# Electronic Supporting Information (ESI)

Surfactin functionalized poly(methyl methacrylate) as eco-friendly nano-adsorbent: from size controlled scalable fabrication to adsorptive removal of inorganic and organic pollutants

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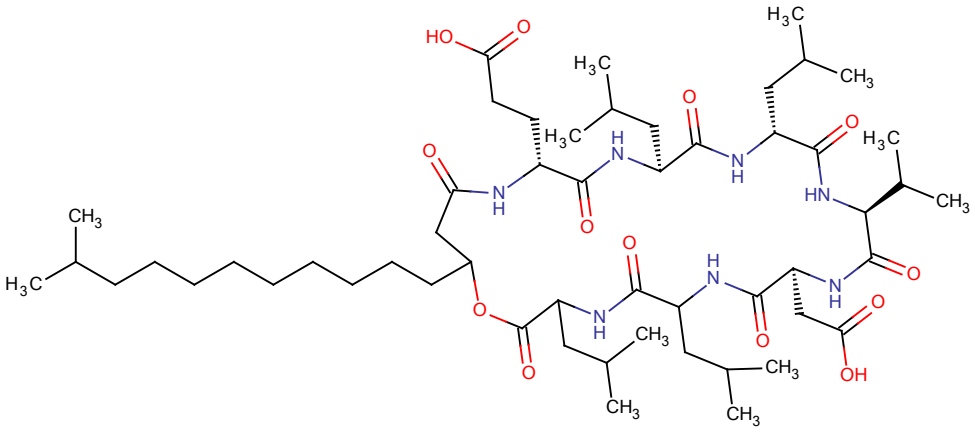


1

2 **Fig. S1.** Overall chemical structure of surfactin lipopeptide.

3

**Determination of monomer conversion, solid content, molecular weights and polydispersity index (PDI)**

The percentage of monomer conversion to polymer and latex yield was determined by gravimetric analysis. A small sample (5-10 ml) was taken and placed quickly into a capped vial containing several drops of hydroquinone inhibitor solution to stop the polymerization. The sample was then poured into a pre-weighed watch glass and weighed. It was then dried in an oven at 120 $^{o}$C until constant weight. A final measurement of the watch glass + dry polymer sample was then made. For each set of operating conditions, experiments were repeated and the repeatability of measurements was within ±10%, as indicated by error bars on the graphical plots.

The total number of latex particles in the system ($N_P$) and the number of polymer chains per particle ($N$) as well as the conversion ($X_m$) are calculated according to the following equations:

$$N_P = \frac{6\rho_0 V X_m}{\rho \pi D^3} \quad (1)$$

$$N = \frac{4}{3}\frac{\rho\pi(D/2)^3 N_A}{\overline{M}_n} \quad (2)$$

$$X_m\,(\%) = \frac{W_1}{W_2} \times 100 \quad (3)$$

where $\rho_0$ is the density of MMA (0.94 g cm$^{-3}$ at 25 °C), $V$ is the total volume of MMA, $X_m$ is polymerization conversion, $\rho$ is the density of PMMA (g cm$^{-3}$ at 25 °C), D is the diameter of the particle, $N_A$ is 6.02×10$^{23}$ mol$^{-1}$, $M_n$ is the number-average molecular weight, and $W_1$ and $W_2$ are the weights of the polymer and MMA, respectively.

**Energy calculations**

*1. Energy delivered during conventional mechanically stirred emulsion polymerization method*

Voltage input in magnetic stirrer = 230 V.

Current measured using digital multimeter (Model 801, Meco Instruments Pvt. Ltd., India) = 37 mA = $37 \times 10^{-3}$ A.

Power input in overhead stirrer = voltage input × current measured = 230 (V) × $37 \times 10^{-3}$ (A) = 8.51 W (J/s).

Time required for completion of reaction = 1 h (3600 s).

Net energy delivered during conventional method = power input in magnetic stirrer × time required for completion of reaction = 8.51 J/s × 3600 s = 30636 J = 30.636 kJ.

Energy supplied in form of heat to maintain reaction temperature 55 $^{o}$C = $mC_{p,\,mix}$ ($T_{process}$ - $T_{ref}$) = 130.38 × 4.0058 × (55 - 25) = 15668.3 J = 15.67 kJ.

Total energy supplied during conventional method = 30.636 + 15.67 = 46.31 kJ.

Quantity of material processed = quantity of [water + KPS + surfactin + MMA] = 100 ml + 0.25 g + 0.025 g + 5 g = 105.28 g.

Net energy supplied for processing of material using conventional method = net energy delivered during conventional method/quantity of material processed = 46.31 (kJ) / 105.28 (g) = $43.98 \times 10^{-2}$ (kJ/g). (A)

*2. Energy delivered during sonochemical polymerization*

Energy delivered during sonication = energy required to synthesize nPMMA.

