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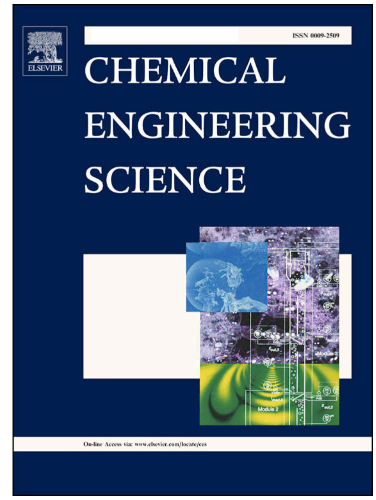

Simultaneous Optimisation of Residence Time, Heat and Mass Transfer in Laminar Duct Flows

Daniel R. Lester, Benny Kuan, Guy Metcalfe

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Simultaneous Optimisation of Residence Time, Heat and Mass Transfer in Laminar Duct Flows

Daniel R. Lester[a], Benny Kuan[b], Guy Metcalfe[c]

[a]*School of Engineering, RMIT University, Melbourne, Victoria 3000, Australia*
[b]*CSIRO Mineral Resources Flagship, Clayton, Victoria 3169, Australia*
[c]*School of Mathematical Sciences, Monash University, Clayton Victoria 3800, Australia*

Abstract

Suitably designed laminar duct flows admit chaotic advection which, in concert with diffusion, can lead to rapid heat and mass transport and sharpening of the residence time distribution (RTD). Whilst evolution of these distinct scalar fields are strongly related as the exact relationships between these distinct fields is unknown, nor to what extent they can be simultaneously optimised. In this paper we present a unified framework for the simultaneous optimisation in laminar duct flows of the three scalar fields, RTD, temperature, and mass concentration in terms of the eigenmodes of the advection-diffusion operator, which generalize classical Taylor-Aris axial dispersion. We apply this optimisation framework to a twisted pipe flow (TPF) at Péclet number $Pe = 10^5$, and find 47- and 237-fold increases in transverse heat and mass transfer respectively over straight tube flow, along with a 2,000-fold suppression of RTD variance growth. We shown that generality of the eigenmode decomposition suggests this framework is universal to all duct flows.

Keywords: chaotic advection, optimisation, duct flow, strange eigenmode, residence time distribution

1. Introduction

Scalar transport is fundamental to many continuous flow processes where rapid heat and mass transfer is necessary for both process control and product quality. Many such processes occur in laminar duct flows, with examples ranging from micro-mixers [37] and continuous flow chemical reactors [27], to