

High Gradient Magnetic Separation of Weakly Magnetic Nanoparticle Suspension Around a Sphere

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INTRODUCTION

Magnetophoresis is defined as the motion of magnetic particles, relative to their surrounding fluid, under the influence of an externally imposed magnetic field gradient, with applications spanning industries such as mineral processing, wastewater treatment, environmental remediation, and biotechnology.

$$F_{mp} = \frac{4\pi}{3} \frac{\Delta\chi R_p^3 c}{\mu_0} (\mathbf{B} \cdot \nabla) \mathbf{B}$$

Under the influence of an applied magnetic field, a particle experiences a magnetic force that is directly proportional to magnetic susceptibility of the particle and the magnetic field gradients.

OBJECTIVE

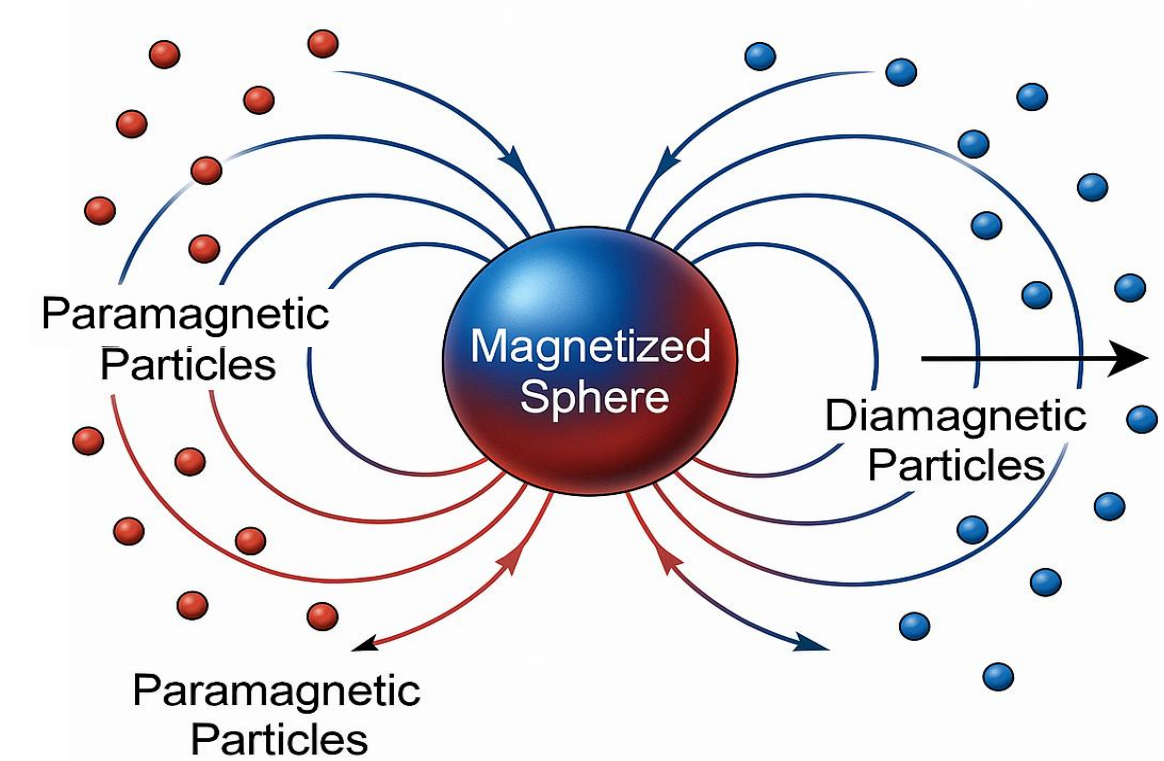


Figure 1: Representation of particle behavior around magnetized sphere.

- I. Investigate the potential of spherical geometries in high-gradient magnetic separation (HGMS) for nanoparticle systems.
- II. Advance the understanding of particle-magnetic field interactions for improved design and optimization of HGMS systems targeting both paramagnetic and diamagnetic particles.

