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FRAUNHOFER INSTITUTE FOR CHEMICAL TECHNOLOGY ICT, BRANCH ICT-IMM

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1 *Magnetic separation*
2 *Ferrofluid*

PRECISELY CONTROLLED CONTINUOUS SYNTHESIS OF MAGNETIC NANOPARTICLES

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Introduction

Magnetic nanoparticles are of enormous interest due to their unique physical properties and they are found beneficial for versatile applications in technical, biological and medical products. Magnetic particles are broadly utilized for separation procedures, e.g. in diagnostic assays or biomolecule purification. They have already been used clinically in some areas, for example in magnetic resonance tomography or, more recently, for magnetic fluid hyperthermia treatment in cancer therapy. However, the specific requirements of every application on the particle characteristics have to be evaluated carefully to exploit the full potential of each application.

Features such as core size, polydispersity, particle shape and crystallinity have a direct impact on the magnetic properties and thus the performance in the various fields of application. We address the urgent need for efficient and reliable synthesis processes, which allow an exact adaptation of the particle properties to the specific challenges of the respective application.

Continuous flow synthesis of nanoparticles

In nanoparticle synthesis, reproducibility is one of the most important goals. The particle properties and hence the product quality typically result directly from the particle size and particle size distribution. Whereas in batch syntheses difficulties in reproducibility and scalability are common problems, these can be adequately addressed by our flow reaction technology. Moreover, the use of

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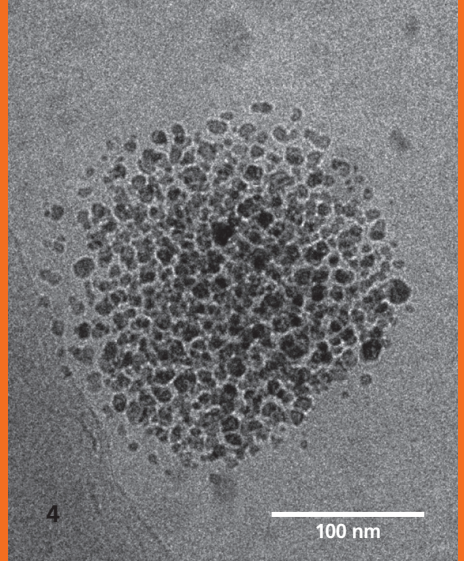

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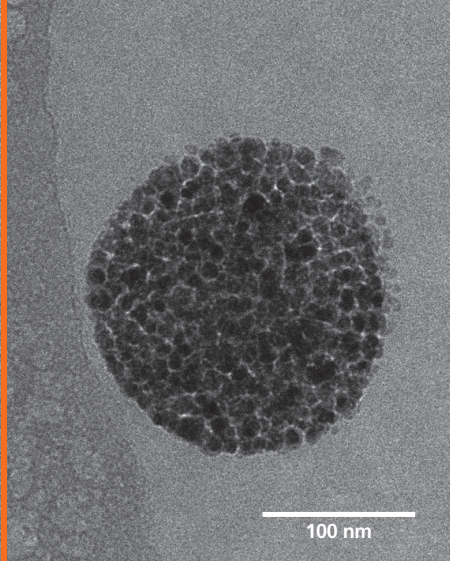


continuous synthesis processes offers a number of advantages that cannot be achieved with conventional batch syntheses.

Modular reactors for nanoparticle synthesis

Fraunhofer ICT-IMM develops modular reactors for continuous flow synthesis, designed for highly reproducible nanoparticle synthesis. Central part of our reaction setup is a microfluidic mixer developed by Fraunhofer ICT-IMM, combined with a temperature-controlled residence-time section. The setup is modular by design and can be adapted to specific needs. This enables the precise synthesis of high quality, uniform nanoparticles with optimized properties, tailored for the desired (biomedical) application.

Controlling the process parameters

The key benefit of continuous flow syntheses is the precise control over the process parameters such as flow rates, residence time (s) and temperature (s). By proper adjustment of these parameters, the desired product properties are achieved.

Scalability has been demonstrated for many cases and has been realized by both internal scale-up and parallelization and by external numbering-up.

Magnetic single-core iron oxide nanoparticles

In the case of the magnetic iron oxide nanoparticles, we can adjust the core size (from less than 10 nm to over 100 nm, examples see below) with high reliability and reproducibility. We established an energy- and resource-efficient process as we are using an aqueous synthesis route (no organic solvents), cheap reagents and low reaction temperatures (< 80 °C). Currently, flow rates of up to 100 mL/min or 150 L/d can be realized.

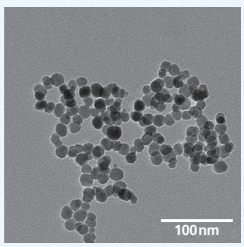
The possibility of introducing both hydrophilic as well as hydrophobic surface functionalities enhances the range of possible applications to technical applications, e.g. as additives in lubricants. Furthermore, our technology enables a controlled clustering of the single cores and offers the design of more complex hybrid materials.

R&D services, partnering

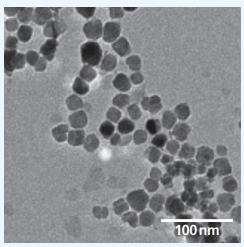
We are looking forward to establish and optimize continuous processes for our clients, tailored to their specific needs. Additionally, we are also seeking for collaborations with industrial and academic partners to participate in national and international R&D projects.

3 *Caterpillar micro mixer*
4 *Magnetic hybrid nanoparticles (TEM images)*

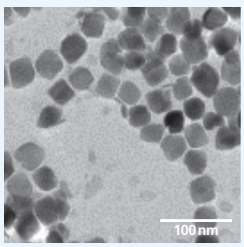
Range of different sizes of magnetic single-core iron oxide



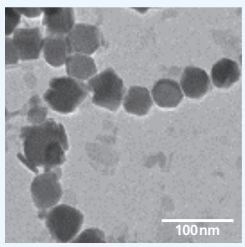
ca. 14 nm



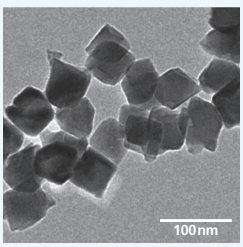
ca. 25 nm



ca. 30 nm



ca. 37 nm



ca. 50 nm