

Compact Plug-Flow Prepolymerization Reactor.

Advancing Flexibility Between Batch and Continuous Elastomer Production

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The elastomer and rubber industry is entering a period of increasing technological pressure. Producers are expected to improve sustainability, reduce emissions and energy consumption, increase operational flexibility, and simultaneously deliver more differentiated materials with increasingly stringent quality specifications.

Many synthetic rubber plants currently in operation were originally designed decades ago and continue to rely on process concepts that, although robust, present important limitations regarding efficiency, flexibility, and process control. As discussed previously in the European Rubber Journal article "*Sustainability in synthetic rubber plants through advanced process technology*," the industry must accelerate the adoption of advanced process technologies capable of improving flexibility, reducing environmental impact, and enabling greater operational performance.

Among the most important opportunities for innovation is the implementation of reactor technologies capable of bridging the gap between traditional batch polymerization and continuous operation.

Batch and Continuous Operation: Complementary Strengths and Limitations

Batch and continuous polymerization reactors each offer important advantages depending on product requirements and operating philosophy. Batch reactors provide high formulation flexibility and are often preferred for specialty products, product development, and complex polymer architectures. Continuous reactor systems, by contrast, offer high throughput, superior consistency, and improved energy efficiency. However, both technologies also present limitations.

Batch reactor systems frequently face:

- Heat removal constraints during highly exothermic reactions
- Longer cycle times and lower productivity
- Greater campaign-to-campaign variability
- Difficult scale-up conditions

Continuous reactor systems, meanwhile, may encounter:

- Limited flexibility for specialty grades
- Sensitivity during start-up and grade transitions
- Fouling and gel formation under difficult reaction conditions
- Challenges in functionalization and kinetic control

As a result, many elastomer producers operate batch and continuous reactor trains as independent assets. The industry therefore faces an important unmet need: a practical and economical reactor concept capable of hybridizing or progressively transitioning between both operating philosophies without major disruption to existing infrastructure.

Plug-Flow Prepolymerization Reactor as an Enabling Technology

Innventik has developed a patented **Compact Plug-Flow Prepolymerization Reactor** intended to address this operational gap. The reactor technology is protected by granted Spanish Patent ES 2983867 B2 and international PCT publication WO2025/221134 A1 (PCT/MX2025/050031),

with national phase strategy underway including China Patent Application 202580003162.7 and US patent pending.

The compact plug-flow prepolymerization reactor was conceived as a modular device capable of stabilizing the earliest and most sensitive stages of polymerization before the main reactor system. The objective is not to replace existing reactors, but rather to strengthen process robustness and flexibility by preconditioning the reaction mixture under controlled plug-flow conditions.

The reactor combines several important engineering features:

- Plug-flow reaction behavior with minimal back-mixing
- Controlled partial conversion and viscosity development
- High-efficiency heat transfer
- Dual agitation systems for mixing and self-cleaning
- Multiple injection points for monomers, initiators, solvents, and functionalization agents

Unlike conventional tubular reactors, the compact plug-flow prepolymerization reactor incorporates both central high-speed mixing and peripheral low-speed wall-scraping elements. This combination enables improved hydrodynamics while reducing fouling, hot spots, and gel formation under demanding operating conditions.

Stabilizing the Most Sensitive Reaction Stage

In many elastomer processes, the most difficult stage to control occurs at the beginning of polymerization inside the reactor system. Reaction kinetics are highly sensitive to local concentration gradients, mixing efficiency, temperature profiles, impurities, and viscosity development. These challenges become particularly severe in highly exothermic polymerizations or when operating at elevated solids concentrations.

The plug-flow prepolymerization reactor seeks to stabilize this early reaction stage before the material enters the main production reactor system. By performing controlled partial conversion upstream, downstream reactors receive a more homogeneous and partially reacted feed, improving overall process stability.

