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Research
Green Industrial Processes—Perspective

Surface-Driven High-Pressure Processing

Keith E. Gubbins [a,*], Kai Gu [b], Liangliang Huang [c,*], Yun Long [d], J. Matthew Mansell [a], Erik E. Santiso [a,*], Kaihang Shi [a], Małgorzata Śliwińska-Bartkowiak [e], Deepti Srivastava [a]
[a] *Department of Chemical and Biomolecular Engineering, North Carolina State University, Raleigh, NC 27695-7905, USA*
[b] *Department of Chemistry, Zhejiang University, Hangzhou 310027, China*
[c] *School of Chemical, Biological and Materials Engineering, The University of Oklahoma, Norman, OK 73019, USA*
[d] *Department of Chemical and Biomolecular Engineering, National University of Singapore, Singapore 117585, Singapore*
[e] *Faculty of Physics, Adam Mickiewicz University in Poznań, Poznań 61-614, Poland*

* Corresponding authors.
E-mail addresses: keg@ncsu.edu (K.E. Gubbins), hll@ou.edu (L. Huang), eesantis@ncsu.edu (E.E. Santiso).

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ABSTRACT
The application of high pressure favors many chemical processes, providing higher yields or improved rates in chemical reactions and improved solvent power in separation processes, and allowing activation barriers to be overcome through the increase in molecular energy and molecular collision rates. High pressures—up to millions of bars using diamond anvil cells—can be achieved in the laboratory, and lead to many new routes for chemical synthesis and the synthesis of new materials with desirable thermodynamic, transport, and electronic properties. On the industrial scale, however, high-pressure processing is currently limited by the cost of compression and by materials limitations, so that few industrial processes are carried out at pressures above 25 MPa. An alternative approach to high-pressure processing is proposed here, in which very high local pressures are generated using the surface-driven interactions from a solid substrate. Recent experiments and molecular simulations show that such interactions can lead to local pressures as high as tens of thousands of bars, and even millions of bars in some cases. Since the active high-pressure processing zone is inhomogeneous, the pressure is different in different directions. In many cases, it is the pressure in the direction parallel to the surface of the substrate (the tangential pressure) that is most greatly enhanced. This pressure is exerted on the molecules to be processed, but not on the solid substrate or the containing vessel. Current knowledge of such pressure enhancement is reviewed, and the possibility of an alternative route to high-pressure processing based on surface-driven forces is discussed. Such surface-driven high-pressure processing would have the advantage of achieving much higher pressures than are possible with traditional bulk-phase processing, since it eliminates the need for mechanical compression. Moreover, no increased pressure is exerted on the containing vessel for the process, thus eliminating concerns about materials failure.

1. A new green route to high-pressure manufacturing

Pressure is a fundamental thermodynamic variable that has the potential to control and enhance the manufacture of chemicals and solid materials with a wide range of desired properties. High pressures are necessary in many manufacturing processes in the chemical, oil and gas, food, pharmaceutical, agrichemicals, and materials industries. Such compression is often required to achieve satisfactory yields and rates in chemical reactors and solvent power in separations, and for the synthesis of novel, high-pressure materials. Familiar examples are the Haber process to produce ammonia (typically 15–25 MPa); the manufacture of methanol from syngas (usually 5–10 MPa); high-pressure hydrogenation, carbonylation, and amination reactions (to 1.5 MPa); the synthesis of pharmaceuticals; and supercritical gas extraction and reaction (7–40 MPa). In conventional processing, these pressures are achieved through the compression of a bulk phase. However, such compression is expensive, because of both the thermodynamic work required and the need to develop multistage pumps that can withstand these pressures. As a result, high-pressure industrial processes seldom exceed a pressure of about 25