© creative

Scientific paper

Facile Synthesis of Poly(DMAEMA-co-MPS)-coated Porous Silica Nanocarriers as Dual-targeting Drug Delivery Platform: Experimental and Biological Investigations

Mohammad Hegazy,^{1,2,*} Pei Zhou,³ Guangyu Wu,⁴ Nadia Taloub,^{1,5} Muhammad Zayed,⁶ Xin Huang^{1,*} and Yudong Huang^{1,*}

¹ MIIT Key Laboratory of Critical Materials Technology for New Energy Conversion and Storage, Key Laboratory of Microsystems and Microstructures Manufacturing, School of Chemistry and Chemical Engineering,

Harbin Institute of Technology, Harbin 150001, China

⁴ College of Biology and the Environment, Co-Innovation Center for the Sustainable Forestry in Southern China, Nanjing Forestry University, Nanjing, Jiangsu 210037, China

⁵ LIPE Laboratory, University of Constantine 3, 25000 Constantine, Algeria

⁶ Botany and Microbiology Department, Menoufia University, Shebin El-Kom, 32511, Egypt

* Corresponding author: E-mail: dr_hegazy2000@yahoo.com; xinhuang@hit.edu.cn; huangyd@hit.edu.cn

Received: 07-12-2019

Abstract

Inorganic structures with functionalized polymers play essential roles in diverse biological trends. Herein, thermal and CO_2 dual-stimuli nanomaterials composed of mesoporous silica nanoparticles (MSN) anchored with two grafted copolymers: poly(3-methacryloxypropyltrimethoxysilane) "PMPS" & poly(N,N-dimethylaminoethyl methacrylate) "PDMAE-MA" were synthesized via one-step reaction and characterized by BET as well as BJH methods to estimate pore sizes, pore volumes, and surface areas. The smart PDMAEMA acted as an active gatekeeper to adjust the loading or *in vitro* release processes of a fungicidal drug-loaded inside the mesopores by altering temperature or CO_2 of the tested environment. Furthermore, treating the nanomaterials by CO_2 for a few minutes was found to have a bactericidal effect with promising results as indicated by the disk diffusion technique. In general, the positive biological activity against selected strains of bacteria and fungi indicates that these particles may be helpful for engineering more efficient antifungal or antibacterial agents for pharmaceutical applications.

Keywords: CO₂-responsive release, thermal-triggered release, biopolymeric materials, antimicrobial agents

1. Introduction

Over the past two decades, smart polymeric materials have been exploited for versatile applications e.g. ion absorbance capacity, wastewater treatment, cargo delivery systems, photodynamic or photothermal effects, and enhancing the mechanical properties as well as the interfacial performance of specific fibers. A famous ex-

ample is MSN which have been used widely as drug carriers in biomedical technologies, thanks to several merits e.g. biocompatibility, easiness of surface-modification, and controllable mesopore sizes.⁷ PDMAEMA was applied as a CO₂ responsive polymer in aqueous solutions as a result of protonation of the tertiary amine group which can also deprotonate reversibly by N₂ stimulation, i.e. swelling-shrinking effect.⁸ Furthermore, this smart

² Department of Polymer Chemistry, Faculty of Science, Menoufia University, Shebin El-Kom 32511, Egypt

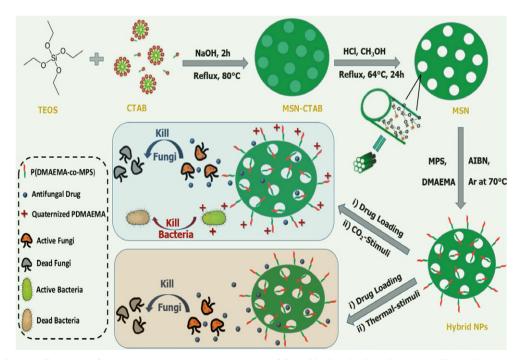
³ School of Environmental and Municipal Engineering, North China University of Water Resources and Electric Power, Zhengzhou 450011, China

polymer showed pretty good thermo-responsiveness, as it can form coil-to-globule states by changing temperatures degrees and showed a lower critical solution temperature (LCST) in aqueous solutions, which is a similar character to the well-known thermosensitive poly(N-iso-propylacrylamide) (PNIPAAm). More interestingly, quaternization of terminal amino groups of PDMAEMA had promising antimicrobial activity against some bacterial strains. 12

