

Mass transport analysis of non-Newtonian fluids under combined electroosmotically and pressure driven flow in rectangular microreactors



Zakiyeh Yousefian, Mohammad Hassan Saidi*

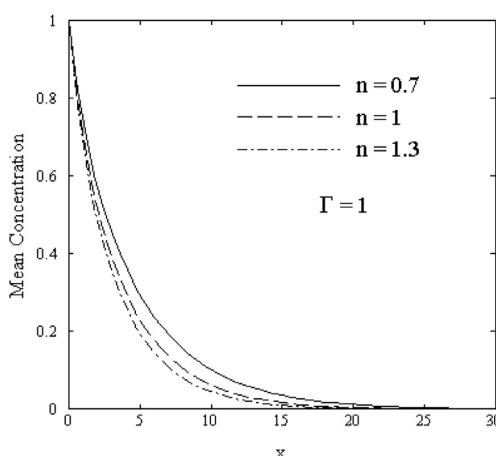
Center of Excellence in Energy Conversion, School of Mechanical Engineering, Sharif University of Technology, P.O. Box: 11155-956, Tehran, Iran

HIGHLIGHTS

- Mass transfer of power-law fluids in a mixed flow has been analyzed.
- Analysis is based on variable axial concentration gradient in the microreactor.
- Mean concentration is an increasing function of Péclet and Debye–Hückel parameters.
- Favorable pressure gradient slows down the decreasing trend of mean concentration.
- Mean concentration decreases with increasing Damkohler number.

GRAPHICAL ABSTRACT

Shear-thinning fluids are more affected by flow driving forces than Newtonians and shear-thickenings for all operating parameters.



ARTICLE INFO

Article history:

Received 22 June 2016

Received in revised form 15 August 2016

Accepted 18 August 2016

Available online 20 August 2016

Keywords:

Microfluidics
Electroosmotic flow
Power-law fluids
Mass transfer
Microreactor

ABSTRACT

Hydrodynamically fully developed flow of power-law fluids under combined action of electroosmotic and pressure gradient forces in rectangular microreactors is analyzed considering heterogeneous catalytic reactions. The Poisson-Boltzmann, Cauchy momentum, and concentration equations are considered in two dimensions and after being dimensionless are numerically solved applying a finite difference algorithm. Variation of axial concentration gradient, and axial and horizontal mass diffusions are taken into account as well. To accomplish a more general analysis, the velocity distribution is obtained by solving continuity and Cauchy momentum equations and is not considered as an average axial velocity for solving the concentration equation. Profiles of mean concentration of reactants are analyzed as functions of operating variables. Results reveal that mean concentration increases with increasing Péclet number and dimensionless Debye–Hückel parameter. It is also a decreasing function of Damkohler number. Presence of pressure gradient will affect the decreasing trend of mean concentration through the channel. Shear-thinning fluids, due to their nature, are most strongly influenced by pressure gradient and Newtonian and shear-thickening fluids are less affected, respectively. Favorable pressure gradient will decelerate mean concentration rate of decrease and adverse pressure gradient acts the opposite. Moreover, a larger

* Corresponding author.

E-mail addresses: zakiyeh.yousefian@gmail.com (Z. Yousefian), saman@sharif.edu (M. Hassan Saidi).

aspect ratio leads to slower descending rate of mean concentration in purely electroosmotic and pressure-assisted flows while in a pressure-opposed flow, the behavior might change depending on the strength of pressure gradient and the value of channel aspect ratio.

© 2016 Elsevier B.V. All rights reserved.

Nomenclature

C	Concentration [kmolm^{-3}]
C_0	Inlet concentration of solute [kmolm^{-3}]
D	Diffusivity of the reactant [m^2s^{-1}]
Da	Damkohler number for first order reaction
e	Proton charge [C]
E_x	Electric field in the axial direction [Vm^{-1}]
F	Component of body force vector [Nm^{-3}]
$\mathbf{F}$	Body force vector [Nm^{-3}]
H	Half channel height [m]
k_1	First order reaction rate constant [ms^{-1}]
k_B	Boltzmann constant [JK^{-1}]
L	Channel length [m]
m	Flow consistency index [Pas^n]
n	Flow behavior index
n_0	Ion density at neutral conditions [m^{-3}]
p	Pressure [Pa]
Pe	Péclet number
t	Time [s]
T	Absolute temperature [K]
u_{HS}	Helmholtz-Smoluchowski velocity [ms^{-1}]
$\mathbf{u}$	Velocity vector [ms^{-1}]
u	Axial velocity [ms^{-1}]
W	Half channel width [m]
x	Axial direction [m]
y	Vertical direction [m]
z	Horizontal direction [m]
Z	Valence number of ions in solution

