUSSION

3.1. Structural Characterization Studies

FT-IR studies

FT-IR spectra of the SrMoO₄:Eu³⁺-MCM-41- γ -Fe₂O₃ and SrMoO₄:Eu³⁺-MCM-41- γ -Fe₂O₃-Ibu were taken in the range of 400–4000 cm⁻¹. The absorption peak at 587 cm⁻¹ could be related to the vibration of γ Fe–O [5–8] and the other peaks at 454, 632, 795 and 892 cm⁻¹ are pure maghemite (γ -Fe₂O₃). The broad band observed in the FT-IR spectrum in the range of about 2600-3800 cm⁻¹ shows the asymmetric stretching vibrations of the H–O–H (3435 cm⁻¹) and Si–O–H (3700 cm⁻¹) groups. The band seen at 1632 cm⁻¹ corresponds to H–O–H bending vibration in adsorbed water molecules. The peaks observed at 1087 cm⁻¹ and 1228 cm⁻¹ belong to the stretching vibrations of siloxane (Si–O–Si) bridges. Bending vibration of Si–O groups is observed at 799 cm⁻¹. In the FT-IR spectrum of Ibuprofen the peaks observed at 2950-2520, 3060, 3470 and 1717 cm⁻¹ are attributed to the stretching vibrations of the aliphatic –C–H, aromatic C–H, O–H in the carboxylic acid, and the intense peak at 1717 cm⁻¹ is attributed to the stretching vibration of –C=O in the carbonyl. When the FT-IR spectra of the drug loaded and unloaded SrMoO₄:Eu³⁺-MCM-41- γ -Fe₂O₃ were compared it was seen that the peaks observed in the ibuprofen. 2957 cm⁻¹ and 1514-1465 cm⁻¹ ranges in drug loaded microstructures may be due to ibuprofen. The FT-IR results indicate that ibuprofen was successfully loaded in the microstructures.

XRD studies

Low angle XRD and XRD powder diffraction pattern of SrMoO₄:Eu³⁺-MCM-41- γ -Fe₂O₃ are presented in Figure 1 and 2. The reflections (1 0 0) and (1 1 0) observed at 2.5° in the low angle XRD powder pattern indicate the regular mesoporous MCM-41 structure. The reflections (1 1 2), (0 0 4), (2 0 0), (2 0 2), (2 2 0), (1 1 6) and (3 1 2) in the XRD powder pattern belong to SrMoO₄:Eu³⁺-MCM-41- γ -Fe₂O₃. The reflections of (1 0 6), (2 1 1 2), (4 2 8) and (4 4 1) also belong to γ -Fe₂O₃. The XRD powder pattern indicated that the composite contains γ -Fe₂O₃ (PDF card no: 00-013-0458). In the XRD pattern, the 15-25° broad peak belongs to the amorphous SiO₂ structure.