Because of the possible applications in various promising areas including material science and life science, this study aims to synthesize and characterize pharmaceutical nanocontainers with dual-sensitive character to release the loaded cargos with a response to CO₂ or temperature or both together, followed by biological evaluation against microbial strains as illustrated in Scheme 1. We exploited the alkoxysilane moiety of silicon derivative monomer 3-methacryloxypropyltrimethoxysilane (MPS) to link it (through a condensation reaction) with silanols surface of MSN from one side. In contrast, the other side (active double bond) was polymerized simultaneously with N,N-dimethylaminoethyl methacrylate (DMAEMA) monomer via thermal polymerization using AIBN as azo initiator.^{13,14} The growing PDMAEMA onto the MSN surface was used as a cap to maintain or trigger anidulafungin, which utilized as a model antifungal drug. The release behavior of the cargo was investigated by the two mentioned responses and tested against some microorganisms to evaluate the biological activity. The advantages of this construction are not only for the simple synthesis via a onestep experiment, but also lie for obtaining high drug loading capacity, effective response for thermo- or CO₂-stimuli and the potential application as antifungal or antibacterial agents, especially after converting PDMAEMA into its cationic form.

2. Materials and Characterization Techniques

The chemicals and reagents were purchased with analytical grade via Sigma-Aldrich. The specific surface areas and mesoporous structures were obtained through N₂ adsorption-desorption isotherms. The cloud point for a given polymeric material solution was chosen as the corresponding inflection point of "the transmittance versus temperature curve". The LCST results of the aqueous material solutions were determined at a 50% decrease of the optical transmittance, through measuring the wavelength at 500 nm using a UV-visible spectrophotometer (Shimadzu UV-1700). The temperature degrees of the sample cells were controlled thermostatically by using an exterior constant temperature bath. Zeta potential analysis for polymeric material solutions (pH 6.8, 5.0 mM buffer PBS, 0.2 mg/mL material sample) was tested by using a ZETASIZER (Malvern Instruments, Britain) at 25 °C. Both loading and releasing contents of anidulafungin drug were studied by UV-Vis spectrophotometry at λmax of 303 nm. Random isolates from Escherichia coli (E.coli, gram-negative bacteria) as well as Candida albicans (C. albicans, fungi) were obtained from the College of Life Science, Northeast Forestry University, Harbin, China.



Scheme 1. Schematic illustration of MSN/P(MPS-co-DMAEMA) generation followed by drug loading, then CO_2 and hyperthermia-induced release through the dual-functional biomedical platform.

The culture medium was nutrient agar (NA) which prepared by adding agar (20 gm), beef extract (3 gm), peptone (5 gm) and sodium chloride (5 gm) then completed to one liter of deionized water.

3. Methods

MSN/P(MPS-co-DMAEMA) nanocarriers were prepared by established polymerization method, ¹⁵ and then loaded with anidulafungin drug after several purifications according to Rahoui et al. ¹⁶ The loading content of the drug was estimated from UV-Vis spectra via Eq. (1).

(MPS-co-DMAEMA) nanocarriers were represented in Fig. 1.

Both MSN and MSN/P(MPS-co-DMAEMA) nano-carriers were synthesized according to Scheme 1, then characterized by N₂ sorption isotherms (Fig. 2), using BET and BJH methods. For both materials, the isotherms were of type IV, which suggesting the mesoporous nature¹⁹ as indicated in Fig. 2A. The high surface area of 705 m² g⁻¹ for MSN had decreased considerably to 257 m² g⁻¹ after coating with the copolymer layer to obtain MSN/P(MPS- co-DMAEMA) (see Table 1), which matching well with similar studies.^{20,21} Similarly and from pore size distribution curves (Fig. 2B) and the same Table, there was a decrease in the pore

Loading content (%) =
$$\frac{\text{the initial amount of drug} - \text{the supernatant free amount of drug}}{\text{the weight of loaded drug nanocarriers}} \times 100$$
 (1)

On contrast, *in vitro* drug release experiments were tested in physiological saline solution (PSS) and estimated according to Eq. (2) at different periods (from 1h to 24h). The release behavior in PSS (100 mM) using dialysis membrane (molecular weight cut-off: 8000–14000 Da) were calculated by detecting the corresponding absorbance peak of anidulafungin at 303 nm using different environments including; (i) temperature lower and higher LCST of PDMAEMA (i.e. 25 °C & 45 °C) and (ii) bubbling with $\rm CO_2$ for 10 min at the two mentioned temperatures.