MATERIALS AND METHODS

Nanoparticles

Paramagnetic	Mn ₂ O ₃	Radius=50 nm	$\chi = 14100 \times 10^{-6} \text{ cm}^3/\text{mole}$
Diamagnetic	Bi ₂ O ₃	Radius=40 nm	$\chi = -83 \times 10^{-6} \text{ cm}^3/\text{mole}$

Parameters

Concentration (mg/L)	Magnetic field (T)	Sphere dia. (mm)
10 - 100	0 - 1	2 - 5

EXPERIMENTAL SETUP

The experimental setup consists of a 1T electromagnet with poles approximately 10 cm in diameter that generates the magnetic field. The stainless-steel 440 grade sphere is positioned centrally within the cuvette.

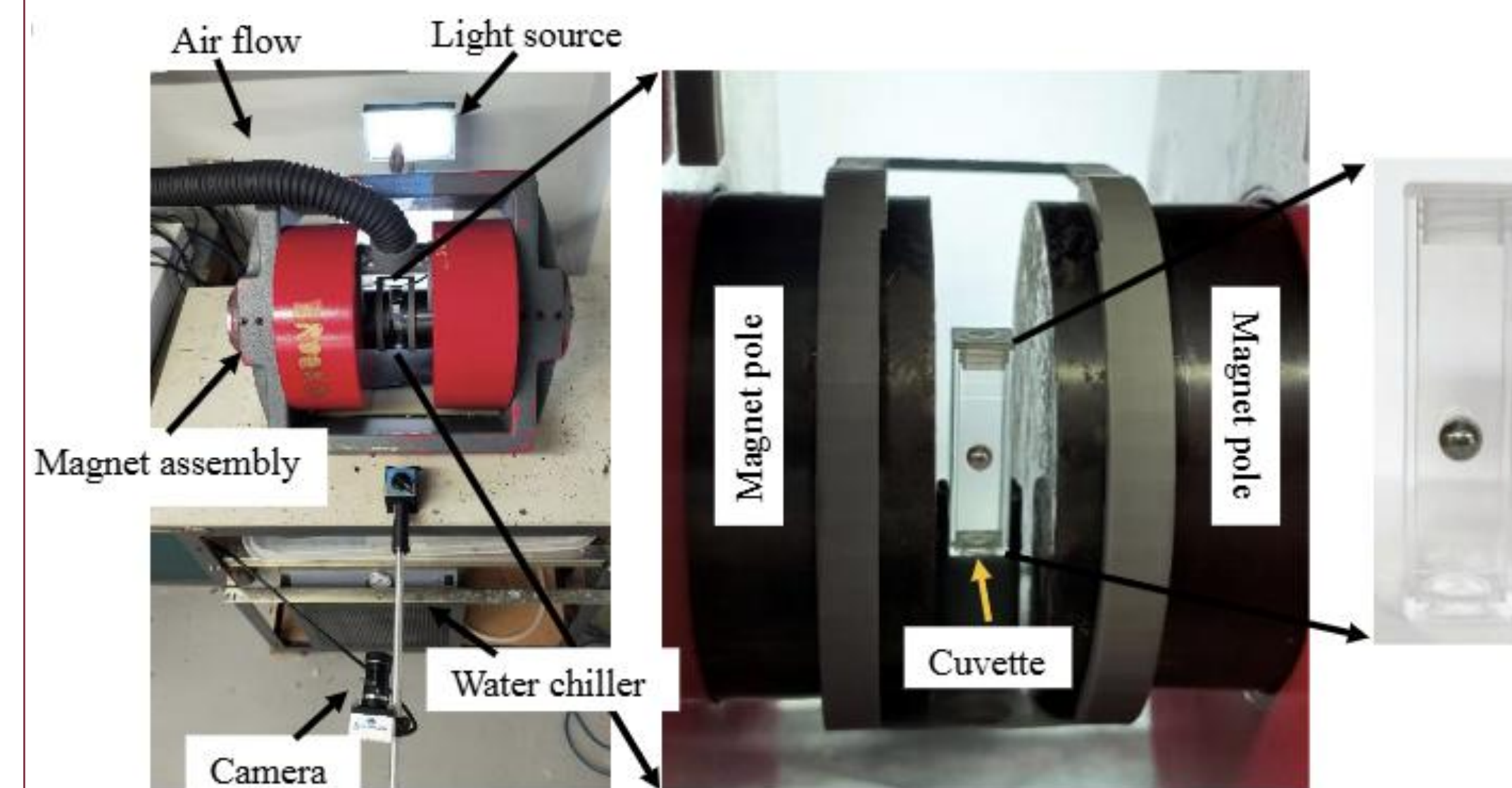


Figure 2: Experimental setup for the present study and the representation of a cuvette with sphere inside.

MAGNETIC FIELD

To simulate the magnetic field around sphere, a finite element-based numerical simulation technique was applied using COMSOL Multiphysics 6.1.