Electrical energy delivered during sonication (indicated by the power meter) = 53.5 kJ.

Efficiency of horn taken for the calculation = 18.9% (estimated independently using calorimetric studies).

Actual energy delivered by horn during sonication = energy delivered during sonication using horn × efficiency of horn = 53.5 × 18.9/100 = 10.11 kJ.

Quantity of material processed = quantity of [water + KPS + surfactin + MMA] = 100 ml + 0.25 g + 0.025 g + 5 g = 105.28 g.

Net energy supplied for processing of material using sonochemical method = actual energy delivered by horn during sonication/quantity of material processed = 10.11 (kJ) / 105.28 (g) = $9.60 \times 10^{-2}$ (kJ/g). (B)

*3. Energy saved*

Net energy saved = [net energy supplied for processing of material using atomized microemulsion method (A)] - [net energy supplied for processing of material using sonochemical emulsion polymerization (B)] = $43.98 \times 10^{-2}$ (kJ/g) - $9.60 \times 10^{-2}$ (kJ/g) = $34.38 \times 10^{-2}$ (kJ/g).

**Calculation of cavitational yield**

*1. Conventional mechanically stirred emulsion polymerization*

Rate of polymerization = 1.26 g $l^{-1}$

Power density (J $l^{-1}$) = supplied total electrical energy = 46.31 kJ = 46310 J $l^{-1}$

Cavitational yield = 1.26 (g $l^{-1}$) / 46310 (J $l^{-1}$) = $0.27 \times 10^{-4}$ g $J^{-1}$

*2. sonochemical polymerization*

Rate of polymerization = 1.51 g $l^{-1}$

Power density (J $l^{-1}$) = supplied total electrical energy = 10.11 kJ = 10110 J $l^{-1}$

Cavitational yield = 1.51 (g $l^{-1}$) / 10110 (J $l^{-1}$) = $1.5 \times 10^{-4}$ g $J^{-1}$

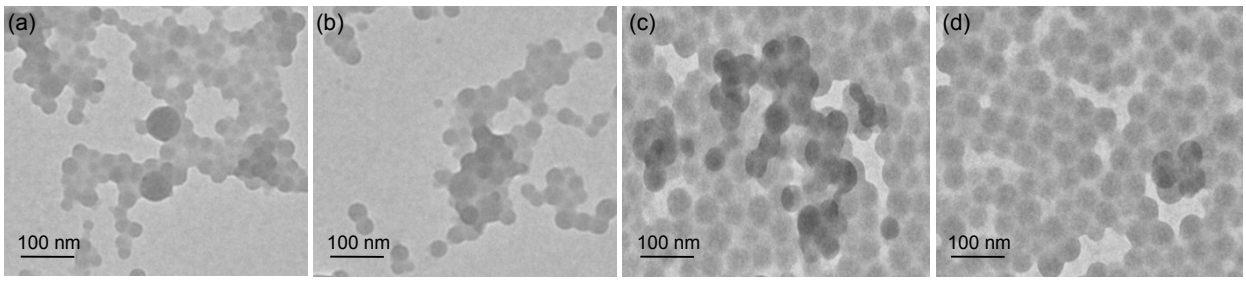


**Fig. S2.** Effect of surfactin concentration (wt. % of MMA) on morphology and size of $nPMMA_{SP}$ particles: (a) 1%, (b) 2%, (c) 3% and (d) 4%. Other conditions are same as Fig. 1.

