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Editorial

Microreactor-Assisted Nanomaterial Processing: Scaling by an Equal up and Equal down Approach

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EDITORIAL

Many high-quality nanocrystals have been successfully produced at the laboratory scale by hot injection. Hot injection methods involve the rapid injection of pre-mixed chemical reagents into a hot and vigorously stirred solvent containing coordinating molecules for modifying the surface of precipitated nanocrystals. Nanoparticle formation begins with the collision of reactant molecules, followed by chemical reaction, nucleation, and growth. In hot injection, a large number of nucleation centers are initially formed due to the sudden increase of temperature. Nanocrystal size distributions are managed through the use of the coordinating ligands in the hot solvent which prevent or limit particle growth via Ostwald ripening. Additional improvements in nanocrystal size distributions can be achieved through selective precipitation, whereby the slow addition of a non-solvent to the colloidal solution of particles provides controlled growth of larger particles.

While significant progress has been made in the synthesis of novel nanomaterials via hot injection in the laboratory, hot injection methods are difficult to scale-up. Considerable experience and skill is required to reproduce optimum results even for small laboratory-scale synthesis. This is in part due to the process dynamics (i.e. temperature and concentration gradients and residence time distributions) which are difficult to control within a batch environment yet have a pronounced effect on the size and shape distributions of nanocrystals. Scale-up of hot injection methods involves the use of large reaction vessels in which mixing, heat transfer and mass transfer can be quite complex based on long diffusional distances making reaction times long and process control difficult. Scale-up of nanomaterials within these types of batch processes is difficult requiring extended time and money for commercial-scale process design and optimization.

Microchannel reactors provide unique capabilities in achieving high levels of size and shape control while providing a more rapid path for scale-up by numbering-up [1]. Advanced process control provided by microchannel reactors includes precise and rapid changes in reaction conditions, spatial separation of reagent introduction, and unparalleled temporal resolution. Synthesis of nanomaterials using continuous flow microchannel reactors has attracted much attention in the past decadeT [1-5]. The reported microchannel reactors, however, are normally operated at relatively small flow rates (1~ 100 μL/min). While claims have been made for the ease of scaling-up nanomaterial synthesis within parallel-channel microreactors, the technical literature is very limited in providing scaled-up demonstrations [7] for the microchannel processing of nanomaterials.

One promising approach to the production scaling of nanomaterials is the equal-down/equal-up [8] strategy which can be enabled by the use of microchannel reactors. This approach starts with the process or product requirements to be realized at the industrial-scale which defines the main criteria for successful transition to the marketplace. These key requirements are used to specify design goals for laboratory-scale devices in an equal-down step. In the case of microchannel reactors, this would

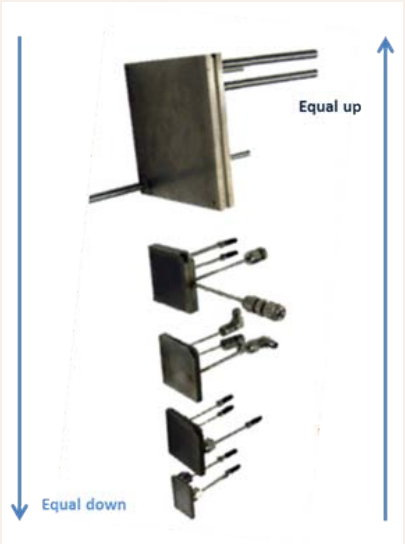

Figure 1 Equal-up/Equal down scale of microreactors from MBI.

be the production requirements for a single channel in order to enable scale-up by numbering up. The reaction conditions of the single channel laboratory design are designed to be equal to the industrial-scale design with respect to the governing heat transfer, mass transfer and reaction kinetics, leading to similarity with respect to key reactor geometries and materials, fluid dynamics, mixing methods, reaction engineering approaches, and thermal management strategies. This approach lends itself well to the use of microchannel reactors which can be scaled-up by increasing the number of microchannels. A consequence of developing the laboratory-scale microchannel reactor and process chemistry, which controls the micro-scale heat transfer, mass transfer and reaction kinetics, is the definition of the shape and structure of the active unit reactor cell that can be replicated to produce higher chemical production volumes. Unit cell results obtained from the laboratory-scale demonstration are then used for the detail design of the industrial-scale reactor in an equal-up step. The key parameters of the unit cell, such as channel width, channel length and modified residence time, are made to be the same in the industrial-scale reactor with the only difference being the number of channels, the size of headers, and the fabrication techniques used to implement the reactor design. This scaling approach has the potential to shorten the scale-up time of nanomaterials and allow newly developed nanomaterials to gain faster acceptance within the marketplace.

REFERENCES

1. Ehrfeld W, Hessel V, Löwe H, Microreactors, Wiley-VCH Weinheim 2000.
2. deMello J, deMello A. Microscale reactors: nanoscale products. Lab Chip. 2004; 4: 11N-15N.
3. Chang CH, Paul B.K, Atre S, Remcho V, Hutchison J. J. Nanopart. 2008; 10: 965-980
4. Song Y, Hormes J, Kumar CS. Microfluidic synthesis of nanomaterials. Small. 2008; 4: 698-711.
5. Marre S, Jensen KF. Synthesis of micro and nanostructures in microfluidic systems. Chem Soc Rev. 2010; 39: 1183-1202.
6. Chun-Xia Zhao, Lizhong He, Shi Zhang Qiao, Anton P J. Middelberg, Chem.Eng.Sci, , 2011; 66, 1463.
7. Jin HD, Garrison A, Tseng T, Paul BK, Chang CH. High-rate synthesis of phosphine-stabilized undecagold nanoclusters using a multilayered micromixer. Nanotechnology. 2010; 21: 445604.
8. Becker F, Albrecht J, Markowz G, Schütte R, Schirrmeister S, Caspary KJ, Döring H, Schwartz T, Dietzsch E, Klemm E, Kruppa T, Schüth F, IMRET 8, 2005, TK131 f.

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