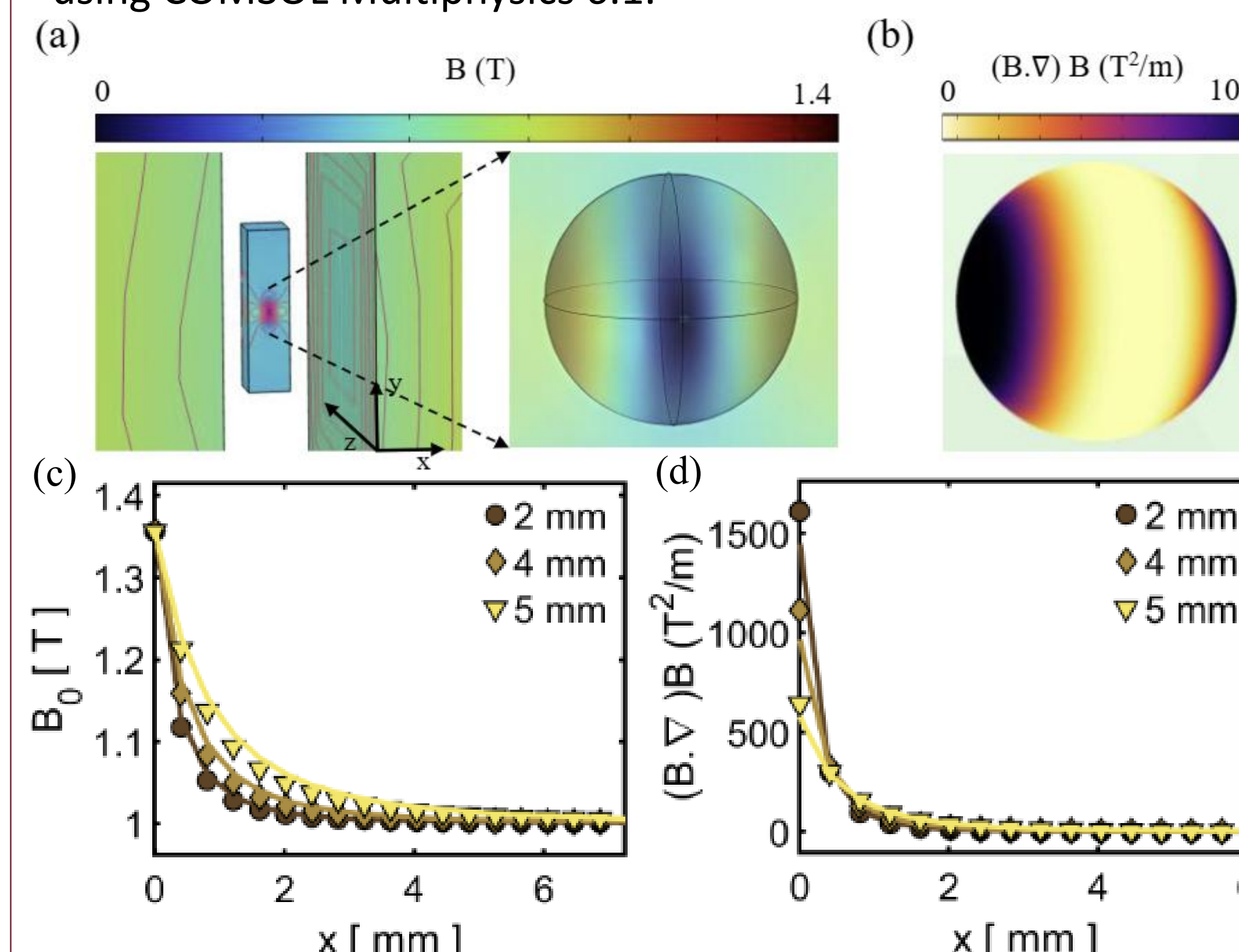


Figure 3: (a) Three-dimensional simulation of the magnetic flux density around a sphere with a diameter of 5mm under the influence of $B = 1 \text{ T}$ applied magnetic field. (b) Corresponding 3D profile of the magnetic field gradient around a sphere under the same conditions as in figure 3.a. (c) Averaged magnetic flux density and (d) its gradients around sphere of different diameters under a 1 T uniform magnetic field. Symbols represent the simulation results, curves show theoretical predictions, $x=0$ corresponds to the sphere surface