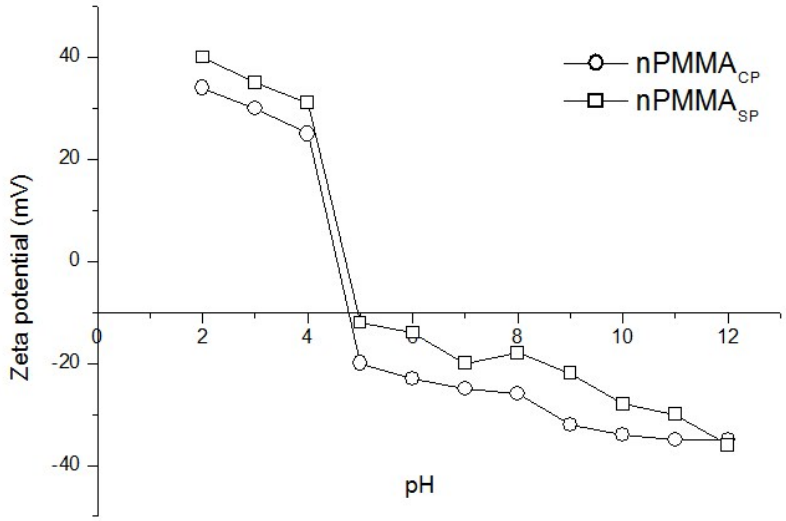


**Fig. S3.** The pH dependence of zeta-potential of $nPMMA_{SP}$ and $nPMMA_{CP}$ particles. (Reaction conditions: $nPMMA_{SP}$: monomer-to-water 20 wt.%; monomer-to-initiator 0.4 wt.%; surfactin 4 wt.%, calculated vs monomer; temperature, 55±2 $^{o}$C; time, 1 h; $nPMMA_{CP}$: monomer-to-water 20 wt.%; monomer-to-initiator 0.4 wt.%; surfactin 4 wt.%, calculated vs monomer; temperature, 55±2 $^{o}$C; agitation, 250 rpm; time, 1 h).

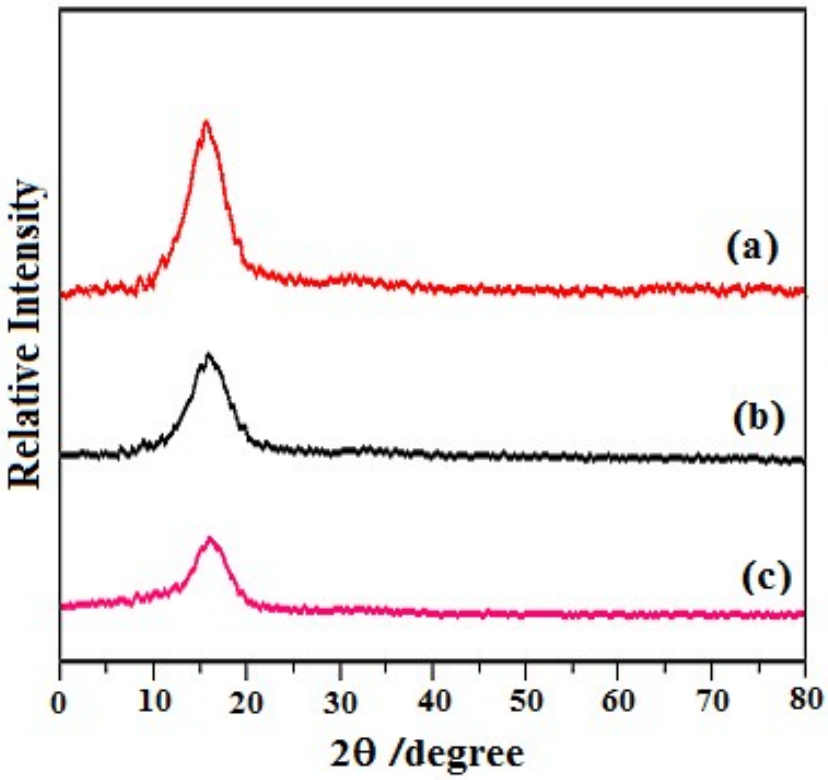


**Fig. S4.** XRD patterns of (a) $nPMMA_{SP}$, (b) $nPMMA_{CP}$ and (c) bulk PMMA.

The diffraction peak observed at 15.10° was assigned to the amorphous phase of PMMA. This peak was more prominent in $nPMMA_{SP}$. It suggested the crystalline nature of $nPMMA_{SP}$ was more than $nPMMA_{CP}$ and bulk PMMA.

