

The Global Energy Crisis is Reshaping the Chemical Industry: new Strategies and Technologies

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The chemical industry faces major challenges owing to the global energy crisis that required to reshape production processes¹. Sustainable industrial chemistry relies on the optimisation of protocols and downstream such as extraction, purification and drying. Process intensification, which includes non-conventional techniques and continuous manufacturing, has emerged as a key strategy to improve efficiency and environmental impact. Technologies such as ultra-sound, microwaves, mechanochemistry and reactive extrusion offer improved performance but face scalability and proprietary barriers. Flow chemistry offers additional benefits, including smaller reactors, lower energy consumption (from 40 to 90%) and increased safety through continuous, automated reactions. However, implementing these methods requires overcoming engineering, economic and regulatory hurdles. Biphasic catalysis and sonochemical activation in liquid-liquid systems are promising approaches for scalable reactions under mild conditions. Mechanochemistry involves the activation of chemical reactions by mechanical energy under solvent-free conditions, avoiding conventional thermal processing in organic solvents. Most organic reactions have been successfully performed in ball mills often with high chemo- and regioselectivity, even with multifunctional substrates². The increasing industrial interest in mechanochemical reactions³ has revealed critical challenges related to scale-up, particularly due to the difficulty in accurately measuring and controlling temperature and pressure, which can impact reproducibility. Recent developments have therefore focused on continuous mechanochemical technologies. Among these reactive extrusion (REX) has emerged as a particularly promising approach for industrial implementation. In this technique, screws (single, twin, or multiple) generate mechanical energy through shear, compression, and friction, while enabling precise control over temperature, mixing, and residence time⁴. Reaction optimisation requires adequate residence time which is governed by the design and sequence of screw elements, including conveying, kneading, mixing, and reverse units, the latter corresponding to backward conveying elements with negative pitch. For systems involving diluted slurries, continuous bead milling represents a complementary approach. In these reactors, fast-rotating discs mobilise beads (30–80% v/v), generating high shear and efficient mixing. Operation is typically performed in recirculation mode to achieve sufficient conversion. Alternative technologies capable of processing solvent-free or slurry mixtures remain limited. Among them, microwave-assisted flow reactors equipped with Archimedean screws or screw pumps have been explored⁵. The implementation of solvent-free or slurry systems in continuous flow contributes to process intensification, enabling more sustainable and efficient chemical processes through reduced energy consumption, minimised waste generation, and improved resource utilisation.

References:

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