RESULTS AND DISCUSSION

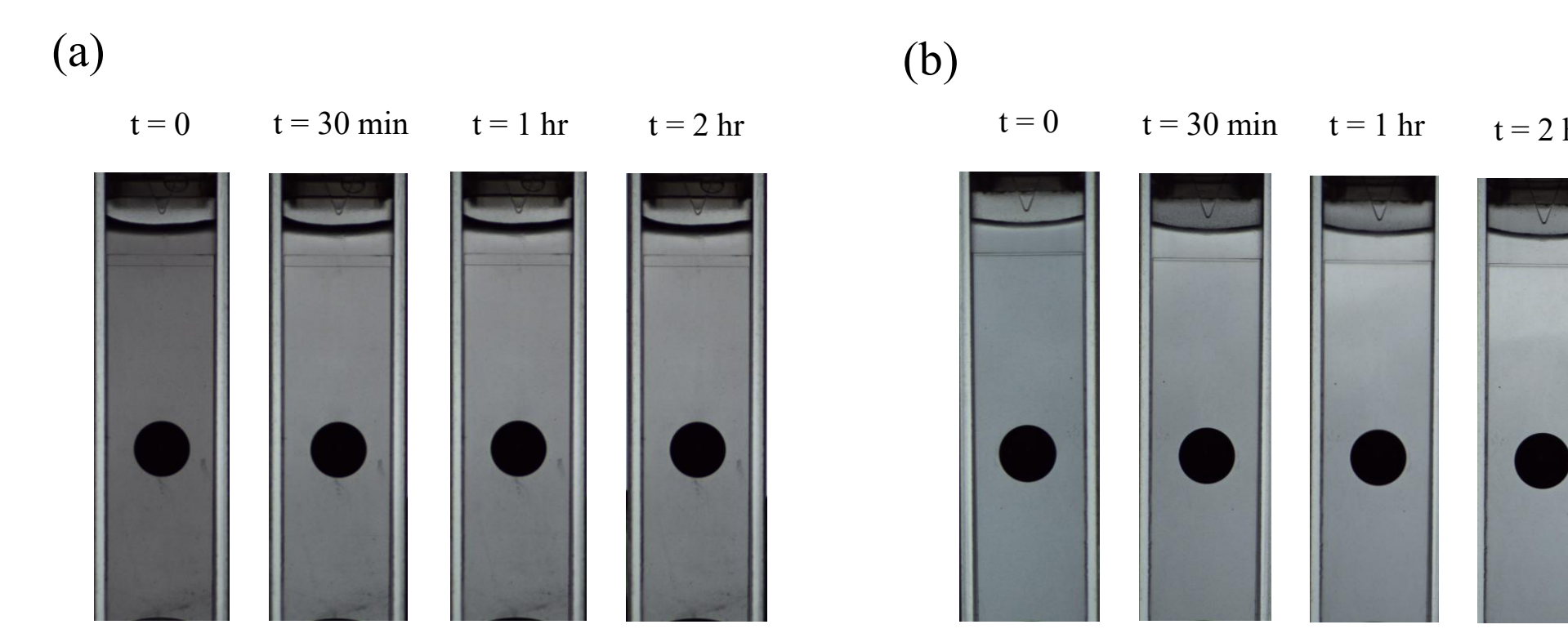


Figure 4: (a) The experimental results for (a) manganese oxide and (b) bismuth oxide at a concentration = 100 mg/L, magnetic field $B = 0 \text{ T}$ and sphere diameter, $d = 5 \text{ mm}$.

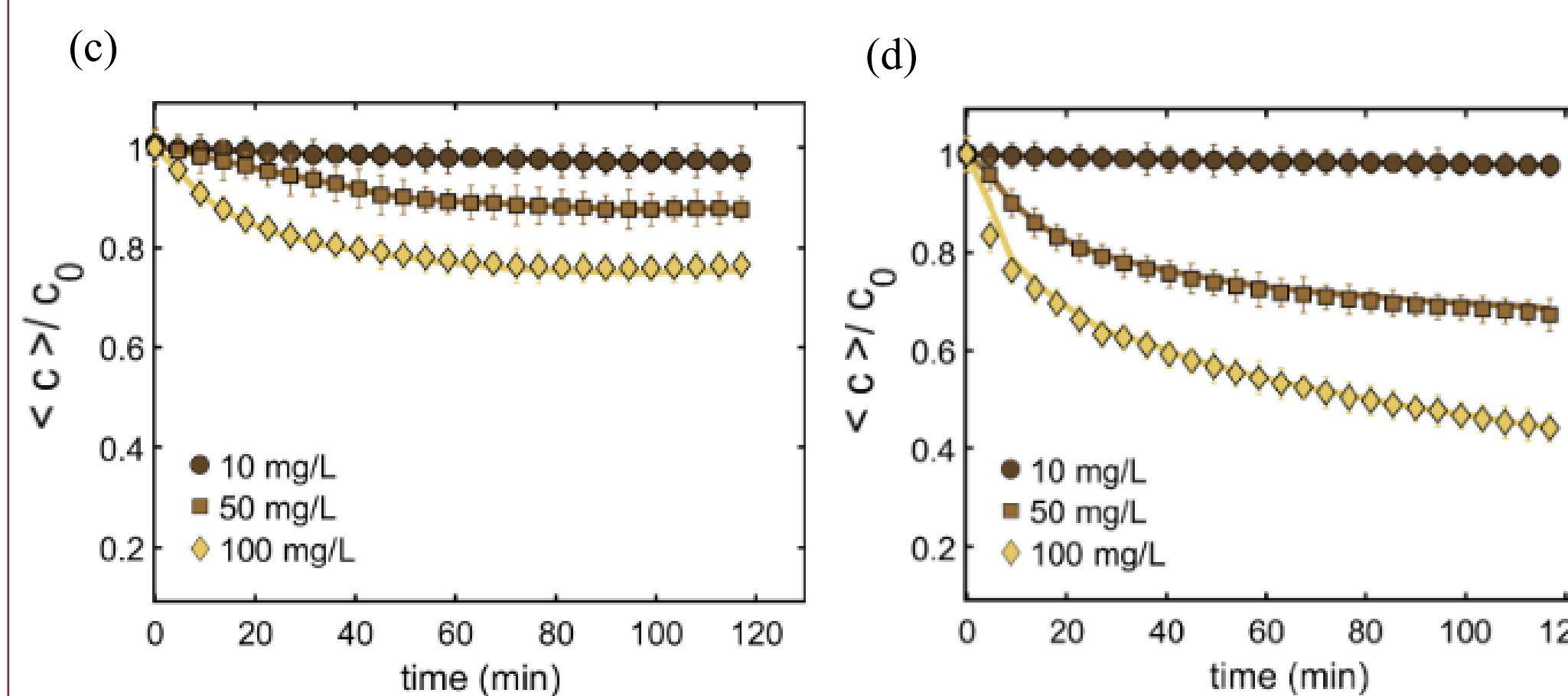
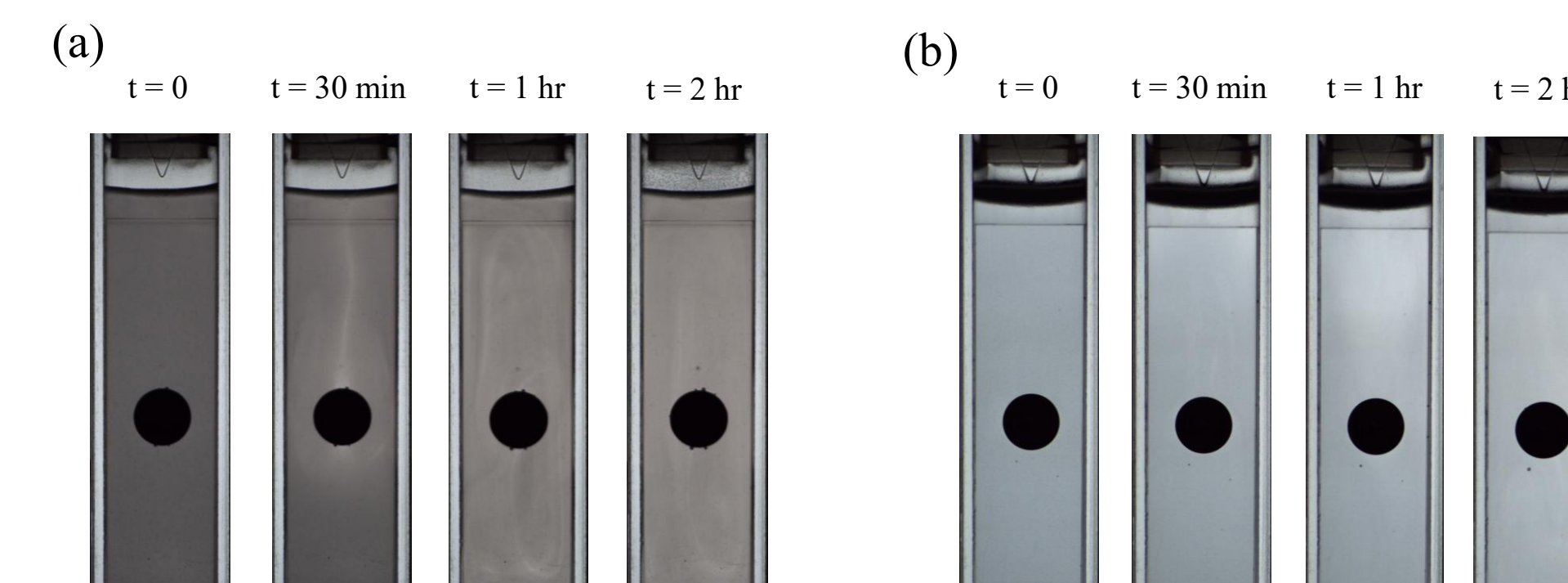