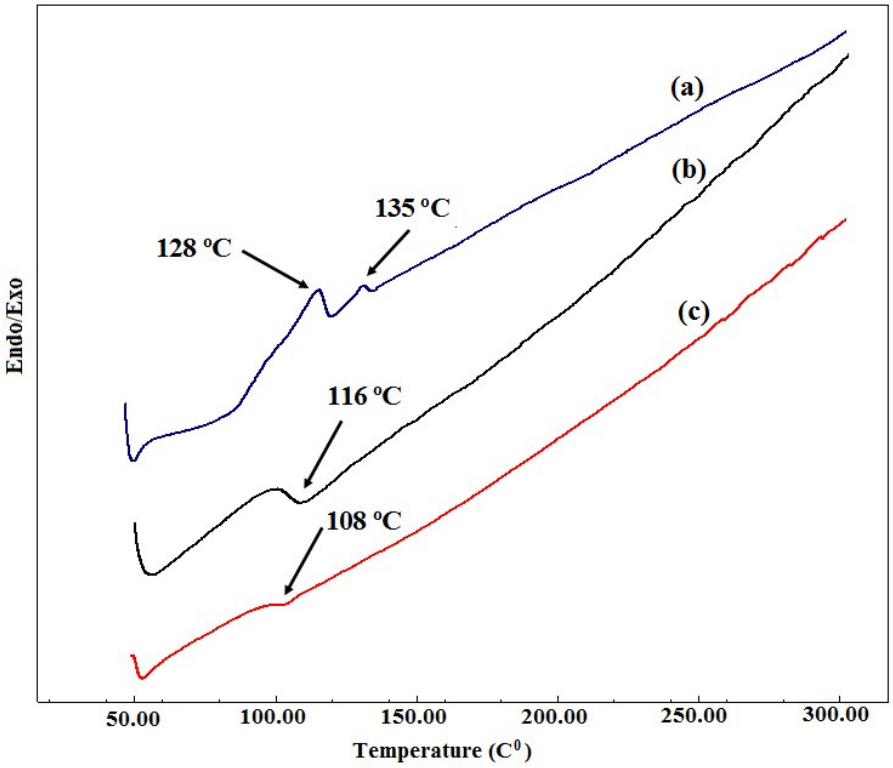


**Fig. S5.** DSC curves of (a) $nPMMA_{SP}$ and (b) $nPMMA_{CP}$ and (c) bulk PMMA.

It was observed that first scan of $nPMMA_{SP}$ showed two step exothermic peaks at 128 and 135 °C that were attributed to $T_{g1}$ along with respective peaks of $T_m$ arising due to the presence of little amount of surfactin (Fig. S5a). This finding corroborated with the thin shell layer of biosurfactants observed in TEM. The lower value of $T_{g1}$ (Fig. S5b) for $nPMMA_{CP}$ (116 °C) was due to its relatively large size and lower surface area as compared to $nPMMA_{SP}$. Moreover, the peak for surfactin shell could not be detected due to poor grafting of surfactin onto nPMMA in case of $nPMMA_{CP}$. Bulk PMMA showed regular $T_g$ at 108 °C like commercial grade PMMA (Fig. S5c). The reason for high $T_g$ of polymer nanoparticles than bulk PMMA might be a decrease in particle size to nano-scale that results in an increase in surface area and higher surface energy.

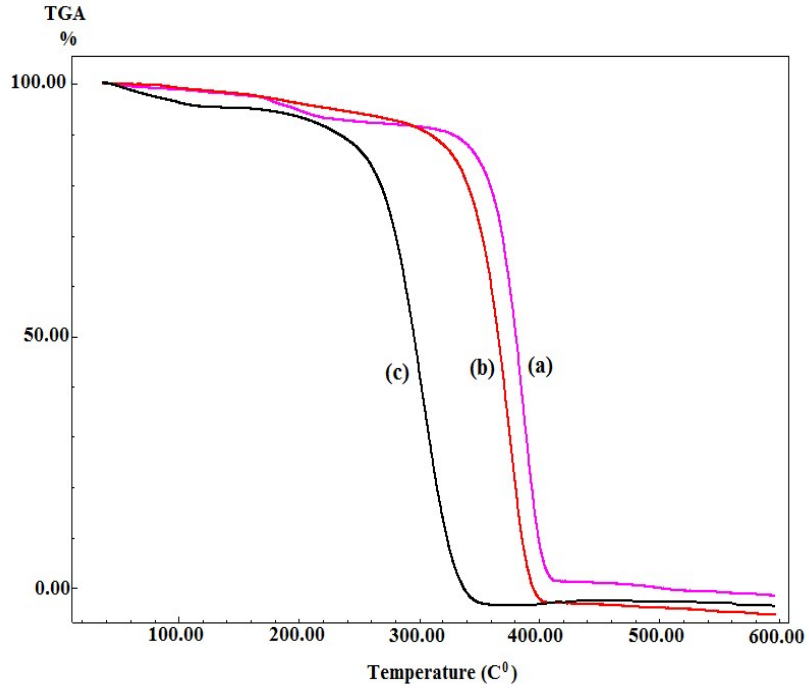


**Fig. S6.** TGA thermogram of (a) $nPMMA_{SP}$ and (b) $nPMMA_{CP}$ and (c) bulk PMMA.

A remarkable change in thermal behaviour between $nPMMA_{SP}$, $nPMMA_{CP}$ and bulk PMMA was observed. The $nPMMA_{SP}$ showed higher thermal stability [$d_{on}$ = 372 °C and $d_{off}$ = 415 °C with % weight loss ($W_L$) = 100%] than $nPMMA_{CP}$ [$d_{on}$ = 352 °C and $d_{off}$ = 406 °C with % weight loss ($W_L$) = 100%] and bulk PMMA [$d_{on}$ = 282 °C and $d_{off}$ = 356 °C with 100% $W_L$]. Thus, the thermal stability pattern followed the order: $nPMMA_{SP}$ > $nPMMA_{CP}$ > bulk PMMA.