volume (from 0.66 to 0.51 mL/g) along with the mean pore diameter (from 8.82 to 6.53 nm), when going from MSN to MSN/P(MPS-co-DMAEMA). The maintained large pore volumeandhighsurfaceareafor MSN/P(MPS-co-DMAEMA nanocarriers, refers to that their mesopores have not been blocked after anchoring both PMPS & PDMAEMA on the silica surface, and consequently have the opportunity to carry the drug in the next step.

The pH-dependent electro-kinetic characterizations were used to demonstrate the effect of pH changes on the

Releasing content (%) =
$$\frac{\text{the amount of drug in the release medium}}{\text{the amount of loaded drug into nanocarriers}} \times 100$$
 (2)

The antimicrobial activity for the nanocarriers containing anidulafungin (NCA) was tested (after the releasing process with the two stimuli) using the well diffusion technique. The inoculum density in the chosen NA plate was 10⁸ CFU · ml⁻¹, which related to the 0.5 McFarland turbidity scale.¹⁷ The seeded plates were dried in the incubator at 36 °C for 25 min. A borer of cork with 7 ml diameter was applied to cut uniform wells onto the inoculated agar surface, then around 100 µl of every sample (20 mg/ml) was added to the well. Free anidulafungin and tetracycline were used (with the same concentration as NCA) as the positive control for antifungal and antibacterial activities, respectively. Deionized water and filter paper were used as the negative control (around 100 µl of the solvent). The plates were accordingly incubated for one day at the normal body temperature (37) °C). By the end of incubation time, the biological activity was tested through inhibition zones in millimeters.¹⁸

4. Results and Discussion

The corresponding chemical structures of MPS monomer, DMAEMA monomer, MSN and MSN/P

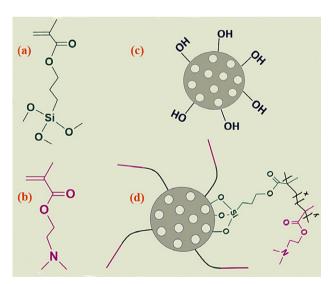


Fig. 1. Chemical structures of (a) MPS monomer, (b) DMAEMA monomer, (c) MSN and (d) MSN/P(MPS-co-DMAEMA) nanocarriers.

obtained nanocarrier solutions, and to strengthen the understanding of the process and its usefulness. As shown in

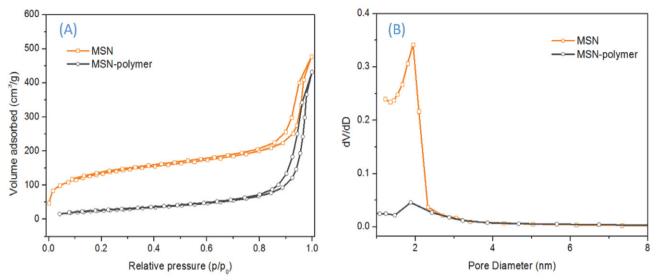


Fig. 2. (A) N₂ adsorption-desorption isotherms and (B) pore size distribution curves for MSN and MSN/P(MPS-co-DMAEMA).

Table 1. Structure parameters of MSN and MSN/P(MPS-co -DMAEMA) derived from nitrogen sorption.

Samples	BET surface area (m ² /g)	Pore volume (mL/g)	Mean pore diameter (nm)
MSN	705	0.66	8.82
MSN/P(MPS-co-DMAEMA)	257	0.51	6.53

Fig. 3, the apparent zeta-potential (ζ) decreases notably with the pH increasing, which perhaps due to protonation of tertiary-amine groups (involved within PDMAEMA backbones) by acidic media, therefore, ζ has high positive values with low pH values and vice versa. The critical pH for PDMAEMA chains needed to plug the pores of the prepared nanocarriers was measured to be pH 7.2 which is lower than 7.4 value (human blood medium). Thus, one can conclude that in case this system is used as a smart drug delivery nanocarrier, the release of any encapsulat-

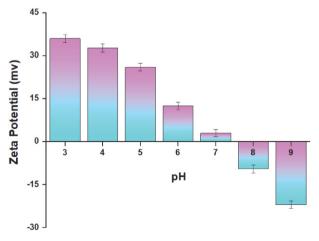


Fig. 3. Apparent zeta-potential (ζ) measurements for MSN/P(MPS-co-DMAEMA) nanocarriers determined from pH-dependent experiments.

ed-drug from MSN/P(MPS-co-DMAEMA) can only be noticed after reaching the desired pathological organs, where the pH values are slightly acidic (e.g. treatment of CO₂ gas in our study here).