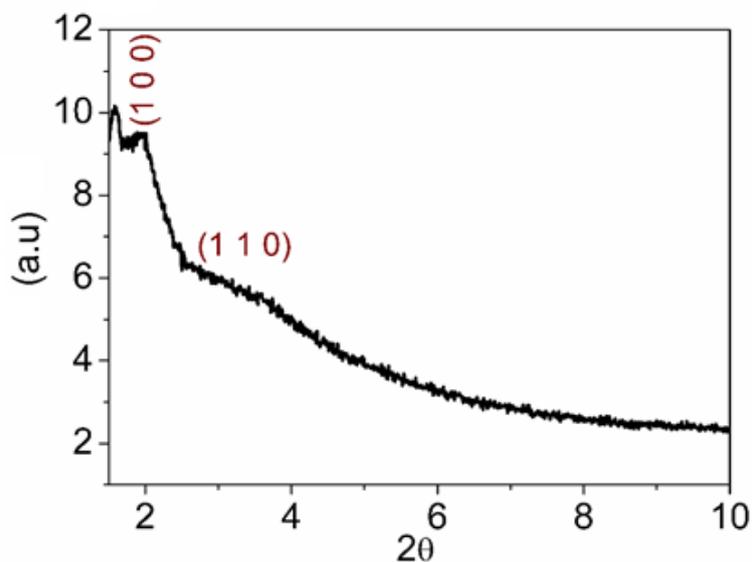


Figure 1. XRD Powder Pattern of MCM-41

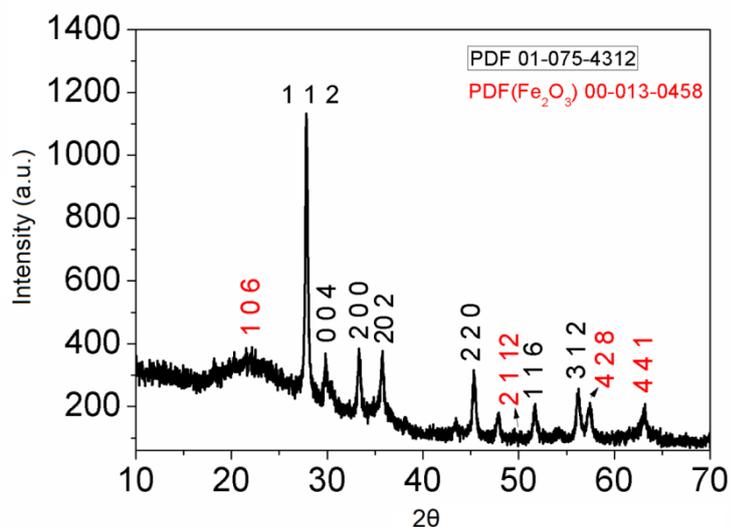


Figure 2. XRD Powder Pattern of SrMoO₄:Eu³⁺-MCM-41-γ-Fe₂O₃

Thermal Analysis of SrMoO₄:Eu³⁺-MCM-41-γ-Fe₂O₃

The amount of Ibuprofen loaded in the drug loaded SrMoO₄:Eu³⁺-MCM-41-γ-Fe₂O₃ microstructures, which were calculated from the TG curves, was found to be 14%. The TG curves of the microstructures are given in Figure 3.

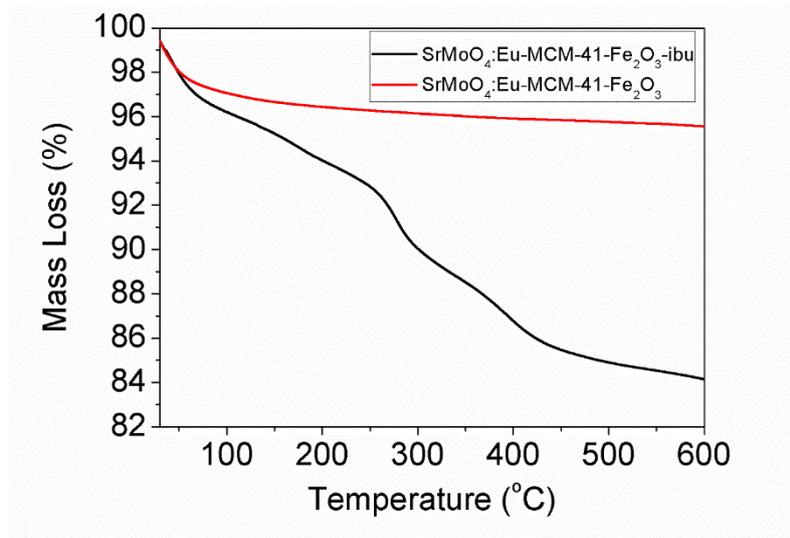


Figure 3. TG Curves of Ibuprofen loaded SrMoO₄:Eu³⁺-MCM-41-γ-Fe₂O₃ microstructure.

In vitro Ibuprofen Releasing Studies

Drug release profiles were determined from the plot of cumulative percentages of drug release against time. The release behavior of ibuprofen from SrMoO₄:Eu³⁺-MCM-41-γ-Fe₂O₃-Ibu was investigated in the PBS solution at pH = 7.4 and at 37 °C for 66 hours as shown in Figure 4. In the first 8 hours, Ibuprofen is released on the surface absorbed and clinging to weak interactions. After than, slow release of ibuprofen attached to the pores was observed. Ibuprofen interacts with hydrogen in the pores with silanol (Si-OH) groups. Wave swing is observed in the drug release profiles. This behavior is attributed to non-uniform distribution of drug molecules in the layered matrices well besided diffusibility, number and thickness of layers [9].

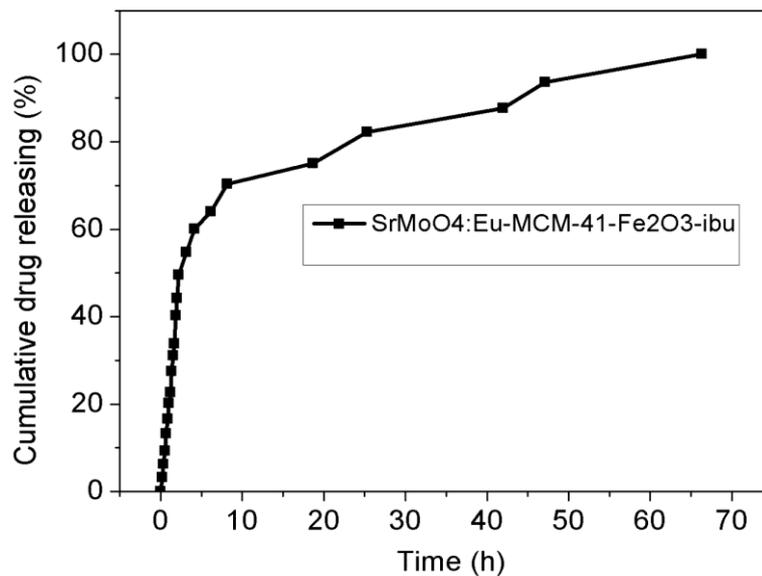


Figure 4. Cumulative drug release (%) curves

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