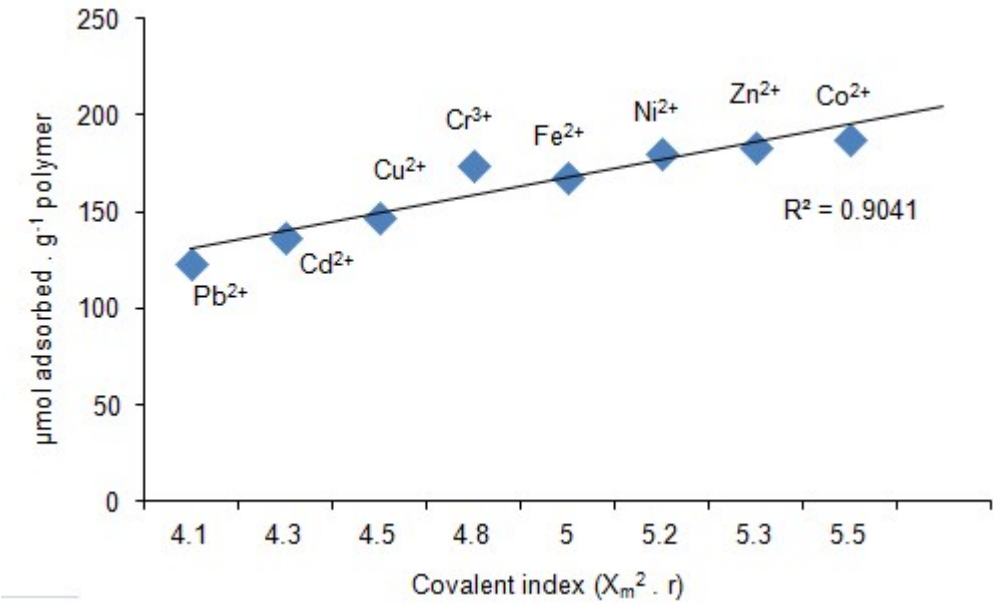


**Fig. S7.** Plot of the adsorption capacities against the covalent indices.

| Parameter | Setting |
|---|---|
| λ | 130 nm to 770 nm |
| RF Power | 1300 W |
| Nebulizer | Low flow |
| Plasma Flow | 15 l $min^{-1}$ |
| Auxiliary Flow | 0.2 l $min^{-1}$ |
| Nebulizer Flow | 0.8 l $min^{-1}$ |
| Pump Rate/ Sample Flow | 1.5 ml $min^{-1}$ |
| Spray Chamber | HF resistant cyclonic |
| Integration Time | 10-20 seconds |
| Number of replicates | 3 |

**Table S1.** ICP-AES instrumental operating parameters used for the determination of potentially toxic metals binding to nano-adsorbents used in this study.

| Run | MMA:KPS (wt.%) | Solid content (%) | $t^*_{blue}$ (min) | Particle size (nm) | | Polydispersity index | $N_p \times 10^{18}$ | $N$ |
|---|---|---|---|---|---|---|---|---|
| | | | | DLS | TEM | | | |
| Sonochemical emulsion polymerization | | | | | | | | |
| 1 | 0.0 | 12.171± 0.122 | 11 | 218.137±6.554 | 180.011±10.550 | 0.952±0.012 | 0.913±0.552 | 11 |
| 2 | 0.1 | 13.153±0.321 | 09 | 138.662±11.833 | 106.557±10.322 | 0.741±0.066 | 3.935±0.116 | 23 |
| 3 | 0.2 | 14.155±0.116 | 07 | 139.538±6.115 | 105.086±10.555 | 0.894±0.092 | 4.664±0.562 | 24 |
| 4 | 0.3 | 16.882±0.344 | 07 | 104.512±8.831 | 81.055±7.510 | 0.732±0.122 | 6.317±0.124 | 21 |
| 5 | 0.4 | 27.534±0.217 | 04 | 75.421±2.832 | 60.225±1.511 | 0.554±0.092 | 7.883±0.323 | 14 |
| 6 | 0.5 | 18.682±0.217 | 06 | 90.554±7.894 | 79.522±1.833 | 0.911±0.166 | 7.032±0.339 | 19 |
| 7 | 1.0 | 17.152±0.143 | 06 | 79.552±11.446 | 73.625±1.723 | 0.655±0.124 | 6.964±0.321 | 18 |
| 8 | 1.5 | 25.551±0.222 | 05 | 72.511±10.871 | 63.512±3.476 | 0.727±0.164 | 6.551±0.552 | 14 |
| 9 | 2.0 | 22.155±0.344 | 05 | 76.025±5.112 | 64.533±4.222 | 0.643±0.088 | 4.877±0.803 | 15 |
| 10 | 3.0 | 21.693±0.255 | 04 | 75.523±3.835 | 66.216±3.821 | 0.592±0.074 | 3.714±0.221 | 17 |
| Conventional polymerization (with mechanical stirring) | | | | | | | | |
| 1 | 0.0 | 11.142±0.124 | 14 | 229.025±12.912 | 190.088±7.444 | 0.973±0.088 | 0.855±0.188 | 13 |
| 2 | 0.1 | 12.571±0.361 | 12 | 155.013±10.225 | 125.057±12.875 | 0.752±0.071 | 3.143±0.255 | 21 |
| 3 | 0.2 | 13.144±0.112 | 11 | 131.085±7.287 | 110.024±10.514 | 0.806±0.150 | 3.618±0.624 | 20 |
| 4 | 0.3 | 14.856±0.333 | 09 | 110.511±9.132 | 85.533±6.527 | 0.711±0.033 | 5.511±0.255 | 23 |
| 5 | 0.4 | 25.554±0.242 | 07 | 79.533±2.562 | 72.341±3.522 | 0.632±0.061 | 6.722±0.511 | 12 |
| 6 | 0.5 | 18.682±0.114 | 07 | 95.542±2.830 | 80.066±3.555 | 0.875±0.075 | 6.777±0.222 | 21 |
| 7 | 1.0 | 16.551±0.211 | 08 | 100.016±8.732 | 85.042±5.425 | 0.633±0.177 | 5.854±0.541 | 25 |
| 8 | 1.5 | 22.554±0.224 | 05 | 90.088±6.656 | 82.552±6.138 | 0.633±0.055 | 6.183±0.207 | 15 |
| 9 | 2.0 | 21.133±0.313 | 05 | 95.035±8.555 | 90.086±13.565 | 0.662±0.021 | 4.537±0.212 | 18 |
| 10 | 3.0 | 20.652±0.115 | 05 | 135.017±8.937 | 116.211±11.558 | 0.697±0.044 | 3.653±0.443 | 14 |