Greek Symbols

α	Channel aspect ratio
β	Stretching parameter
Γ	Scale ratio of pressure driven velocity to electroosmotic velocity
$\dot{\gamma}$	Strain rate tensor [s^{-1}]
$\dot{\gamma}$	Magnitude of the strain rate tensor [s^{-1}]
ε	Fluid permittivity [$\text{CV}^{-1}\text{m}^{-1}$]
ζ	Zeta potential [V]
K	Dimensionless Debye-Hückel parameter
λ_D	Debye length [m]
μ	Effective viscosity [Pas^n]
ρ	Density [kgm^{-3}]
ρ_e	Net electric charge density [Cm^{-3}]
$\boldsymbol{\tau}$	Stress tensor [Pa]
τ	Stress tensor component [Pa]
Φ	Externally imposed electrostatic potential [V]
ϕ	Electrostatic potential [V]
ψ	Electric double layer (EDL) potential [V]

Subscripts

av	Average
m	Mean
0	Reference

Superscripts

g	Guess value
$\wedge$	Transformed variable
$*$	Dimensionless variable

1. Introduction

microfluidics is an emerging field of interest due to its potential capabilities of flow control and manipulation. Microreactors are miniaturized chemical systems whose characteristic dimensions are typically in the sub-micrometer to the sub-millimeter range [1]. The advantages of microreactors include, (1) increase of Surface-to-Volume Ratio which leads to high heat and mass transfer rates; (2) fast and cost-saving screening of materials and processes; (3) better reaction and flow control; (4) easier scale-up of production capacity; (5) smaller plant size for distributed production, etc [1,2]. Electroosmosis is a newly born method for flow generation in microchannels with unique excellences like having an almost slug flow leading to minimal hydrodynamic dispersion. This feature provides precise control for better conducting of reactions [3]. Moreover, using this technique, omits the moving parts as in mechanical micropumps, and also brings about an easier fabrication and a reliable operation.

Electrokinetic flow of a Newtonian fluid in ultrafine capillary slits was initially analyzed by Burgreen and Nakache [4]. They suggested a complex analytical solution for the Poisson-Boltzmann equation. By using the Debye-Hückel linearization for low zeta potentials, Rice and Whitehead [5] studied the fully developed electroosmotic flow in narrow cylindrical capillaries. Levine et al. [6] analyzed the same geometry for high zeta potentials by means of an approximation method. Analytical solution for the electroosmotic flow through an annulus is obtained by Kang et al. [7] while both of cylindrical walls carry high zeta potentials. Alfadhel et al. [8] developed a mathematical model to describe velocity field of a steady flow in a membrane microreactor considering slip velocity at the walls. Yang [9] analytically investigated the fully developed electroosmotic flow in rectangular microchannels. The same study was done for semicircular channels by Wang et al. [10]. Mondal et al. [11] suggested a mathematical model for combined electroosmotic and pressure driven flow of a Newtonian fluid in a rectangular microchannel at high zeta potential and overlapping electrical double-layer. They studied velocity profile and heat transfer in the channel. Analytical solutions based on perturbation technique for electroosmotic flow through rough microtubes was presented by Keramati et al. [12]. They investigated effects of roughness on electroosmotic flow and heat transfer. The above mentioned research works were most often assuming Newtonian law of viscosity for the working fluid. However, biofluids encountered in microfluidic devices may have quite different behavior. Hence, it seems essential to study flow characteristics of non-Newtonian fluids in presence

Download English Version:

<https://daneshyari.com/en/article/6978219>

Download Persian Version:

<https://daneshyari.com/article/6978219>

[Daneshyari.com](https://daneshyari.com)