Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 66 (2015) 265 – 268

Energy Procedia

The 12th International Conference on Combustion & Energy Utilisation – 12ICCEU

A numerical investigation on characteristics of turbulent premixed flame in porous media

Zhong-Shan Chen, Mao-Zhao Xie *, Hong-Sheng Liu, Meng Yue

School of Energy and Power Engineering, Dalian University of Technology, Dalian 116024, China

Abstract

A numerical study on the turbulent combustion in porous media is conducted based on 2D staggered cylinders using the eddy dissipation concept model (EDC) with emphasis on characteristics of the turbulent premixed flame. The results show that as the velocity increases, the sheet of laminar flame is stretched and distorted gradually. A burned island forms at the recirculating zone due to the entrainment. Based on the parameter study, it is find that turbulent kinetic energy gradually decay after the reaction taking place. The pseudo thermal flame thickness is less than the length scale of a representative elementary volume. The Damköhler number at quasi-steady state is in the order of 10, indicating that the flame is in the flamelet regime.

Peer-review under responsibility of the Engineering Department, Lancaster University
Keywords: turbulent combustion, porous media , flame thickness, Damköhler number, EDC model

1. Introduction

Porous medium combustion (PMC) as an advanced technique has acquired more and more attentions for its obvious advantages, such as higher burning rate, increased power dynamic range, extension of both lean and rich flammability limits and low emissions of pollutants [1]. A diverse number of outstanding industrial and residential applications have been proposed, e.g. household water heating systems, hydrogen production, radiant burners and burning organic pollutants with extremely low heat content [2].

Most of the published investigations are concentrated on the premixed combustion in porous media. Some detailed and excellent reviews of the subject can be found in references [3-5]. However, in many practical applications, the combustion takes place in the form of turbulence, such as regenerative diesel engine or reciprocating heat engine, yet the knowledge on that is relatively little compared to the laminar case. In the open literature, most investigators attributed the contribution of turbulence into the elevated transport properties, such as the effective thermal conductivity, whereas the distorting impact on the flame by the large turbulent vortexes was rarely addressed to our knowledge. In this paper, we attempt to gain a clearer understanding of the characteristics of the turbulent premixed flame in porous media,

* Corresponding author. Tel.: +86 0411 84706302; fax: +86 0411 84708460
E-mail address: xmz@dlut.edu.cn, chenzhan@mail.dlut.edu.cn (M.-Z. Xie)

Peer-review under responsibility of the Engineering Department, Lancaster University
doi:10.1016/j.egypro.2015.02.051

including flame shape evolution, flame thickness and turbulent kinetic energy though calculations at the pore scale for a 2-dimensional staggered cylinders configuration.

2. Numerical model

2.1. Physical model

To avoid enormous time consumption, a part of the computational zone of the 2-D pseudo packed pebble bed in [6] is simulated in this paper (see Fig. 1). In this situation, the heat exchange between the outer walls and the environment is not considered. The porous zone of 165mm in length is composed of cylinders of 10mm in diameter, and two clear fluid regions of 20mm and 100mm, respectively, are attached onto the ends of the porous zone. The porosity of the porous zone is 0.36.

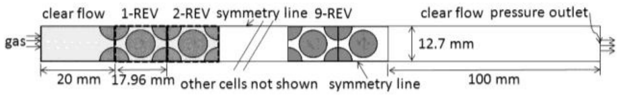

Figure 1. The schematic diagram of computational domain

2.2. Equations

For simplification, some assumptions are introduced as in Ref. [7]. Under these assumptions, a set of simplified differential equations such as gas state, mass conservation, momentum conservation, species mass conservation, turbulent kinetic energy and its dissipation and energy conservation for the fluid and solid phases are obtained naturally. The chemical reaction is considered through a two-step simplified mechanism of CH_4 and the solid radiation role is calculated with the discrete ordinate method. The interaction of turbulence and chemical reaction is modelled by the EDC model. In addition, the physical properties of the fluid and solid phases are evaluated as functions of the local temperature and mixture composition. The solid cylinder properties are taken at the character temperature of 1300K.

2.3. Initial and boundary conditions

In order to obtain a relatively actual initial flow field, we firstly simulated a case of lower-velocity filtration combustion with the stoichiometric ratio at an inlet velocity of 0.3 m/s, and assume that the premixed mixture has been preheated before it comes into the computational zones. Here, this value is set as 500K according to some published experimental data. When the flame reaches the forth row of the cylinder, we stopped the calculation and stored the field data as the initial field for the next stage. Once the initial field is obtained, the boundary conditions are reset according to our requirement. Inlet: $v_{in} = v_0$, $T_{in} = 300$ K, $Y_{CH_4} = Y_0$, $\varepsilon = 0$. The hydraulic diameter is taken as twice the height of the inlet and the turbulent intensity is estimated as 7%. Outlet: $P_{ex} = 1$ atm, $T_{ex} = 300$ K, $Y_{O_2} = 0.23$, $\varepsilon_{ex} = 0$. The boundary condition of the interface is no-slip for the velocity, and it is coupled for the temperature. Besides, the wall is opaque with a given emission rate, $\varepsilon = 0.46$. The top and bottom boundaries are symmetrical to reduce the calculation cost.

3. Results and discussions

To have a high resolution for the fields in the pores, a dense grid is implemented near the wall. By test forth and back, a mesh number of 1.16 million is determined to meet the mesh-independent demand. The mentioned equations in Section 2.2 are solved with FLUENT 6.3 and some own subroutines (UDF) are incorporated into this platform for the data post-process. In all the calculations a 100-second span of time is set to have a better comparison. The effects of velocity and equivalence ratio have been taken into account, i.e. v_0=0.8, 1.5 and 2.0; the equivalence ratio, ϕ =0.6, 0.8 and 1.0. In order to be consistent with the conventional one-dimension calculation, the quantities being discussed are in the terms of a cross section averaging form.