Chemical Engineering Journal 210 (2012) 120–135

Contents lists available at SciVerse ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Continuous species transport and population balance models for first drying stage of nanosuspension droplets

M. Mezhericher [a,b], M. Naumann [c], M. Peglow [c], A. Levy [b,*], E. Tsotsas [c], I. Borde [b]

[a] Department of Mechanical Engineering, Shamoon College of Engineering, Bialik/Basel Sts., Beer-Sheva 84100, Israel
[b] Pearlstone Centre for Aeronautical Engineering Studies, Department of Mechanical Engineering, Ben-Gurion University of the Negev, P.O. Box 653, Beer-Sheva 84105, Israel
[c] Thermal Process Engineering, Otto von Guericke University, Universitätsplatz 2, 39106 Magdeburg, Germany

HIGHLIGHTS

- ▶ Two modelling approaches for nanosuspension droplet drying are compared.
- ▶ Continuous species transport approach uses diffusion equation for nanoparticles.
- ▶ Alternatively, population balance model deals with nanoparticles as a population.
- ▶ Both models were successively validated using published and new experimental data.
- ▶ Without aggregation, differences in the two model parametric predictions are minor.

ARTICLE INFO

Article history:
Received 16 May 2012
Received in revised form 12 August 2012
Accepted 14 August 2012
Available online 23 August 2012

Keywords:
Droplet drying
Diffusion
Heat transfer
Mass transfer
Nanoparticle
Population balance

ABSTRACT

The present contribution reports on comparison and verification of two different modelling approaches to intra-droplet mass transfer for nanosuspension droplet drying in the constant-rate period. The first approach is continuous species transport (CST) modelling coupling external gas-droplet heat and mass transfer to a species transport equation of intra-droplet diffusion of nanoparticles. The second approach is a population balance (PB) model with similar description of external heat and mass transfer from gas to droplet. In contrast to the CST model, the PB approach deals with dispersed particles as a population and accounts for the change of nanoparticle distribution by possible aggregation. Both CST and PB models have been successively validated using published and new experimental drying data on single silica nanosuspension droplet. A parametric study revealed insignificant differences in the predicted temporal evolutions of solid volume fraction profiles and values of locking point between the two models when aggregation was "turned off" in the PB model. These small differences can be explained by different mathematical formulations and numerical implementations of the two modelling approaches. A larger contrast between the CST and PB models is the predicted duration of the first drying stage, which has been found to be longer in the case of CST approach. Such divergence is explained by the absence of a shell shrinkage period in the current PB formulation. When applied with aggregation, the PB model can predict the experimentally observed decrease in the diffusion coefficient after the gelation point.

1. Introduction

Particle engineering processes involving droplets containing dispersed nano-sized particles is a field of growing interest in nowadays industry. Spray drying, spray pyrolysis, combined spray-fluidized bed granulation, fluidized bed drying, aerosol thermolysis and freeze drying may utilise nanoparticle suspensions to produce micro-sized particles and coated particulates [1–5]. However, behind these technologies are complex physical phenomena of multiphase heat and mass transport inside and outside of a single droplet. The external transport phenomena have been extensively studied until now [6–12] and include convective and radiative heat flow towards the droplet, and convective species transfer from the droplet outer surface. In contrast, the governing internal transport phenomena are much more sophisticated because of simultaneous heat transport by thermal conduction, diffusive and advective motion of liquid and nanoparticles, aggregation of nanoparticles into bigger conglomerates, agglomeration of nanoparticles leading to

* Corresponding author.
E-mail addresses: maksime@sce.ac.il, mezher@post.bgu.ac.il (M. Mezhericher), martina.naumann@student.uni-magdeburg.de (M. Naumann), mirko.peglow@vst.uni-magdeburg.de (M. Peglow), avi@bgu.ac.il (A. Levy), evangelos.tsotsas@vst.uni-magdeburg.de (E. Tsotsas), borde@bgu.ac.il (I. Borde).

1385-8947/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.cej.2012.08.038