CONTROL OVER NANO-CRYSTALIZATION IN TURBULENT FLOW IN THE PRESENCE OF MAGNETIC FIELDS

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Introduction
The influence of the magnetic field and the water flow on the crystal form of calcium carbonate precipitated from low-concentration water solution was followed systematically.

By changing the strength of the field the calcite/aragonite/vaterite ratio varied. The crystal form and the particle size distribution of the precipitated calcium carbonate were determined by using X-ray analyses and TEM.

A simple hydro dynamical model, using the Navier-Stoke’s and Maxwell’s equations predicts that there is a strong energy coupling and transfer between turbulent flow and the magnetic fields and they can be amplified to high values. Since the formation of aragonite is enhanced in the presence of magnetic field, scaling is prevented in turbulent flow.

Experimental Method
• Sample solutions of calcium hydrogen carbonate (Ca(HCO₃)₂) were prepared by dissolving finely ground calcium-carbonate powder of analytical purity in deionized water and bubbling the suspension with ground calcium-carbonate powder of analytical purity to precipitate.
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• Experiments were performed in parallel runs.

One of the runs was treated with a magnetic field and the other was not. For the magnetic treatment an applied DC field of between 0.5 and 1.3 T was used.

• The remaining solids were removed by filtering the suspension through a filter.

A controlled drying procedure at 70 °C and 40 % relative humidity in a Weiss humidity chamber obtained the crystals of CaCO₃.

• The X-ray powder diffraction patterns of the precipitating samples were recorded on a Siemens D-5000 diffractometer using a reflection geometry (Bragg-Brentano), with a monochromatized graphite X-ray source.

• Data were collected in the 2θ mode from 20 to 70° in steps of 0.04°; the integration time was 30 s per step. The divergence and anti scatter slits were fixed in 1° and the front slit was 0.2 mm wide.

• For the study of the nucleation and further crystallization of CaCO₃ we used analytical electron microscopy. Samples for the TEM observation and analysis (Joel 2000 FX and Joel 2010 F (FEI)) were prepared using a C/Cu grid that was immersed into the solution for different times (t₁=5 min; t₂=10 min) after the beginning of the process. The nano-sized particles were collected on the grid and examined under the electron microscope. EDXS was used to characterize the chemical composition.

Coupling and transfer of magnetic energy between the molecules and the magnetic field.

• The gap between the ground electronic states of the calcite and the aragonite can be provided by a static magnetic field of ~ 45 Tesla within a typical inter-nuclear distance of 0.5nm between the ions of Ca and CO₃. This value corresponds to an energy density of ~10⁷ Joule/m³.

• Transfer of energy between a turbulent flow and a spontaneous magnetic field can be described by using the macroscopic approach in a phenomenological way. The interaction of the magnetic field and the flow is described by the Maxwell equation

\[ \frac{\partial B}{\partial t} + \nabla \times (\mathbf{v} \times \mathbf{B}) = \sigma \nabla \times \mathbf{E} + \mathbf{J} \]

Where B₀ is the magnetic field and \( \mathbf{J} \) is the current density.

Substituting \( \frac{\partial B}{\partial t} \) from the above equation into the Navier-Stokes equation gives

\[ \frac{\partial \mathbf{v}}{\partial t} = \mathbf{v} \times \mathbf{B} - \nabla P + \frac{1}{\rho} \nabla \cdot \left( \mu \nabla \mathbf{v} \right) \]

Where \( \mathbf{v} \) is the velocity, \( P \) is the pressure of the fluid, \( \rho \) is the density of the fluid, \( \mathbf{B} \) is the magnetic induction and \( \mu \) is the permeability of the free space.

Neglecting quadratic terms of the field in the equation of motion:

\[ \frac{\partial \mathbf{v}}{\partial t} = \mathbf{v} \times \mathbf{B} - \nabla P + \frac{1}{\rho} \nabla \cdot \left( \mu \nabla \mathbf{v} \right) \]

By comparing last equation with the equation of Maxwell

\[ \mathbf{B} = \mu \mathbf{E} \]

In the case of an incompressible flow

\[ \mathbf{B} = \frac{1}{\mu} \nabla \mathbf{u} + \frac{1}{\mu \rho} \nabla \mathbf{P} \]

U being the change of the mean velocity over a distance L

For energy density of the spontaneous magnetic field ~10⁷Joule/m³, which is required to bridge the energy difference between the two forms of CaCO₃, in order to nano-crystallize it as aragonite, the turbulent flow should generate velocity fluctuations of the order of 10⁶ m/sec. Such values of velocity changes could be achieved by thermal fluctuations and/or on the boundary of a conductive surface from ion acceleration by mirror charges on the conductive surfaces.

Experimental Results

Barrett plot (Bₜ = 11). Experimental (crosses), calculated (solid line) and difference (dashed line) Vertical bars dense CaCO₃, θₖ, reflection positions of calcite (top row), aragonite (middle row) and vaterite (lower row).

TEM images of crystals formed in the presence of the magnetic field (left), compared to the crystals obtained without the applied magnetic field (right).

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Crystal obtained at time t₂ with (left) and without (right) the magnetic field.

TEM image of different CaCO₃ crystals TEM image of a diffraction pattern of Vaterite TEM image and a diffraction pattern of Calcite TEM image of different CaCO₃ crystals TEM image and a diffraction pattern of Aragonite

Conclusion
Systematic experimental work showed that magnetic field enhances the formation of aragonite in the early nano-nucleation stages of crystallization of CaCO₃ in water flow systems, reducing thus scaling. The formation of aragonite in the presence of magnetic fields is enhanced when the flow is turbulent. This is due to the energy transfer from the turbulent flow to the magnetic field, which is amplified proportional to the change of the kinetic energy of the flow.

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