Supplementary Information

Metathesis in water conducted by tailor-made encapsulated Grubbs’ catalyst

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1. General

$^1$H and $^{13}$C NMR spectra were recorded with a Bruker Avance III 500 HD (measuring frequency: $^1$H NMR = 500.2 MHz, $^{13}$C NMR = 125.8 MHz) spectrometer in CDCl₃ or D₂O solution. Chemical shifts are referenced to the residual peaks of the solvent [CDCl₃: 7.26 ppm ($^1$H NMR), 77.16 ppm ($^{13}$C NMR)] (H. E. Gottlieb, V. Kotlyar, A. Nudelman, *J. Org. Chem.* 1997, 62, 7512). HPLC experiments were carried out on a Machery-Nagel NUCLEODUR® C18 Gravity-SB (5 µm) column.

2. Particle size

In our first experiments with dispersed Grubbs’ second-generation catalyst in sodium alginate we revealed that the particle size of raw commercial Grubbs’ catalyst is not convenient, since it led to clogged needles during encapsulation procedure. Therefore, we determined the particle size of raw catalyst with a Malvern Mastersizer 3000 particle size analyser to give an average particle size of 177±28 µm (Figure A). After we crushed the catalyst particle aggregates with a spatula to reduce their particle size and enhance the distribution in alginate, particle size was reduced about 50% (92±15 µm). Since the application of ultrasonics for the reduction of particle size is a common method, we ultrasonicated the catalyst to reduce the particle size even more. For that, Grubbs’ catalyst was dispersed in sodium alginate and ultrasonicated with a Hielscher UP200Ht ultrasonic homogeniser. During ultrasonication, the mixture was cooled with ice to prevent catalyst deactivation by heat. Using this method, we reduced particle size to 40% compared to manual crushing (54±7 µm).

![Figure A](image)

*Figure A.* Average particle size Dx (50) of raw, crushed and ultrasonicated Grubbs’ catalyst. (means ± standard deviations; n = 5; different letters above bars indicate significant differences according to ANOVA with Tukey’s post hoc test at p < 0.05).
After that, we conducted the ring-closing metathesis with ultrasonicated catalyst in alginate amide with substrate 1. The reaction rate was reduced by 70% compared to crushed catalyst, which can be explained by ultrasonics that create high pressure and temperature peaks in the medium, thus irreversibly deactivating the catalyst. Therefore, we applied the manual crushing method for all experiments, since with this particle size the problem of clogged needles disappeared.

3. Experimental data

Reaction rates presented in the full paper for non-encapsulated (Figures 1,2) and encapsulated catalyst (Figures 2,3,5) are listed in Table A and B, respectively.

![Images of substrates 1, 3, and 5]

**Table A.** Reaction rates of experiments with non-encapsulated catalyst presented in Figures 1-2.

<table>
<thead>
<tr>
<th>Bead material</th>
<th>Solvent</th>
<th>Substrate</th>
<th>Catalyst loading (mol%)</th>
<th>Reaction rate [µmol · min⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>water-tBuOH (3:1)</td>
<td>1</td>
<td>0.5</td>
<td>0.456±0.054</td>
</tr>
<tr>
<td>-</td>
<td>water</td>
<td>1</td>
<td>0.5</td>
<td>2.64±0.20</td>
</tr>
<tr>
<td>-</td>
<td>tBuOH</td>
<td>1</td>
<td>0.5</td>
<td>0.073±0.004</td>
</tr>
<tr>
<td>-</td>
<td>dichloromethane</td>
<td>1</td>
<td>0.5</td>
<td>3.58±0.17</td>
</tr>
<tr>
<td>-</td>
<td>acetone-water (2:1)</td>
<td>1</td>
<td>0.5</td>
<td>0.347±0.075</td>
</tr>
<tr>
<td>-</td>
<td>water</td>
<td>3</td>
<td>0.5</td>
<td>0.92±0.14</td>
</tr>
<tr>
<td>-</td>
<td>water</td>
<td>5</td>
<td>0.5</td>
<td>25.25±0.93</td>
</tr>
</tbody>
</table>
Table B. Reaction rates of experiments with encapsulated catalyst presented in Figures 2,3,5.