Figure 5: (a) The experimental results for manganese oxide and (b) bismuth oxide at a concentration = 100 mg/L, magnetic field $B = 1 \text{ T}$ and sphere diameter, $d = 5 \text{ mm}$. Spatio-temporal evolution of concentration for (c) manganese oxide and (d) bismuth oxide for sphere diameter = 5mm, magnetic field $B = 1 \text{ T}$.

EFFECT OF MAGNETIC FIELD

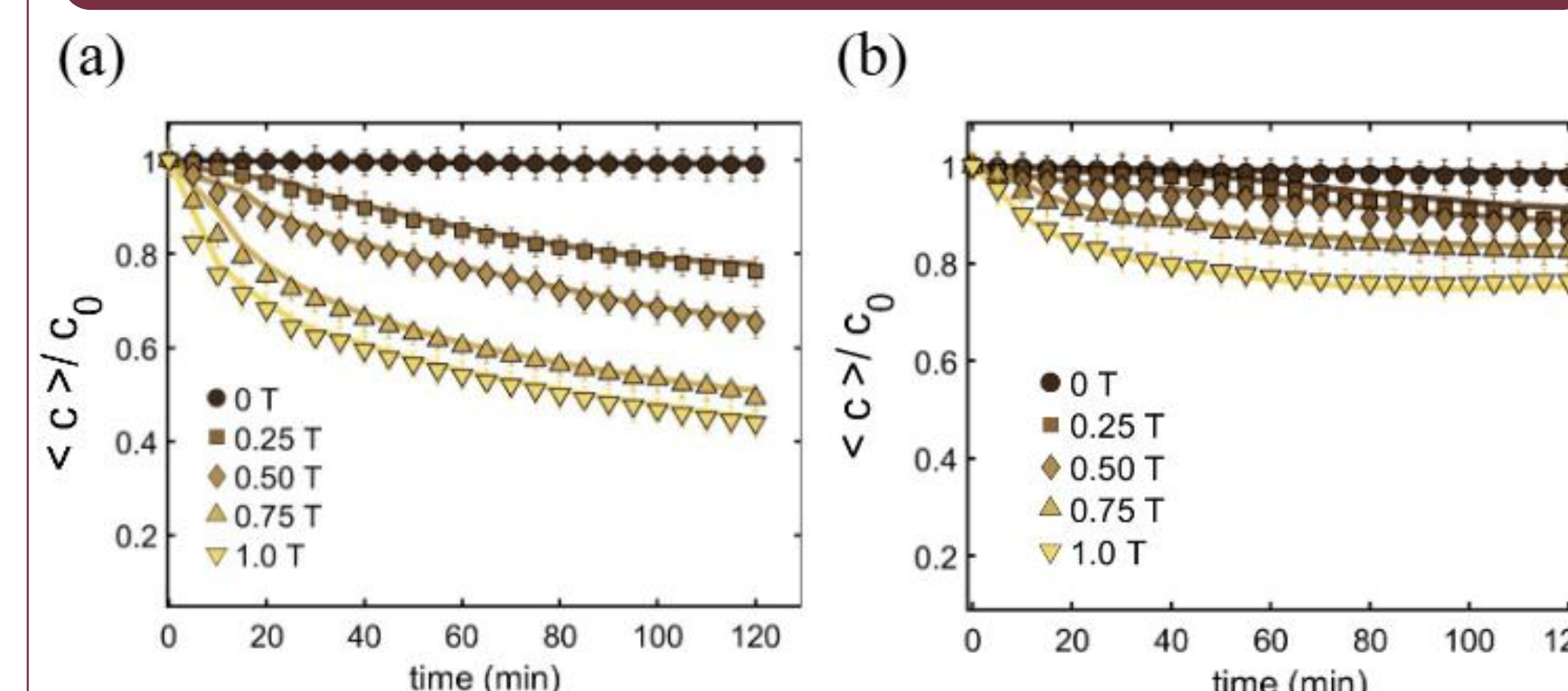


Figure 6: Effect of magnetic field on (a) manganese oxide and (b) bismuth oxide at concentration = 100 mg/L, and sphere diameter $d = 5 \text{ mm}$.