*: the time when the colour of the microemulsion turns blue

**Table S2.** Effect of monomer-to-initiator weight ratios on particle size, PDI, conversion, $N_P$ and $N$ of the particles. Conditions are as in Fig. 1.

| Run | MMA:water (wt.%) | Particle size (nm) | | Polydispersity index | $N_p \times 10^{18}$ | $N$ |
|---|---|---|---|---|---|---|
| | | DLS | TEM | | | |
| Sonochemical emulsion polymerization | | | | | | |
| 1 | 5 | 88.542 | 66.521 | 0.622 | 6.783 | 14 |
| 2 | 10 | 119.515 | 85.017 | 0.721 | 6.557 | 14 |
| 3 | 15 | 114.553 | 90.044 | 0.713 | 5.883 | 15 |
| 3 | 20 | 79.016 | 60.027 | 0.552 | 7.612 | 13 |
| Conventional polymerization (with mechanical stirring) | | | | | | |
| 1 | 5 | 90.557 | 68.066 | 0.657 | 7.004 | 16 |
| 2 | 10 | 111.525 | 85.549 | 0.705 | 7.222 | 17 |
| 3 | 15 | 115.578 | 92.026 | 0.754 | 7.254 | 18 |
| 4 | 20 | 75.055 | 73.022 | 0.613 | 7.102 | 15 |

**Table S3.** Effect of MMA concentration on particle size, PDI, conversion, $N_P$ and $N$ of the particles. Other conditions are same as Fig. 1.

| Run | Acoustic amplitude (%) | Energy input (kJ) | Actual power dissipated (*P*, W) (measured calorimetrically) | Power input per unit volume (kW/m$^3$) | Efficiency (%) | Particle size (nm) | | Polydispersity index | $N_p \times 10^{18}$ | *N* | Conversion (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | DLS | TEM | | | | |
| 1 | 30 | 23.811 | 22.112 | 497.944 | 9.212 | 220.544 | 182.077 | 0.981 | 0.922 | 10 | 67.055 |
| 2 | 40 | 36.215 | 31.433 | 751.552 | 13.111 | 130.532 | 103.036 | 0.745 | 3.963 | 22 | 77.112 |
| 3 | 50 | 53.522 | 45.543 | 1136.841 | 18.967 | 79.511 | 60.044 | 0.553 | 7.632 | 13 | 91.233 |
| 4 | 65 | 67.717 | 60.022 | 1413.514 | 25.055 | 120.043 | 83.052 | 0.752 | 6.251 | 20 | 85.355 |
| 5 | 70 | 77.118 | 65.054 | 1607.504 | 27.183 | 105.022 | 75.513 | 0.663 | 6.573 | 19 | 81.088 |