It is widely known that thermo-sensitive polymers/copolymers can display phase separation by increasing their temperature degrees above the lower critical solution temperature (LCST). Since PDMAEMA is a typical weak polyelectrolyte and its pKa value is 7.0-7.5 (with exhibiting an LCST of 40-50 °C in the aqueous solutions²²), we tested LCST of the obtained MSN/P(MPS-co-DMAEMA) nanocarriers in a pH-controlled environment because the LCST is pH-dependent and the solubility of CO₂ is temperature-dependent.

It is expected that MSN/P(MPS-co-DMAEMA) nanomaterials are pH-responsive as similar to PDMAE-MA due to the presence of terminal dimethylamino groups. The pH-sensitive properties of these polymeric materials are shown in Fig. 4. One can notice the transmittance character (for aqueous solutions of such materials) against temperature degrees at different pH values, whereas the LCST is indicated at a pH range beginning from 3.35 to 10.92. It is clear that the aqueous solutions of MSN/P(MPS-co-DMAEMA) are soluble in low pH environments, such as 3.35 & 6.42, and no LCST is obtained within a temperature range of 20–60 °C for theses environments. This perhaps is due to the occurrence of stable polymeric nanomaterials that formed at low pH and yielding protonated PDMAEMA side chains in the

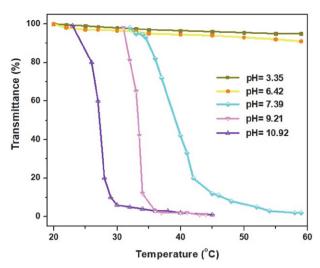


Fig. 4. Transmittance for aqueous solutions of MSN/P(MPS-co-DMAEMA) as a function of temperature degrees at various pH values

outer shell of the nanomaterials, leading to an increase in the electrostatic repulsion force and consequently preventing the phase separation.²³ By contrast, the LCST of MSN/P(MPS-co- DMAEMA) is noticed at pH 7.39. Moreover, the cloud temperature of the polymeric nanomaterials decreases gradually by raising the pH from 7.39 to 10.92, which is similar to the situation of LCST for PDMAEMA homopolymer that discussed by Plamper et al.²⁴

For drug encapsulation studies, anidulafungin was chosen as a model antifungal agent, especially for the treatment of candidemia caused by Candida albicans yeast. The loading content (%) was calculated by UV-Vis spectrophotometry at λ max of 303 nm according to Eq. (1) and it was 17.9 \pm 0.7%, which is still higher than most surface-modified MSN previous studies (lower than 10%). This could be attributed to the hydrogen bonds and strong electrostatic interactions between the drug and nanocarriers.

The triggered release of anidulafungin from NCA was tested by the dialysis method in PSS, according to Eq. (2) under the following environments: (i) 25 °C, (ii) 45 °C, (iii) 25 °C & bubbling with CO₂ for 10 min and (iv) 45 °C & bubbling with CO₂ for 10 min. The results demonstrated that the extended copolymer could perform as a smart gatekeeper for this system according to CO₂ or temperature changes. For the gas-response, the extended PDMAEMA is hydrophobic at neutral or alkaline pH values with collapsed uncharged chains, while it can convert into the weak cationic character in acidic medium with water-soluble, protonated and extended chains (i.e. after treated with CO₂ gas).²⁵ On the other hand, the releasing of anidulafungin at hyperthermia state could be related to thermo-responsive features of the PDMAEMA segments. When the temperature increased (above LCST), the extended PDMAEMA units would shrink to the globular structure due to the weakening or breaking of hydrogen bonds, which resulting in collapsed PDMAEMA chains.²⁶

The release process of the chosen antifungal drug at the four mentioned conditions was indicated in Fig. 5. About 13% of conjugated anidulafungin was only released from the NCA after incubation for 36 hours at room temperature, indicating that many anidulafungin molecules were still covalently incorporated inside the nanocarriers without significant release. Therefore, the release level of anidulafungin is low, which further indicates the stability of this polymeric material at room temperature. Also, there is a hydrophobic interaction between anidulafungin and PMPS chains and at the same time the anidulafungin has interactions with PDMAEMA layers in aqueous media (thanks to its unique chemical constitution).

