Improvement of silver azide crystal morphology and detonation behavior by fast mixing using a microreaction system with integrated static micro mixer

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Mixing Performance of MCFM at Different Flow Rates

To further study the mixing performance of the MCFM at different flow rates, the theoretical calculations with the flow rates (Q_1&Q_2) of 2.0 mL/min, 3.0 mL/min, 5.0 mL/min and 6.0 mL/min were conducted. The corresponding residence time were 460 ms, 306 ms, 183 ms and 153 ms, respectively. Therefore, the *Re* values at these flow rates were 148, 222, 370 and 444, respectively. The simulation results are shown in Figure 1. It can be clearly seen that the complete mixing has been achieved at a distance of 5.99 mm from the inlet when the flow rate changes from 2.0 mL/min to 6.0 mL/min. The difference is that when the flow rate ranges from 2.0 mL/min to 6.0 mL/min, the corresponding time for complete mixing is approximately 115 ms, 76.7 ms, 46 ms and 38.3 ms, respectively. That is to say, with the increase of the flow rate, the mixing speed becomes faster and the mixing efficiency becomes higher. Due to its excellent performance, the rapid mixing is achieved through the passive micromixer (MCFM), which is beneficial for the fast and efficient synthesis of SA. However, the improvement of mixing efficiency is accompanied by a sharp decrease in retention time, which affects the nucleation and growth of SA particles. Therefore, the optimal flow rate must be screened by a combination of experimental verification and theoretical calculation.

