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Review

Jet loop reactors as a versatile reactor set up - Intensifying catalytic reactions: A review

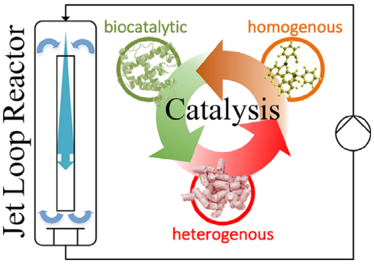
Helge Warmeling, Arno Behr, Andreas J. Vorholt*

TU Dortmund, Bio- and Chemical Engineering, Emil-Figge Straße 66, 44227 Dortmund, Germany

HIGHLIGHTS

- Constructional parameters and optimal design are presented.
- Hydrodynamic properties: residence time distributions and velocity profiles.
- Micro mixing properties: mass transfer coefficients and internal surface areas.
- Results of catalyzed reactions operated in jet loop reactors are summarized.
- Economic considerations for process intensification with jet loop reactors.

GRAPHICAL ABSTRACT



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ABSTRACT

To overcome the challenges of the increasing global energy and feedstock prices intensified process equipment is one way to develop new efficient production pathways for the chemical industry. In this article the authors convey a thorough overview about the jet loop reactor technique. Ensuing an introduction the operation principle of the reactor type is elucidated. Information available in the literature regarding dimensioning and the physical description is summarized in the following to give an outline of constructional possibilities. To underline the main advantages of the set up the macro and micro mixing properties are discussed in detail and exemplary data is presented. Applied chemical and biochemical reactions are reviewed, with particular focus on the enhancement of catalytic reactions subdivided in homogenously, heterogeneously and biocatalyzed conversions.

Contents

Abbreviations: Al, aluminum; CA, cyclooctane; CAS, stirred tank reactor cascade; CD, 1,3-cyclo-octadiene; CFD, computational fluid dynamics; CE, cyclooctene; COD, chemical oxygen demand; CP, conventional Process; CSTR, continuous stirred tank reactor; HAM, hydroaminomethylation; HYFO, hydroformylation; JLR, jet loop reactor; LES, large eddy simulation; LPM, liquid poultry manure; MeOH, methanol; NPV, net present value; OMW, Olive mill wastewater; Pd, palladium; PFR, plug flow reactor; IP, intensified process; IPE, expended intensified process; RSM, component A; RTD, residence time distribution; TMS, thermomorphic multicomponent solvent mixture

* Corresponding author.
E-mail address: Andreas.Vorholt@bci.tu-dortmund.de (A.J. Vorholt).

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1. Introduction

In virtue of the raising global energy demand and the resulting increase of feedstock and energy prices efficient processes gain more and more importance in the processing of chemical and biochemical products. Hence is the development and enhancement of processes with high selectivity and low energy consumption through the introduction of new technologies a key building block in the reconstruction of the chemical industry within the framework of the so called “green chemistry” (Anastas and Heine, 2000; Anastas and Warner, 2000; Anastas, 2009). This concept consists of twelve points that can be used as a guideline to create chemical processes that closely entwist economic and ecological strategies leaving a minimized ecological footprint. Of special interest for this review are the points “*atom economy*”, “*energy efficiency*” and “*catalysis*” due to their high impact in both ecological and economic considerations. A promising tool in the achievement of some of the “green chemistry” principles is the so called process intensification.

Intensified processes drastically enhance transport rates and provide the same processing experience for every molecule which leads to smaller equipment and reduced investment costs. The main objectives of process intensification are summarized as defined by Reay et al. (2013)

1. Improved control of reactor kinetics giving higher selectivity/reduced waste products.
2. Higher energy efficiency.
3. Reduced capital costs.
4. Reduced inventory/improved intrinsic safety/fast response times.

Especially the process intensification of catalyzed processes offers great potential in the restructuring of today's synthesis production pathways. One way to achieve this goal is the utilization of alterative reactor designs beyond standard batch or pipe reactors. Promising concepts are e.g. microreactors, microwave of sonic reactors, combinations of reaction and separation units or high-G equipment (Curcio, 2013). Another intensified reactor type that still plays a minor role in the process industry despite its high efficiency and easy applicability is the jet loop reactor. Therefore this article focuses on the jet loop reactor, a promising reactor set up for the intensification of catalyzed chemical or biochemical reactions.

The jet loop reactor offers an excellent mixing performance at relative low energy consumption, making it particularly interesting for the application in mass transfer limited multi-phase reaction systems (Warnecke et al., 1988). Based on its mixing principle large specific internal surfaces can be achieved resulting in a distinguished convective and diffusive mass transfer. The fine dispersion of reactants moreover promotes an evenly distributed heat transfer which is beneficial in regards of selectivity. Additionally the reactor features an unique controllable residence time profile making it flexible in respect of its applicability in fast and slow reactions (Rippin, 1967).

The authors' intention is to give an overview of the knowledge and information about jet loop technique available in the literature so far in order to find more applications for this new innovative reactor type. Therefore an introduction in the principle of operation of the reactor is followed by constructional details and a guide for optimal design parameters. Due to its outstanding mass transfer performance physical description of macro and micro mixing processes in the apparatus are regarded with special attention. Another focus of this article is the application of jet loop reactors for catalyzed chemical or biochemical reactions published in the literature. Finally economic considerations regarding intensified processes including jet loop reactors are discussed. To provide an easy access to the acquired collection of equations by different authors this article provides a synopsis of harmonized equations for the physical description of jet loop reactors available in the literature with a set of consistent symbols. Therefore this article can either be seen as a starting point for readers interested in the application of jet loop reactor for specific problems delivering a well-grounded set of available information or as an inspiration for whole new fields of application for this promising reactor type.