On the other hand, the released amount of the encapsulated payload reached 25 % after bubbling with CO_2 for 10 min at room temperature and during the same number of hours, indicating that, such carbon dioxide treatment for these polymeric materials can induce the programmed release in a successful way.

Subsequently, at 45 °C (which is above the LCST), the release process increased dramatically to 35 % within only 10 h and reached 63% after 36 h. This substantial increase could be due to the copolymer layer underwent a coil-to globule change and shrank into a compact mass, which allowing pores opening and showing the significant release of the loaded drug. This situation illustrates a good agreement with most known thermoresponsive polymeric-nanomaterials which can keep their cargos at room temperature, and then deliver them within the locally heated diseased sites (~40–42 °C).

Moreover, the release behavior of the drug at 45 °C after bubbling with $\rm CO_2$ for 10 min was noticed to yield around 21% after 10 h & 42 % after 36 h, which was lower than the corresponding release at 45 °C alone without $\rm CO_2$ bubbling. However, the release condition of 45 °C with

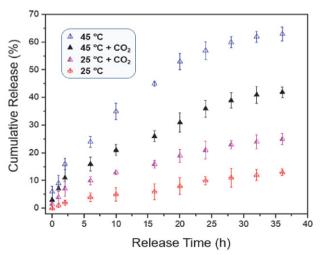


Fig. 5. Controlled release of anidulafungin from NCA at four different conditions.

 CO_2 was still higher than the other previous two conditions (25 °C without CO_2 & 25 °C with CO_2). This could be attributed to the increase of thermo-motions at elevated temperature enhanced the diffusion of anidula fungin from the expanded nanoparticles.

After the releasing processes via dual stimuli from NCA, we evaluated the biological activity through antimicrobial screening using two organisms (E.coli, & C. albicans) according to Table 2. Free anidulafungin and tetracycline were used as the positive control for the antifungal and antibacterial properties, respectively. The results showed that NCA did not express the essential antimicrobial impact on these microorganisms except an exceedingly weak impact on C. albicans, which perhaps due to the minimal leakage of anidulafungin from NCA at room temperature (entry 1 in Table 2). Bubbling with CO₂ for 10 min at this room temperature (single CO₂) stimulus, entry 2 in Table 2), showed a moderate antifungal effect against C. albicans, but a very strong one against E. coli, which could be attributed to formation of ionene polymers (cationic polymers include positive nitrogen or phosphor in their backbones) after reacting with CO₂ gas. This result is in a good agreement with recent studies, which proved that the cationic PDMAEMA+ has a strong bactericidal effect against E. coli and some other bacterial strains, 12,27

On the other hand, upon heating to 45 °C (temperature stimulus alone), no antibacterial impact occurred, but a very strong antifungal effect was obtained. This effect reflects that the temperature stimulus cannot convert PDMAEMA into its quaternary ammonium salt PD-MAEMA+ (which is the key point for bacteria-killing), however, this stimulus can release the loaded anidulafungin extremely which inhibited the growth of the yeast considerably (entry 3 in Table 2). Bubbling with CO₂ gas at this elevated temperature reduced the loaded cargo a little bit to a strong inhibition growth of C. albicans and further this effect converted PDMAEMA to PDMAE-MA⁺ with strong inhibition too for *E. coli* growth (entry 4 in Table 2). It is clear that the most important steps for antifungal and antibacterial effects were for pure temperature stimulus and pure CO₂ stimulus, respectively. Using both stimuli together is also effective against the two microbes, but it is not powerful like using the individual stimulus alone.

Table 2. The cytotoxicity effect of each stimulus on two selected microbial strains *E. coli* and *C. albicans* which symbolized by +: weak, ++: medium, +++: strong and ++++: very strong.

