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Magnetocatalytic Low-Pressure Amide Hydrogenation

Ref.-No.: MI1001-6828-LC

Abstract

This invention presents a novel magnetocatalytic process for the hydrogenation of amides into amines using molecular hydrogen under low-pressure conditions. The method utilizes a commercially available platinum-on-alumina (Pt/Al_2O_3) catalyst functionalized with magnetic iron carbide nanoparticles (ICNPs). When exposed to an alternating current magnetic field (ACMF), these ICNPs generate localized heating, transferring energy efficiently to neighboring platinum sites and enabling catalytic activity at reactor temperatures around 150 °C and hydrogen pressures as low as 1–3 bar. The process achieves high selectivity and conversion even in glass reactors, eliminating the need for traditional high-pressure equipment. Notably, the catalyst system is recyclable, highly energy-efficient, and responsive to intermittent electricity - allowing its integration into sustainable, renewables-based chemical manufacturing.

Background

Amide hydrogenation to amines is a valuable transformation in the synthesis of pharmaceuticals, agrochemicals, and polymers. Traditional catalytic processes require extreme conditions - high pressures (50–900 bar H_2) and temperatures (150–300 °C) - and often involve complex catalysts or stoichiometric reductants. These limitations hinder scalability, safety, and environmental sustainability. Although some efforts have reduced the severity of conditions using specially designed bimetallic catalysts, the required catalyst loadings and reaction times remain impractical. Magnetically induced catalysis has recently emerged as a promising approach, offering selective, localized heating without globally raising reactor temperature. This invention leverages that principle to solve the challenges of conventional amide hydrogenation.

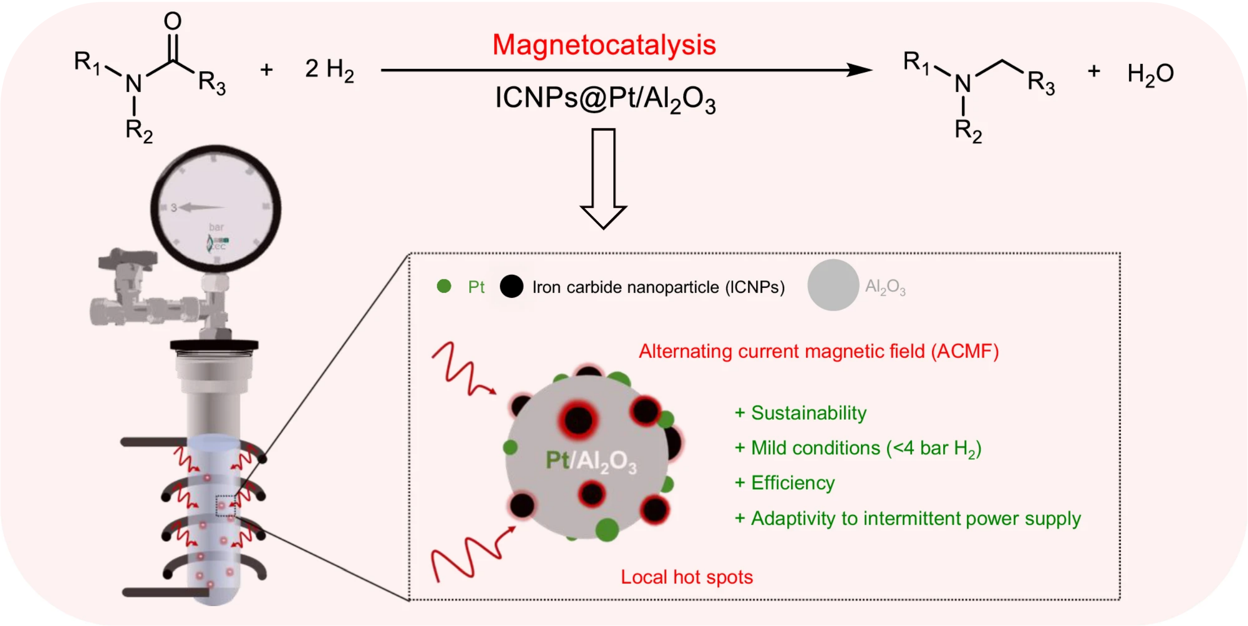

Figure 1: Magnetocatalytic amide hydrogenation using $ICNPs@Pt/Al_2O_3$ under ACMF enables efficient, low-pressure conversion to amines with localized heating and high selectivity.

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The described innovation centers on a magnetically responsive heterogeneous catalyst system: platinum nanoparticles supported on alumina (Pt/Al_2O_3) functionalized with iron carbide nanoparticles (ICNPs). These ICNPs exhibit exceptional magnetic heating capabilities when exposed to an alternating current magnetic field (ACMF, 350 kHz, 72 mT), converting electromagnetic energy into localized heat. This heat is transferred directly to adjacent Pt sites, which then catalyze the hydrogenation of amides with molecular hydrogen (H_2). This strategy enables effective C=O bond cleavage under remarkably mild conditions - reactor temperatures around 150 °C and H_2 pressures as low as 1–3 bar.

The ICNPs are synthesized via carbidization of Fe(0) nanoparticles and then immobilized on commercial Pt/Al_2O_3 through solvent-assisted impregnation and magnetic annealing. This thermal treatment ensures strong interfacial adhesion, preventing nanoparticle leaching and preserving catalyst integrity during cycling. Scanning electron microscopy confirms uniform ICNP distribution, while Mössbauer and X-ray absorption spectroscopy verify the presence of active iron carbide phases and metallic Pt.

Crucially, this system requires no external heating devices; the magnetic heating is instantaneous and spatially confined to the catalyst, minimizing bulk heating and enabling energy-efficient operation. The catalyst shows excellent recyclability, high selectivity toward amine formation, and adaptability to fluctuating magnetic power - allowing for integration with variable renewable energy inputs. This method provides a practical and scalable route for sustainable amide hydrogenation.

Advantages

- **Low-pressure operation**: Efficient hydrogenation achieved at 1–3 bar H_2, reducing equipment demands and safety risks.
- **Energy efficiency**: Magnetocatalysis consumes substantially less energy than conventional heating to deliver the a given product yield
- **Rapid, localized heating**: Fast activation and deactivation via magnetic field switching enables precise process control.
- **Catalyst recyclability**: Maintains activity and selectivity over multiple cycles without Pt or Fe leaching.
- **Scalable and compatible**: Built on commercially available catalysts and reactors, suitable for lab and industrial settings.

Potential applications

- **Pharmaceutical intermediate synthesis**: Production of alkylated amines used in anti-tumor and central nervous system drugs.
- **Fine chemicals and dye manufacturing**: Selective amide-to-amine conversion for downstream derivatization.
- **Polymer precursors**: Sustainable synthesis of amine-functionalized monomers.
- **Green chemistry processes**: Replacement of stoichiometric reductants in reduction chemistry.
- **Renewable-powered chemical plants**: Integration into modular or off-grid production using intermittent power sources.

Publications

Lin, S. H., Ahmedi, S., Kretschmer, A., Campalani, C., Kayser, Y., Kang, L., DeBeer, S., Leitner, W., & Bordet, A. (2025). Low pressure amide hydrogenation enabled by magnetocatalysis. *Nature Communications*, *16*(1), 3464.

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