13 Advances in Modeling Turbulence Phenomena in Heterogeneous Media
Reactive Systems

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CONTENTS

13.1 INTRODUCTION

Modeling of flows in inert porous media has attracted the attention of scientists and engineers worldwide, and in the last decade, a number of outstanding books, handbooks, and edited books have been written on the subject (Pop and Ingham 2001, Ingham and Pop 2005, Vafai 2005, Vadasz 2008, Nield and Bejan 2013).

In addition to thermomechanical models, including new research work aimed at biological applications (Vafai 2010), flows with chemical reactions in inert porous media have been also investigated extensively due to their many engineering applications and the demand for high-efficiency power-producing devices. The growing use of efficient radiant burners can be encountered in the power and process industries, and as such, proper mathematical models of flow, heat, and mass transfer in porous media under combustion can benefit from the development of such engineering equipment.

In this chapter, an overview of recent development in modeling and simulating reactive flow in porous material is presented.

13.2 POROUS BURNERS

The advantages of having a combustion process inside an inert porous matrix are today well documented in the literature (Babkin 1993, Mohamad et al. 1994b, Howell et al. 1996, Bouma and Goey 1999, Henneke and Ellzey 1999, Oliveira and Kaviany 2001, Lammers and Goey 2003, Leonardi et al. 2003), including recent reviews about combustion of gases (Wood and Harries 2008) and liquids (Abdul et al. 2009) in such burners. Hsu et al. (1993) point out some of its benefits, including higher burning speed and volumetric energy release rates, greater combustion stability, and the ability to burn gases with low energy content. Driven by this motivation, the effects on porous ceramic inserts have been investigated in Peard et al. (1993), among others.

Turbulence modeling of combustion within inert porous media has been conducted by Lim and Matthews (1993) on the basis of an extension of the standard $k - \varepsilon$ model of Jones and Launder (1972). Work on direct simulation of turbulence in premixed flames, in cases when the porous dimension is of the order of the flame thickness, also has been reported in Sahraoui and Kaviany (1995).

Further, nonreactive turbulent flow in porous media has been the subject of several studies (Pedras and de Lemos 2001, 2003, de Lemos 2005a), including many applications such as flow through porous baffles (Santos and de Lemos 2006), channels with porous inserts (Assato et al. 2005), and buoyant flows (Braga and de Lemos 2004). In such work, intrapore turbulence is accounted for in all transport equations, but only nonreactive flows have been investigated. Other important contributions in modeling inert flows in porous media can be found in the high-impact and outstanding competing model of turbulence developed by Kuznetsov et al. (2002) and Kuznetsov (2004).

Motivated by the foregoing, this chapter extends previous work on turbulence modeling in porous media to include new predictions of combusting flows. Computations are carried out for inert porous material considering 1D and 2D turbulent flows with one- and two-temperature approaches. In addition, four different thermomechanical models are compared here, namely, laminar flow, laminar flow with radiation transport, turbulent flow, and turbulent flow with radiation transport. As such, this contribution compares the effects of radiation and turbulence in smoothing temperature distributions within porous burners. The material in this chapter reviews the work in de Lemos (2009, 2010) and Coutinho and de Lemos (2012) in a consolidated fashion, in addition to presenting additional information in regard to this topic.

13.3 MACROSCOPIC FLOW

The thermomechanical model employed here is based on the *double-decomposition* concept detailed in de Lemos (2005b) and Saito and de Lemos (2005, 2006). Transport equations are volume averaged according to the volume-averaging theorem (Slattery 1967, Whitaker 1969, Gray and Lee 1977) in addition to using time decomposition of flow variables followed by standard time-averaging procedure for treating turbulence. As the entire equation set is already fully available in the open literature, these equations will be reproduced here, and details about their derivations can be obtained in the aforementioned references. Essentially, in all the aforementioned studies, the flow variables are decomposed in a volume mean and a deviation (classical porous media analysis) in addition to being decomposed in a time mean and a fluctuation (classical turbulent flow treatment).