Potential benefits of the reactor concept include:

- Improved control of reaction kinetics and residence time
- Enhanced heat and mass transfer
- Reduction of hot spots and thermal excursions
- Lower risk of fouling, scaling, and gel formation
- Improved product consistency and reproducibility
- More stable downstream reactor operating conditions

The reactor concept may therefore serve as a practical engineering tool to improve interoperability between batch and continuous assets while supporting higher operational flexibility.

Potential Applications in Elastomer Manufacturing

The original plug-flow prepolymerization reactor was conceived for solution elastomer systems such as SBR and LCBR, but the reactor design philosophy may also be relevant to broader elastomer applications.

EPDM Production

EPDM polymerization presents important operational challenges associated with heat removal, viscosity development, and catalyst sensitivity. Continuous EPDM reactor systems can experience long ramp-up periods due to process holdup, recycle effects, catalyst activation behavior, and measurement latency.

A compact plug-flow prepolymerization reactor may assist by:

- Stabilizing early reaction initiation
- Improving catalyst-contact uniformity
- Reducing local thermal excursions
- Providing better-defined residence-time behavior
- Improving consistency of feed entering downstream reactors

By conditioning the reaction upstream, the prepolymerization reactor may help the process reach stable operating conditions faster while improving reproducibility and operability.

Functionalization in Continuous Reactor Systems

Functionalized elastomers continue to attract increasing interest due to their potential to improve filler interaction, tire performance, and differentiated material properties. However, functionalization in continuous reactor systems remains challenging because of short residence times and the sensitivity of functional reactions to local process conditions. The plug-flow prepolymerization reactor enables controlled early-stage polymer growth under stable temperature and composition profiles, potentially facilitating:

- More homogeneous addition of functional agents
- Reduced side reactions and gel formation
- Improved stability during functionalization
- Narrower and more predictable reactor operating windows

This reactor approach may create a practical pathway toward scalable production of functionalized elastomers without major modifications to existing continuous reactor assets.

Modular and Retrofit-Friendly Reactor Design

One important aspect of the compact plug-flow prepolymerization reactor is its compatibility with existing plant infrastructure. Many producers seek lower-risk modernization strategies capable of improving flexibility and productivity without requiring full replacement of installed reactor systems.

The modular nature of the reactor enables potential integration into:

- Existing batch reactor lines
- Continuous reactor trains
- Hybrid batch-continuous configurations
- Specialty product campaigns
- Capacity debottlenecking projects

Potential operational advantages of the reactor include:

- Faster transitions between operating modes
- Improved reproducibility between campaigns
- Enhanced flexibility for specialty grades
- Reduced disruption to existing infrastructure
- Increased throughput without compromising quality

This type of reactor concept aligns with the broader industry trend toward more flexible, modular, and sustainable production systems.

Toward the Next Generation of Reactor Technology

The rubber industry is entering a period in which sustainability, flexibility, and operational efficiency must coexist. Producers are under increasing pressure to reduce energy consumption and emissions while simultaneously delivering more specialized and differentiated products.

As discussed in the earlier ERJ article, the implementation of advanced reactor technologies, optimized reaction systems, and modern finishing concepts will play a central role in this transformation.

The compact plug-flow prepolymerization reactor represents one possible pathway toward this objective. By stabilizing the most sensitive reaction stages and enabling greater integration between batch and continuous reactor assets, this reactor concept may help producers improve consistency, flexibility, and process robustness while minimizing disruption to existing operations.

Rather than representing a disruptive replacement technology, compact plug-flow prepolymerization reactors should be viewed as practical engineering tools capable of supporting the next generation of elastomer manufacturing.

About the Authors

Dr. Walter Ramirez and Mr. Jorge Campos are founders and Managing Partners of INNVENTIK, an international engineering and consulting firm based in Spain and Mexico, specializing in rubber, elastomers, polymers, process engineering, and technology-market innovation.