	Antimicrobial activity on		
Stimuli Type	E. coli (Bacteria)	C. albicans (Yeast)	
25 °C	NA	+	
25 °C + CO ₂	++++	++	
45 °C	NA	++++	
45 °C + CO ₂	+++	+++	

5. Conclusions

In this article, a temperature- and CO₂-sensitive delivery system composed of grafted copolymer capped MSN was explained. A poly(DMAEMA)-co-poly(MPS) shell on MSN was constructed via a facile one-step reaction (condensation & polymerization) and characterized successfully. The grafted copolymer showed both temperature- and CO₂-sensitive release properties for the antifungal anidulafungin drug, which then confirmed by killing *C. albicans* yeast, with low to moderate results (high in some cases). Most importantly, the PDMAEMA coating can kill *E. coli* bacteria effectively upon converting to its cationic form through CO₂ responses. This novel strategy of designing dual-responses via particles-coating followed by evaluating the biological activity can inspire the engineering of advanced bionanomaterials.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (No. 21871069) and Open Project of Key Laboratory of Microsystems and Microstructures Manufacturing (2016KM003).

Notes

The authors declare no competing financial interest.

6. References

- P. Zhou, L. Wang, G. Wu, Y. Zhou, M. Hegazy, X. Huang, ChemistrySelect 2017, 2, 6249–6253. DOI:10.1002/slct.201701339
- G. Wu, X. Liu, P. Zhou, L. Wang, M. Hegazy, X. Huang, Y. Huang, Mater. Sci. Eng. C 2018, 94, 524–533.

DOI:10.1016/j.msec.2018.09.061

- 3. N. Rahoui, M. Hegazy, B. Jiang, N. Taloub, Y. D. Huang, *Am. J. Anal. Chem.* **2018**, *9*, 273–285. **DOI**:10.4236/ajac.2018.95021
- N. Rahoui, P. Zhou, N. Taloub, M. Hegazy, Y. D. Huang, IOP Conf. Ser.: Mater. Sci. Eng. 2018, 389, 012009.

DOI:10.1088/1757-899X/389/1/012009

N. Taloub, L. Liu, N. Rahoui, M. Hegazy, Y. Huang, *Polym. Test.* 2019, 75, 344–349.

DOI:10.1016/j.polymertesting.2019.02.016

6. N. Taloub, A. Henniche, L. Liu, J. Li, N. Rahoui, M. Hegazy, Y. Huang, *Comp. Part B: Eng.* **2019**, *163*, 260–271.

DOI:10.1016/j.compositesb.2018.11.007

- M. Hegazy, P. Zhou, G. Wu, L. Wang, N. Rahoui, N. Taloub, X. Huang, Y. Huang, *Polym. Chem.* 2017, 8, 5852–5864. DOI:10.1039/C7PY01179B
- 8. W. Fan, X. Tong, F. Farnia, B. Yu, Y. Zhao, *Chem. Mater.* **2017**, *29*, 5693–5701. **DOI:**10.1021/acs.chemmater.7b01656
- X. Tang, X. Liang, L. Gao, X. Fan, Q. Zhou, J. Polym. Sci. Part A: Polym. Chem. 2010, 48, 2564–2570.
 DOI:10.1002/pola.24034

- P. Zhou, S. Wu, X. Liu, M. Hegazy, G. Wu, X. Huang, ACS Appl. Mater. Interfaces 2018, 10, 38565–38573.
 DOI:10.1021/acsami.8b11216
- G. Wu, X. Liu, P. Zhou, Z. Xu, M. Hegazy, X. Huang, Y. Huang, *Mater. Sci. Eng. C* 2019, 99, 1153–1163.
 DOI:10.1016/j.msec.2019.02.069
- 12. Y. Xue, H. Xiao, Y. Zhang, *Int. J. Mol. Sci.* **2015**, *16*, 3626–3655. **DOI:**10.3390/ijms16023626
- 13. S. El-Hamouly, M. Azab, M. Hegazy et al., Asian J. Chem. 2012, 24, 176-180.
- P. Zhou, S. Wu, M. Hegazy, H. Li, X. Xu, H. Lu, Xin Huang, *Mater. Sci. Eng. C* 2019, 104, 109914.
 DOI:10.1016/j.msec.2019.109914
- M. Hegazy, N. Rahoui, A. A. Elyazed, D. E. Fouad, Xin Huang, Yudong Huang, *Polym. Korea* 2019, 43, 387–393.
 DOI:10.7317/pk.2019.43.3.387
- 16. N. Rahoui, B. Jiang, N. Taloub, M. Hegazy, Y. D. Huang, J. Biomater. Sci., Polym. Ed. **2018**, 29, 1482–1497.
 - **DOI:**10.1080/09205063.2018.1466470
- N. Longkumer, K. Richa, R. Karmaker, V. Kuotsu, A. Supong,
 L. Jamir, P. Bharali, U. B. Sinha, *Acta Chim. Slov.* **2019**, *66*,
 276–283. **DOI**:10.17344/acsi.2018.4580
- M. Hegazy, S. El-Hamouly, M. Azab, S. Beshir, M. Zayed, *Polym. Sci. Ser. B* 2014, 56, 182–190.
 - **DOI:**10.1134/S1560090414020067