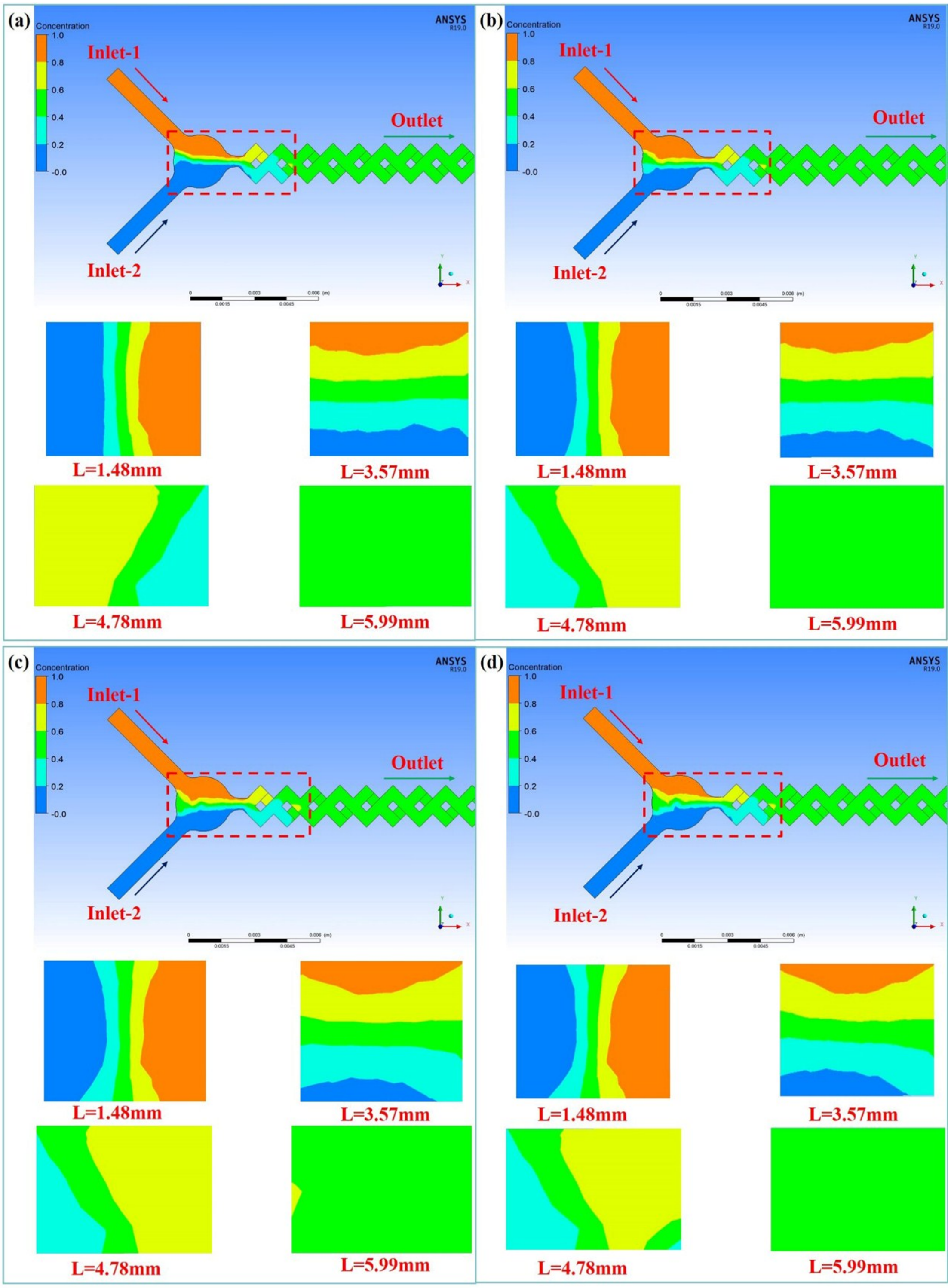

Figure 1. Mixing results of the MCFM with the flow rates of 2.0 mL/min (a), 3.0 mL/min (b), 5.0 mL/min (c) and 6.0 mL/min (d).

Effect of the Flow Rates on SA Particles

In order to screen the optimal flow rate, the influence of reagent velocity on crystal shape and particle size distribution of SA at microscale was studied. Therefore, experiments at 0.1 M of the two reactants with the flow rates of 2.0 mL/min, 3.0 mL/min, 4.0 mL/min and 5.0 mL/min were conducted. The crystals were collected by vacuum filtration and were rinsed with deionized water.

The crystal morphologies and particle size distribution of SA synthesized with different flow rates using the passive microreaction system are shown in Figure 2. The crystal morphology of SA produced at the flow rate of 2.0 mL/min is short columnar. As the flow rate of the reagents increases from 2.0 mL/min to 4.0 mL/min, the crystal morphologies of SA synthesized at microscale change from short columnar to spherical or spherical-like, and become more uniform. However, when the flow rate changes from 4.0 mL/min to 5.0 mL/min, the crystal morphology of SA becomes inhomogeneous and intends to agglomerate. In addition, the corresponding particle size distribution of SA were tested. For 2.0 mL/min, the particles are highly polydisperse with the size varying from 712.4 nm to 2304.7 nm. For 3.0 mL/min, the size of SA particles varies from 220.2 nm to 1718.5 nm. For 4.0 mL/min, the size of SA particles varies from 712.4 nm to 1106.4 nm. For 5.0 mL/min, the particle size ranges from 220.2 nm to 1106.4 nm. When the flow rate increases from 2.0 mL/min to 4.0 mL/min, the PSD becomes narrower. However, when the flow rate increases from 4.0 mL/min to 5.0 mL/min, the PSD becomes wider.

Whether the flow rates are as low as 2.0 mL/min or as high as 5.0 mL/min, the rapid mixing of the two reagents can be achieved through the passive micromixer (MCFM). However, the residence time of the two reagents in the mixing region is inversely proportional to the total flow rate. When the flow rate ranges from 2.0 mL/min to 5.0 mL/min, the corresponding residence time are 460 ms, 306 ms, 230 ms and 183 ms, respectively. Appropriate residence time is crucial to the crystal morphology and PSD of SA. Therefore, it is a good choice for the optimization on crystal morphology and PSD of SA to use 4.0 mL/min as the most suitable flow rate.