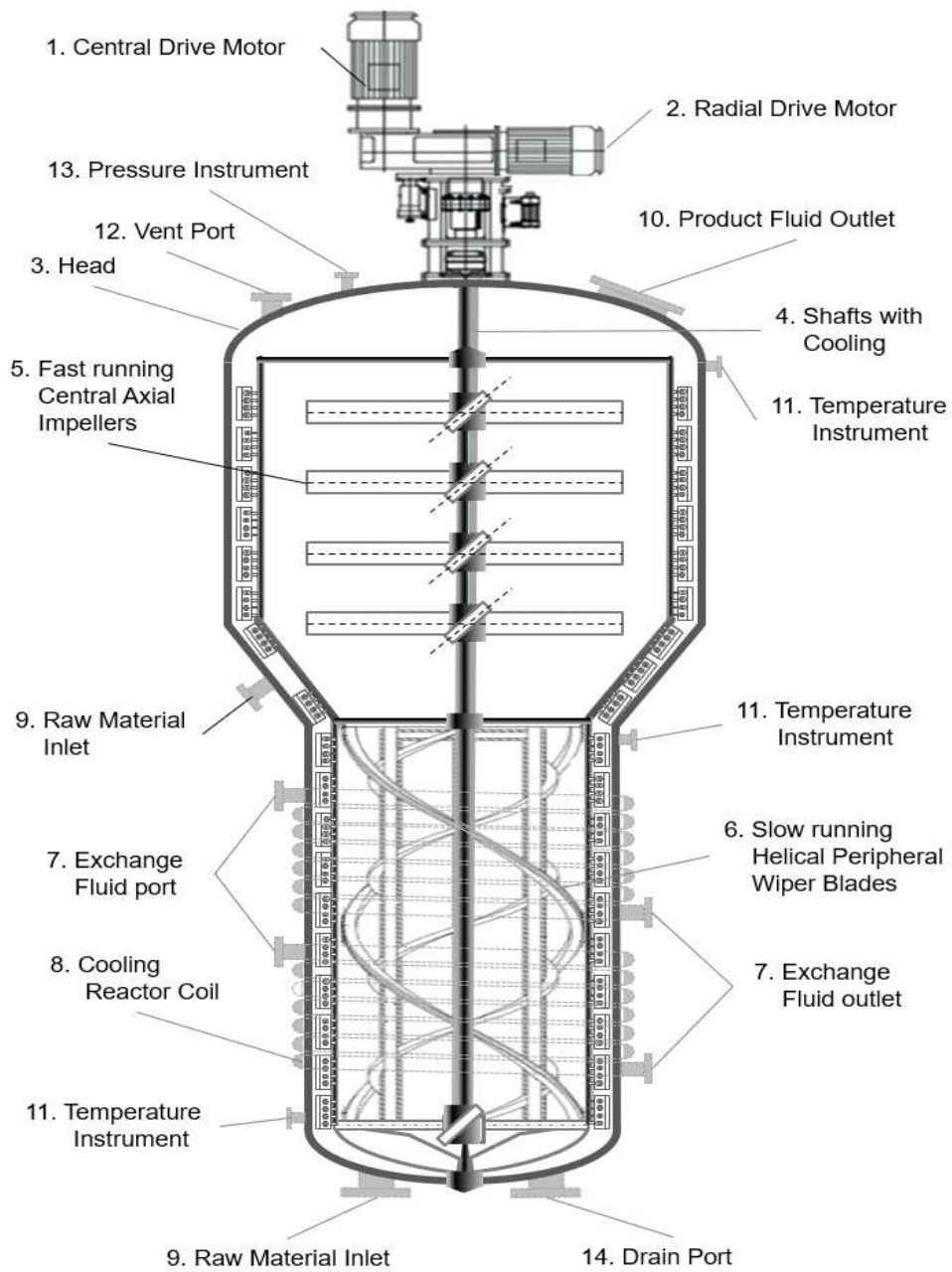


Figure: Conceptual Diagram: Drawing is not at scale.