- A. Vasile, M. Ignat, M. F. Zaltariov, L. Sacarescu, I. Stoleriu, D. Draganescu, M. Dumitras, Lacramioara Ochiuz, *Acta Chim. Slov.* 2018, 65, 97–107. DOI:10.17344/acsi.2017.3641
- N. Rahoui, B. Jiang, M. Hegazy, N. Taloub, Y. Wang, M. Yu,
 Y. D. Huang, *Colloids Surf. B: Biointerf.* 2018, 171, 176–185.
 DOI:10.1016/j.colsurfb.2018.07.015
- M. Hegazy, P. Zhou, N. Rahoui, G. Wu, N. Taloub, Y. Lin,
 X. Huang, Y. Huang, *Colloids Surf. A: Physicochem. Eng. Asp.* 2019, 581, 123797. DOI:10.1016/j.colsurfa.2019.123797
- Z. Dong, J. Mao, D. Wang, M. Yang, X. Ji, *Langmuir* 2015, 31, 8930–8939. DOI:10.1021/acs.langmuir.5b02159
- L. Ma, R. Liu, J. Tan, D. Wang, X. Jin, H. Kang, M. Wu, Y. Huang, *Langmuir* 2010, 26(11), 8697–8703.
 DOI:10.1021/la904431z
- F. A. Plamper, M. Ruppel, A. Schmalz, O. Borisov, M. Ballauff,
 A. H. E. Muller, *Macromolecules* 2007, 40, 8361.
 DOI:10.1021/ma071203b
- H. Che, M. Huo, L. Peng, Q. Ye, J. Guo, K. Wang, Y. Wei, J. Yuan, *Polym. Chem.* 2015, 6, 2319–2326.
 DOI:10.1039/C4PY01800A
- H. Zou, W. Yuan, Polym. Chem. 2015, 6, 2457–2465.
 DOI:10.1039/C5PY00024F
- B. Wang, Q. Xu, Z. Ye, H. Liu, Q. Lin, K. Nan, Y. Li, Y. Wang,
 L. Qi, H. Chen, ACS Appl. Mater. Interfaces 2016, 8, 27207–27217. DOI:10.1021/acsami.6b08893

Povzetek

Anorganske strukture funkcionalizirane s polimeri imajo pomembno vlogo na različnih bioloških področjih. V tej raziskavi smo z enostopenjsko reakcijo sintetizirali dvojno odziven nanomaterial, pripravljen iz mezoporozne silike na katero smo graftirali dva okoljsko-odzivna polimera: poli (3-metakriloksipropiltrimetoksilan) "PMPS" in poli(N,N-dimetilaminoetil metakrilat) "PDMAEMA". Pripravljen material smo karakterizirali z BET in BJH tehnikami, da smo določili velikost por, volumen por in specifično površino. PDMAEMA je deloval kot aktivno stikalo, ki je določalo nalaganje oziroma in-vitro sproščanje protiglivičnega zdravila adsorbiranega v mezoporah materiala, glede na spremembe v temperature oziroma $\rm CO_2$ koncentracije okolice. Če smo sintetiziran material izpostavili $\rm CO_2$ atmosferi za nekaj minut, se je s tehniko difuzije na disku pokazal obetajoč bakteriocidni učinek. V splošnem smo pokazali pozitiven učinek proti nekaterim bakterijskim sevom in glivam kar nakazuje možnost, da bi lahko sintetizirani delci pripomogli k načrtovanju bolj učinkovitih protiglivičnih in protibakterijskih učinkovin za farmacevtske aplikacije.



Except when otherwise noted, articles in this journal are published under the terms and conditions of the Creative Commons Attribution 4.0 International License