<table>
<thead>
<tr>
<th>Bead material</th>
<th>Solvent</th>
<th>Substrate</th>
<th>Catalyst loading (mol%)</th>
<th>Reaction rate [µmol ∙ min⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>calcium alginate</td>
<td>water</td>
<td>1</td>
<td>0.5</td>
<td>0.047±0.002</td>
</tr>
<tr>
<td>calcium alginate</td>
<td>water</td>
<td>3</td>
<td>0.5</td>
<td>0.095±0.035</td>
</tr>
<tr>
<td>calcium alginate</td>
<td>water</td>
<td>3</td>
<td>0.5</td>
<td>no reaction</td>
</tr>
<tr>
<td>calcium alginate</td>
<td>water-tBuOH (3:1)</td>
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<td>0.5</td>
<td>0.031±0.005</td>
</tr>
<tr>
<td>calcium alginate</td>
<td>acetone-water (2:1)</td>
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<td>0.5</td>
<td>0.013±0.003</td>
</tr>
<tr>
<td>calcium alginate</td>
<td>methanol-water (2:1)</td>
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<td>0.5</td>
<td>no reaction</td>
</tr>
<tr>
<td>calcium alginate</td>
<td>water-Tween</td>
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<td>0.006±0.002</td>
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<tr>
<td>alginate amide</td>
<td>water</td>
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<td>0.5</td>
<td>0.108±0.041</td>
</tr>
<tr>
<td>alginate amide</td>
<td>water</td>
<td>3</td>
<td>0.5</td>
<td>0.146±0.082</td>
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<td>calcium alginate</td>
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<td>1</td>
<td>2.5</td>
<td>0.192±0.082</td>
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<tr>
<td>alginate amide</td>
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<td>0.333±0.081</td>
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<td>water</td>
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<td>2.5</td>
<td>0.083±0.004</td>
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<tr>
<td>alginate amide</td>
<td>water</td>
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<td>2.5</td>
<td>0.357±0.034</td>
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<tr>
<td>calcium alginate</td>
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<td>5.0</td>
<td>0.214±0.055</td>
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<tr>
<td>alginate amide</td>
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<td>5.0</td>
<td>0.502±0.011</td>
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<td>water</td>
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<td>0.097±0.016</td>
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<td>alginate amide</td>
<td>water</td>
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<td>5.0</td>
<td>0.398±0.096</td>
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</tbody>
</table>

3.1 Turnover frequencies (TOFs; Figure 6)
The given TOFs in Figure 6 were calculated as follows: Using 0.25 mmol substrate results in 6.25 µmol catalyst (2.5 mol%). For the reaction with substrate 1 (in alginate amide), dividing the reaction rate of 0.333 µmol ∙ min⁻¹ by 6.25 µmol results in a TOF of 0.05328 min⁻¹ (3.20 h⁻¹). A TOF of 0.05712 min⁻¹ (3.43 h⁻¹) was calculated for the reaction with substrate 3 (in alginate amide). To evaluate these TOFs, for example, a study showed that with encapsulated Ru-catalyst on mesoporous silica (SBA-1) a TOF of 3.78 h⁻¹ (0.063 min⁻¹) was achieved for substrate 1 (H. Yang, Z. Ma, T. Zhou, W. Zhang, J. Chao, Y. Qin, ChemCatChem 2013, 5, 2278). Hence, our TOFs are of a similar order of magnitude.
4. Preparation of octyl-grafted alginate amide

Octyl-grafted alginate amide was synthesised according to an adapted reported procedure (W. Hu, J. Li, H. Hou, H. Yan, Y. Feng, X. Mi, Q. Lin, Asian J. Chem. 2013, 25, 9904). Sodium alginate (3.0 g) was dissolved in water (90 ml), resulting in a 3.33% w/v solution. EDC · HCl (0.73 g) was added to this solution and pH was adjusted to 3.4 with HCl(aq) (0.5 M). After diluting the solution with 30 ml water (resulting in 2.5% w/v), octyl amine (5.1 ml) was added. Then, the reaction mixture was stirred for 24 h at 35 °C. By adding ethanol (300 ml) after the reaction time, the product was precipitated. The mixture was centrifuged, washed with ethanol (5 x 20 ml) and dried for three days at room temperature. After milling the chunky solid in a ball mill, a fine white powder (2.72 g) was obtained.

In the following, protons are assigned to the octyl group:

\(^1\)H-NMR (500.2 MHz, D₂O, 296 K): \(\delta = 0.87\) (t, \(3^J_{H,H} = 5.4\) Hz, 3H, CH₂(CH₂)₆CH₃), 1.29-1.67 (m, 12H, CH₂(CH₂)₆CH₃), 2.99 (t, \(3^J_{H,H} = 7.2\) Hz, 2H, CH₂(CH₂)₆CH₃) ppm.