**Table S4.** Effect of acoustic amplitude on particle size, PDI, conversion, $N_P$ and $N$ of nPMMA$_{SP}$ particles.

| Run | Wt. % biosurfactant (of MMA) | Particle size (nm) | | Polydispersity index | $N_p \times 10^{18}$ | $N$ |
|---|---|---|---|---|---|---|
| | | DLS | TEM | | | |
| Sonochemical emulsion polymerization | | | | | | |
| 1 | 1.0 | 120.077 | 85.027 | 0.704 | 5.544 | 14 |
| 2 | 2.0 | 90.022 | 67.512 | 0.632 | 6.751 | 14 |
| 3 | 3.0 | 110.037 | 82.044 | 0.734 | 6.613 | 13 |
| 4 | 4.0 | 85.054 | 60.036 | 0.572 | 7.577 | 14 |
| Conventional polymerization (with mechanical stirring) | | | | | | |
| 1 | 1.0 | 120.022 | 85.082 | 0.791 | 6.233 | 17 |
| 2 | 2.0 | 90.016 | 67.555 | 0.651 | 7.264 | 15 |
| 3 | 3.0 | 110.052 | 82.023 | 0.762 | 7.172 | 18 |
| 4 | 4.0 | 85.073 | 70.516 | 0.513 | 6.735 | 14 |

**Table S5.** Effect of surfactin concentration on particle size, PDI, conversion, $N_P$ and $N$ of the particles. Other conditions are same as Fig. 1.

| Model | Parameters | $Co^{2+}$ | $Zn^{2+}$ | $Ni^{2+}$ | $Cr^{3+}$ |
|---|---|---|---|---|---|
| **Pseudo-first-order** | $k_1$ ($min^{-1}$) | 0.038 | 0.045 | 0.044 | 0.032 |
| | $q_{e,calc}$ (mg $g^{-1}$) | 30.155 | 28.463 | 27.434 | 34.141 |
| | $R^2$ | 0.943 | 0.947 | 0.935 | 0.953 |
| | *RMSE* | 0.031 | 0.024 | 8.652 | 0.814 |
| | *ERRSQ* | 0.242 | 0.173 | 63.303 | 6.431 |
| | | | | | |
| **Pseudo-second-order** | $k_2$ (g $mg^{-1}$ $min^{-1}$) | 0.624 | 0.914 | 0.137 | 0.532 |
| | $q_{e,calc}$ (mg $g^{-1}$) | 34.656 | 34.022 | 31.552 | 44.088 |
| | $R^2$ | 0.998 | 0.999 | 0.999 | 0.994 |
| | *RMSE* | 0.016 | 0.003 | 0.812 | 0.748 |
| | *ERRSQ* | 0.117 | 0.034 | 6.455 | 6.582 |
| | | | | | |
| **Elovich** | $\alpha$ (mg $g^{-1}$ $min^{-1}$) | 5.69E + 24 | 1.66E + 28 | 68.4162 | 3314.526 |
| | $\beta$ (g $mg^{-1}$) | 28.572 | 27.863 | 6.983 | 27.114 |
| | $R^2$ | 0.932 | 0.956 | 0.986 | 0.991 |
| | *RMSE* | 0.085 | 0.039 | 6.372 | 6.831 |
| | *ERRSQ* | 0.689 | 0.477 | 8.105 | 6.214 |
| | | | | | |
| **Intraparticle diffusion** | $k_d$ (mg $g^{-1}$ $min^{-0.5}$) | 0.005 | 0.008 | 0.037 | 0.014 |
| | $C$ (mg $g^{-1}$) | 30.683 | 32.111 | 30.473 | 43.572 |
| | $R^2$ | 0.974 | 0.982 | 0.955 | 0.962 |
| | *RMSE* | 0.027 | 0.082 | 3.178 | 5.166 |
| | *ERRSQ* | 0.587 | 0.325 | 8.144 | 6.024 |

