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Numerical study of the flow pattern and heat transfer enhancement in oscillatory baffled reactors with helical coil inserts

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abstract

Oscillatory baffled reactors (OBRs) are a means of process intensification as they allow processes with long residence time to be converted from batch to continuous processing. Helically baffled OBRs have only been developed at "mesoscale" so far, but at this scale have displayed significant advantages in terms of the increased range of conditions over which plug flow is achieved. Scale-up studies are underway to determine whether this is replicated at larger scales. This paper reports fluid mechanical modeling of a helically baffled oscillatory flow for the first time. Time-dependent flow structures induced in tubular reactors have been analyzed on the basis of periodic, laminar flow numerical simulation. A reversing swirled core flow and its interaction with the unsteady mechanism of vortex shedding downstream of the wires has been described. This has allowed greater understanding of the flow structures, which will underpin optimal design and scale-up. The potential for heat transfer enhancement is discussed, considering the compound effect of oscillatory motion and helical coil inserts. The results show that the heat transfer for the helical baffled tube could be enhanced by a factor of 4 compared to a smooth tube in the tested range of oscillation conditions.

Keywords: Oscillatory flow; Helical coils; Flow pattern; Heat transfer enhancement; CFD

1. Introduction

Oscillatory baffled reactors (OBRs) are a form of plug flow reactor, ideal for performing long reactions in continuous mode, as the mixing is independent of the net flow rate (Stonestreet and Van der Veeken, 1999). Unlike tubular reactors, where a high superficial velocity is required to obtain good mixing, OBRs can provide plug flow behavior at net flow Reynolds numbers in the laminar flow regime. The plug flow nature of the flow is produced by interaction between the oscillating fluid and the sharp-edge of baffles, which creates series of well-mixed volumes. This largely decouples achievement of plug flow from net flow velocity, leading to the OBR's niche application in converting long residence time batch processes to continuous, where conventional plug flow reactor designs have an impractically high length-to-diameter ratio (Harvey et al., 2001). Moreover, OBRs can be used to improve a wide variety of chemical processes. A full review of the applications of oscillatory flow technology is presented in Ni et al. (2003).

In the last years, mesoscale OBRs are being developed for laboratory processes. The systems are designed to scale-up to industrial scale directly, or to be used as small-scale production platforms in their own right (Phan and Harvey, 2010, 2011; Phan et al., 2011). Mesoscale (milliliter) baffled reactors have also been demonstrated to reduce feedstock materials and waste when screening processes due to its small volume (Harvey et al., 2003; Reis et al., 2006). The different meso-reactor baffle designs reported in the literature employ designs such as integral baffles, helical baffles, axial circular baffles (or "central" baffles) that can be easily fabricated at "mesoscales" (here typically ∼5 mm diameter) and can be operated at low flow rates (from l/min to ml/min), whereas

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