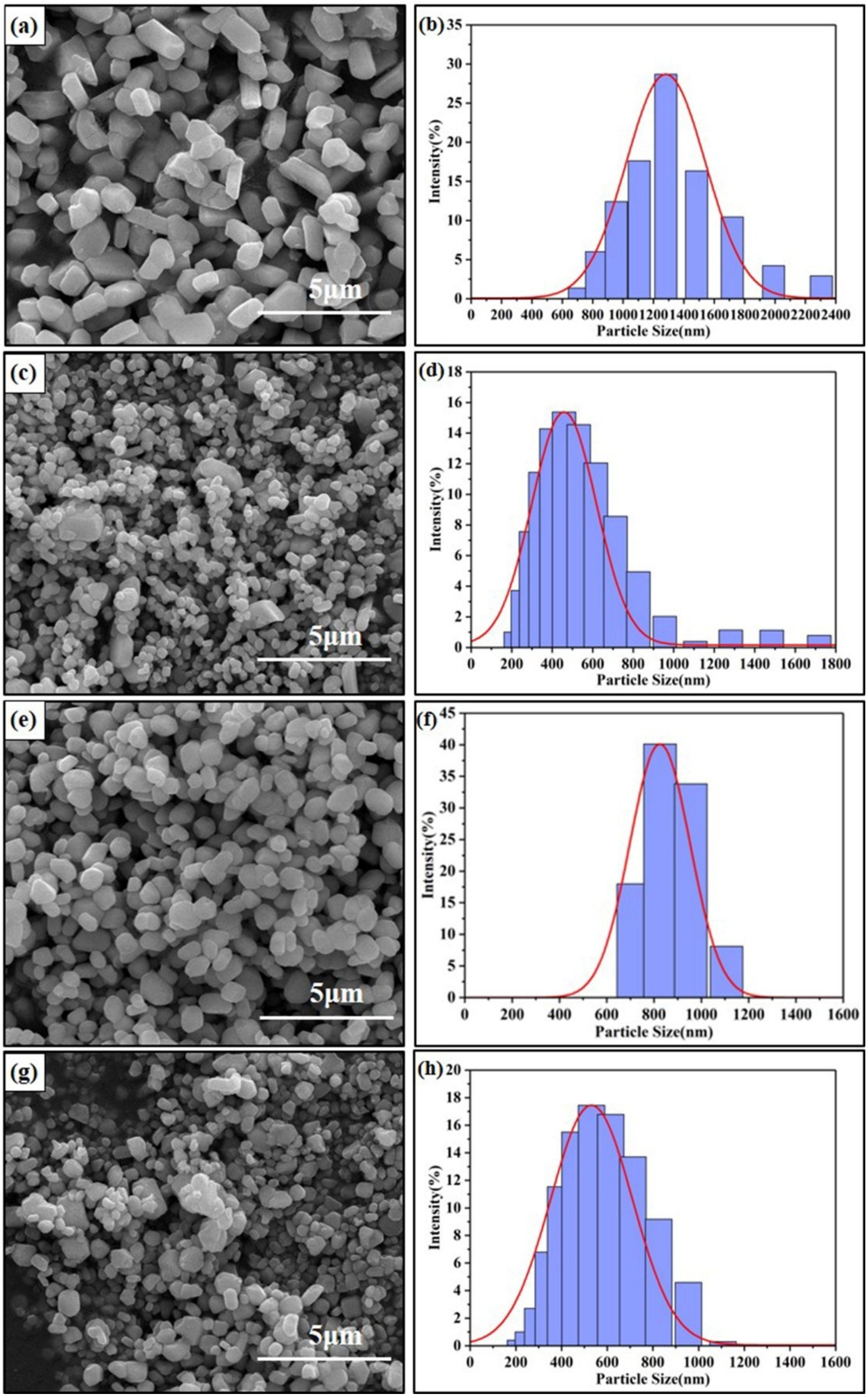

Figure 2. The crystal morphology and the corresponding PSD of SA with the flow rates of 2.0 mL/min (a, b), 3.0 mL/min (c, d), 4.0 mL/min (e, f) and 5.0 mL/min (g, h)