EFFECT OF SPHERE DIAMETER

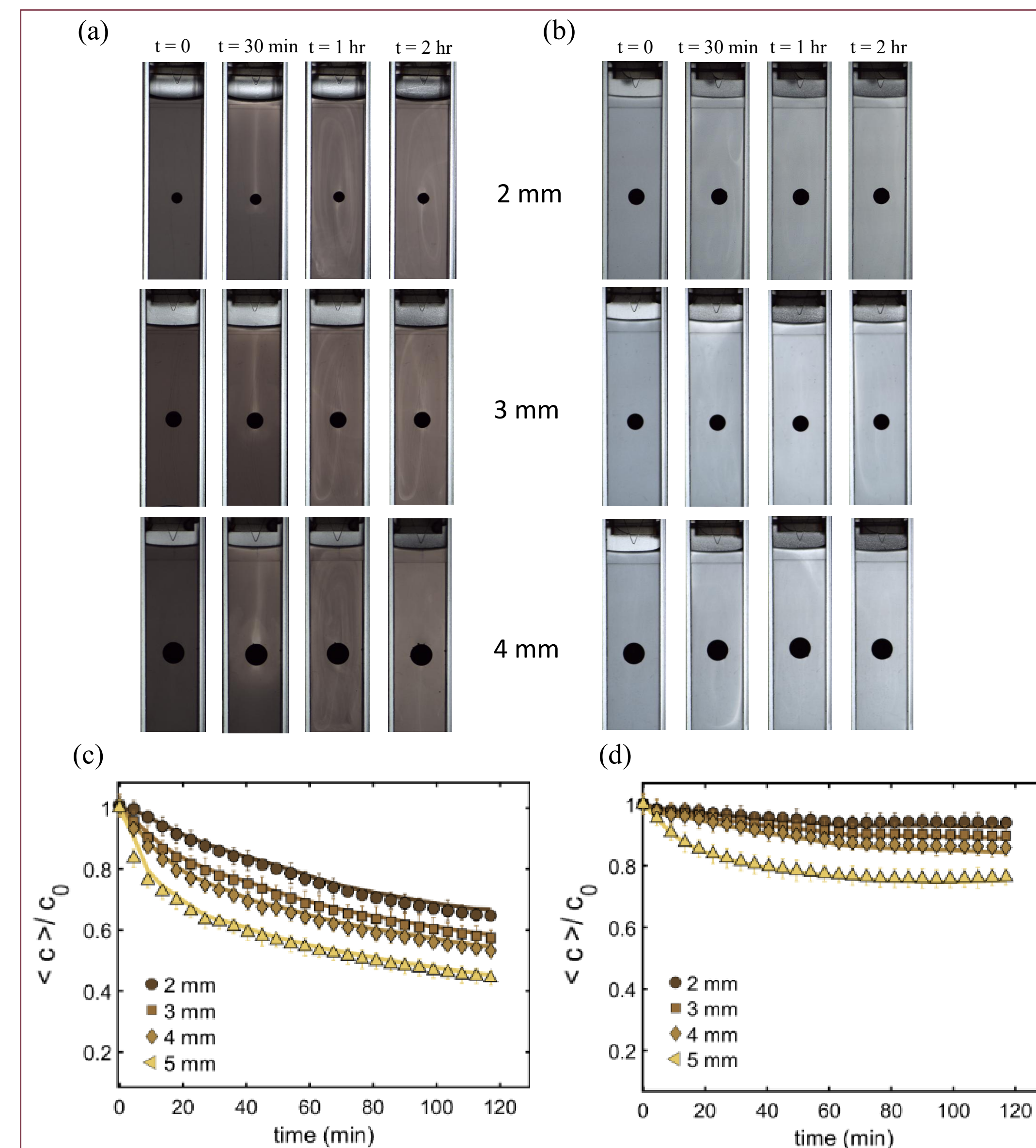


Figure 7: Effect of sphere diameter for (a) manganese oxide and (b) bismuth oxide nanoparticles at concentration = 100 mg/L, and magnetic field $B = 1 \text{ T}$. Spatio-temporal evolution of concentration for (c) manganese oxide and (d) bismuth oxide for different sphere diameters at concentration = 100 mg/L, magnetic field $B = 1 \text{ T}$.

CONCLUSIONS

- I. Paramagnetic particles were attracted toward the sphere and accumulated in regions with a strong magnetic field gradient.
- II. In contrast, diamagnetic particles experienced a repulsive force and tended to deposit on top of the sphere.
- III. The separation efficiency for both types of nanoparticles improved with increasing sphere diameter and magnetic field strength.
- IV. Future work will focus on exploring the influence of magnetic susceptibility on the separation process.

REFERENCES



ACKNOWLEDGEMENTS

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