The analytical data are in accordance to those reported (W. Hu, J. Li, H. Hou, H. Yan, Y. Feng, X. Mi, Q. Lin, Asian J. Chem. 2013, 25, 9904).

\(^1\)H NMR spectra revealed introduced octyl groups (0.8-1.7 ppm):

![Sodium alginate](image1.png)

![Octyl-grafted alginate amide](image2.png)
5. NMR spectra

![NMR spectra of compound 2]
6. HPLC analysis

The analysis of conversion for the calculation of reaction rates required a fast and high-throughput analysis method. Therefore, we chose to perform this analysis via HPLC. Samples of relevant substances were analysed alone and subsequently together to develop a suitable method. With this method, it is possible to determine substrate / product ratios, after calibrations with defined substrate / product ratios were performed. We evaluated our method to be suitable for our application by preparing mixtures of substrate and product with different ratios. We also considered possible substrate or product decomposition and therefore measured the samples again after a week, showing no change in the substrate/product ratio.

6.1 Calibration for substrate 1

\[ \text{substrate : product} = 90 : 10 \]

\[ \text{substrate : product} = 80 : 20 \]
substrate : product = 70 : 30

substrate : product = 60 : 40

substrate : product = 50 : 50
substrate : product = 10 : 90

<table>
<thead>
<tr>
<th>% Product</th>
<th>% Substrate</th>
<th>Integral product</th>
<th>Integral substrate</th>
<th>Integral product / Integral substrate</th>
</tr>
</thead>
<tbody>
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<td>93461</td>
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</tbody>
</table>
6.2 Calibration for substrate 3

- Substrate : Product = 90 : 10
  ![Calibration Graph 1](image1)

- Substrate : Product = 80 : 20
  ![Calibration Graph 2](image2)

- Substrate : Product = 70 : 30
  ![Calibration Graph 3](image3)
substrate : product = 60 : 40

substrate : product = 50 : 50

substrate : product = 40 : 60
substrate : product = 30 : 70

substrate : product = 20 : 80

substrate : product = 10 : 90
<table>
<thead>
<tr>
<th>% Product</th>
<th>% Substrate</th>
<th>Integral product</th>
<th>Integral substrate</th>
<th>Integral product / Integral substrate</th>
</tr>
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</tr>
</tbody>
</table>

Calibration substrate 3

\[ y = 101.01x + 3.4866 \]

\[ R^2 = 0.9964 \]
6.3 Calibration substrate 5

substrate : product = 90 : 10

substrate : product = 80 : 20

substrate : product = 70 : 30
substrate : product = 60 : 40

substrate : product = 50 : 50

substrate : product = 40 : 60
substrate : product = 30 : 70

substrate : product = 20 : 80

substrate : product = 10 : 90
<table>
<thead>
<tr>
<th>% Product</th>
<th>% Substrate</th>
<th>Integral product</th>
<th>Integral substrate</th>
<th>Integral product / Integral substrate</th>
</tr>
</thead>
<tbody>
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<td>-</td>
<td>Manually set to “1”</td>
</tr>
</tbody>
</table>

Calibration substrate 5

\[ y = 139.43x^2 - 33.015x \]

\[ R^2 = 0.9791 \]
6.4 Example for determination of substrate-product-ratios:
Non-encapsulated catalyst (0.5 mol%) in water, substrate 1, repetition 1/3
<table>
<thead>
<tr>
<th>Time / min</th>
<th>Integral product</th>
<th>Integral substrate</th>
<th>Integral product/Integral substrate</th>
<th>Conversion / %</th>
</tr>
</thead>
<tbody>
<tr>
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<td>962717</td>
<td>0.051204674</td>
<td>5</td>
</tr>
<tr>
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<td>122164</td>
<td>848692</td>
<td>0.125831225</td>
<td>12</td>
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<tr>
<td>20</td>
<td>128490</td>
<td>359430</td>
<td>0.263342351</td>
<td>26</td>
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<tr>
<td>40</td>
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<td>525759</td>
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<td>4383</td>
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<td>95</td>
</tr>
</tbody>
</table>

The initial reaction rate was calculated within the first 60 minutes.
6.5 Chromatogram for calculation of conversion after 24 h reaction time with substrate 1 and 2.5 mol% catalyst in alginate amide

6.6 Chromatogram for calculation of conversion after 24 h reaction time with substrate 3 and 2.5 mol% catalyst in alginate amide