**Table S6.** Kinetic model parameters and error function data for the metal ions sorption onto $nPMMA_{SP}$ particles.

| Isotherms | Parameters | $Co^{2+}$ | $Zn^{2+}$ | $Ni^{2+}$ | $Cr^{3+}$ |
|---|---|---|---|---|---|
| **Langmuir** | $Q_0$ (mg $g^{-1}$) | 24.573 | 25.857 | 27.843 | 36.479 |
| | $K_L$ (l $mg^{-1}$) | 0.044 | 0.031 | 0.038 | 0.042 |
| | $R^2$ | 0.904 | 0.895 | 0.937 | 0.983 |
| | *RMSE* | 0.066 | 0.012 | 0.568 | 0.552 |
| | *ERRSQ* | 0.311 | 0.432 | 3.558 | 2.637 |
| | | | | | |
| **Freundlich** | $K_F$ | 7.471 | 5.213 | 4.332 | 4.884 |
| | $1/n$ | 0.532 | 0.441 | 0.383 | 0.414 |
| | $R^2$ | 0.927 | 0.958 | 0.962 | 0.902 |
| | *RMSE* | 0.088 | 0.853 | 1.274 | 1.548 |
| | *ERRSQ* | 10.889 | 2.442 | 3.769 | 2.551 |
| | | | | | |
| **Temkin** | $b_T$ | 9.664 | 8.892 | 6.432 | 9.221 |
| | $A_T$ (l $g^{-1}$) | 1.183 | 2.122 | 0.443 | 0.522 |
| | $R^2$ | 0.933 | 0.944 | 0.921 | 0.922 |
| | *RMSE* | 0.042 | 0.017 | 0.441 | 0.502 |
| | *ERRSQ* | 0.818 | 0.779 | 1.764 | 3.374 |
| | | | | | |
| **Redlich-Peterson** | $K_R$ (l $g^{-1}$) | 0.781 | 1.374 | 4.733 | 5.662 |
| | $a_R$ ($mg^{-1}$) | 0.055 | 0.132 | 0.035 | 0.042 |
| | $g$ | 10.221 | 0.834 | 0.942 | 0.785 |
| | $R^2$ | 0.954 | 0.955 | 0.962 | 0.944 |
| | *RMSE* | 0.033 | 0.021 | 0.034 | 0.104 |
| | *ERRSQ* | 0.219 | 0.422 | 1.215 | 1.593 |
| | | | | | |
| **Sips** | $K_S$ (l $g^{-1}$) | 0.042 | 0.081 | 0.031 | 0.044 |
| | $Q_S$ (mg $g^{-1}$) | 31.152 | 30.528 | 29.471 | 40.143 |
| | $n_S$ | 0.943 | 0.052 | 1.232 | 1.621 |
| | $R^2$ | 0.977 | 0.953 | 0.951 | 0.962 |
| | *RMSE* | 0.037 | 0.088 | 0.044 | 0.492 |
| | *ERRSQ* | 0.204 | 0.394 | 1.032 | 1.042 |

**Table S7.** Isotherm parameters and error deviation data for the adsorption of $Co^{2+}$, $Zn^{2+}$, $Ni^{2+}$ and $Cr^{3+}$ onto $nPMMA_{SP}$.

| Model parameters | $Co^{2+}$ retention capacity (mg $g^{-1}$) | |
|---|---|---|
| | **-20%** | **+20%** |
| **Langmuir** | | |
| $Q_0$ (mg $g^{-1}$) | 30.448 | 30.977 |
| $K_L$ (l $mg^{-1}$) | 30.545 | 30.757 |
| **Freundlich** | | |
| $K_F$ | 30.656 | 30.757 |
| $n$ | 30.541 | 30.855 |
| **Temkin** | | |
| $b_T$ | 33.785 | 31.583 |
| $A_T$ (l $g^{-1}$) | 32.882 | 31.555 |
| **Redlich-Peterson** | | |
| $K_R$ (l $g^{-1}$) | 31.782 | 31.733 |
| $a_R$ ($mg^{-1}$) | 30.557 | 30.463 |
| $g$ | 32.188 | 32.056 |
| **Sips** | | |
| $K_S$ (l $g^{-1}$) | 30.555 | 30.146 |
| $Q_S$ (mg $g^{-1}$) | 30.505 | 30.478 |
| $n_S$ | 31.035 | 30.862 |
| **Pseudo-first-order** | | |
| $k_1$ | 30.066 | 30.212 |
| $q_e$ | 30.882 | 31.044 |
| **Pseudo-second-order** | | |
| $k_2$ | 30.062 | 30.015 |
| $q_e$ | 30.112 | 30.026 |
| **Elovich** | | |
| $\alpha$ | 33.565 | 31.511 |
| $\beta$ | 32.805 | 31.152 |
| **Intraparticle diffusion** | | |
| $k_d$ | 32.647 | 31.505 |
| $C$ | 31.893 | 31.051 |

**Table S8.** Parametric sensitivity of the model parameters for $Co^{2+}$.

| Metal ions | $\Delta H^o$ (kJ mol$^{-1}$) | $\Delta S^o$ (J mol$^{-1}$K$^{-1}$) | $\Delta G^o$ (kJ mol$^{-1}$) | | |
|---|---|---|---|---|---|
| | | | **303 K** | **313 K** | **323 K** |
| **$Co^{2+}$** | -18.966 | -43.554 | -3.556 | -3.462 | -2.401 |
| **$Zn^{2+}$** | -8.932 | -33.442 | -0.205 | -0.202 | -0.183 |
| **$Ni^{2+}$** | -10.882 | -34.823 | 0.321 | 0.308 | 0.253 |
| **$Cr^{3+}$** | -13.185 | -38.171 | 0.781 | 0.713 | 0.582 |

**Table S9.** Thermodynamic parameters for the metal ions sorption onto $nPMMA_{SP}$.