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Experimental study on temperature variation in a porous inert media burner for premixed methane air combustion

Hongmin Wang [a,*], Chunzhi Wei [a], Pinghui Zhao [b], Taohong Ye [b]

[a] School of Mechanical & Automotive Engineering, South China University of Technology, Guangzhou 510640, China

[b] Department of Thermal Science and Energy Engineering, University of Science and Technology of China, Hefei 230027, China

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ABSTRACT

The detailed axial temperature variations of the porous media burner during startup and switch-off processes were experimentally measured and analyzed for the premixed methane air combustion. A tubular burner filled by alumina pellets with diameters of 10 mm and 4.3 mm, respectively, was used as the porous media burner to study the effect of the burner inlet gas flow rate, equivalence ratio, and diameter of alumina pellets on the combustion temperature distribution along the burner axis and the combustion wave velocity. The results showed that the superadiabatic combustion could be achieved for the combustion wave velocity greater than zero, and the critical equivalence ratio corresponding to the superadiabatic combustion was bigger for the smaller pellet diameter or higher inlet air flow rate. This study can provide the useful information for the design and operation of the porous media burner, and is significant to understand the combustion phenomena in the porous media burner.

1. Introduction

Combustion in PIM (porous inert media) has attracted more and more interest in recent decades due to the higher combustion rates, higher flame temperature, wide power load range, extended flammability limits of equivalence ratio, and the low emissions compared with free flame combustion, which makes it extensive applications in various areas [1]. Stationary and transient combustion zone systems are two major design approaches commonly employed in the combustion in porous media. The stationary approach is used in the radiant burners and surface combustor–heaters where the combustion zone is stabilized within the porous matrix, while the transient approach involves a traveling wave where the unsteady combustion zone propagates as a wave either in the downstream or upstream direction within the porous media burner, and the positive or negative enthalpy fluxes make combustion temperatures significantly different from the adiabatic predictions [2]. When the heat from burned downstream is recirculated to preheat the unburned mixture upstream of the reaction zone in the PIM by a combined heat conduction and radiation of the solid phase, the superadiabatic flame or excess enthalpy flame [3] will be yielded, which leads to a peak temperature higher than the corresponding adiabatic flame temperature.

The temperature profile along the porous media burner can provide the important information on the thermal structure of the flame for understanding the heat transfer phenomena and combustion regime taking place in the burner, which is investigated in various research works. Bidi et al. [4] numerically evaluated the effects of the different parameters of combustion in the porous media and studied the flame stabilization and the burner optimization by entropy generation minimization method. The transient temperature distribution at the centerline of the burner was calculated to determine the location and stability of the flame. Mujeebu et al. [5] developed a compact household premixed liquefied petroleum gas burners with higher thermal efficiency than the conventional burner, and the transient temperature distributions along the burner axis were measured to judge whether the burner operated in matrix stabilized combustion mode or surface stabilized combustion mode. Yoksenakul et al. [6] designed and developed a SPMB (self-aspirating porous medium burner) for replacing the self-aspirating and free flame burners. The transient temperature distributions were measured to determine the startup behavior of the burner and describe the combustion phenomena within the burner. Porous media burner coupled with TE (thermoelectric generator) was designed and tested to charge the cell phone, where the wall of porous media burner provided the high temperature side for the TE. The temperature

* Corresponding author. Tel.: +86 13798172356; fax: +86 20 23880183.
E-mail address: hmwang123@sina.com (H. Wang).

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distributions along the wall of porous media burner were measured to facilitate the design of an efficient TE generator [7,8]. Li [9] experimentally investigated the premixed hydrogen air combustion in a micro-combustor where the 3 mm thick porous media made by stainless steel mesh was inserted in the combustor. The results showed the peak temperature occurred at the position of the porous media for different inlet conditions and when the position of the porous media inserted in the combustor changed, the peak temperature correspondingly changed to the position of the porous media. The temperature profile measured indicated that the flame was effectively anchored by the inserted porous media. Bakery [10] studied the methane air combustion in the porous media under the high pressure and temperature. The axial temperature distribution of the burner was measured as a function of distance and relative air ratios, which was used to analyze how the successive stable positions of the flame advance and spread over the whole length of the PIM with relative air ratio.

The temperature profile along the porous media reactor for fuel rich combustion is helpful to analyze the reaction mechanism for hydrogen production. Numerical and experimental study of the conversion of methane to hydrogen in a porous media reactor showed that a larger specific heat of the porous media resulted in a slower moving combustion wave that had a smaller steam-reforming zone, which yielded a smaller methane conversion efficiency, while a larger thermal conductivity of the porous media resulted in a lower peak temperature, which led to a lower conversion efficiencies [11]. The axial temperature profile along the porous media reactor showed that the flame was self adjusted to a new position according to the imposed operating conditions and tended to move to downstream for high equivalence ratios and high flow velocities, while it stabilized more upstream for low equivalence ratios and low flow velocities [12].

As above mentioned, the temperature variation is involved in the various aspects of the methane combustion in the porous media, and hence the systematic measurement and detailed interpretation of the temperature profile and wave velocity for the methane combustion in the porous media are important to understand the combustion phenomena in the porous media burner. The emphasis of the present work will be put on the axial temperature variation during the startup and switch-off processes and the effect of diameter of alumina pellets and operating conditions of inlet flow rates and equivalence ratios on the temperature profile and velocity of combustion wave. The results can provide the useful information for the design and operation of the porous media burner, and are significant for deeper understanding of the combustion phenomena in the porous media burner.

2. Experimental

2.1. Experiment setup

Fig. 1a shows the experimental system designed for studying the temperature variation along the burner length. The air was supplied by an air compressor while the commercial bottle methane was used in this study. The pressure relief valves and calibrated mass flow controllers with accuracy of ±2% were used in both methane and air lines to control their pressures and mass flow rates, respectively. A tubular burner with inner diameter of 40 mm and height of 260 mm filled by alumina pellets formed the porous media burner. The basic structure of the burner with position of thermocouples is shown in Fig. 1b. The pellets with diameters of 4.3 mm and 10 mm were used in this study. To prevent the heat loss, 100 mm thick high-temperature insulation was applied on the outside of the burner. In order to map the temperature profile along the porous media burner length, 12 S-type thermocouples were uniformly positioned along the axis of the burner. The 12 thermocouples were marked as 1 to 12 from inlet to outlet of the burner, and the corresponding temperatures were denoted as T_1 to T_{12}. The distance between the thermocouples was 20 mm, which was the same as the distance between the 1st thermocouple and the burner inlet. Methane and air were fully mixed in a mixing chamber prior to introducing into the porous media burner at the

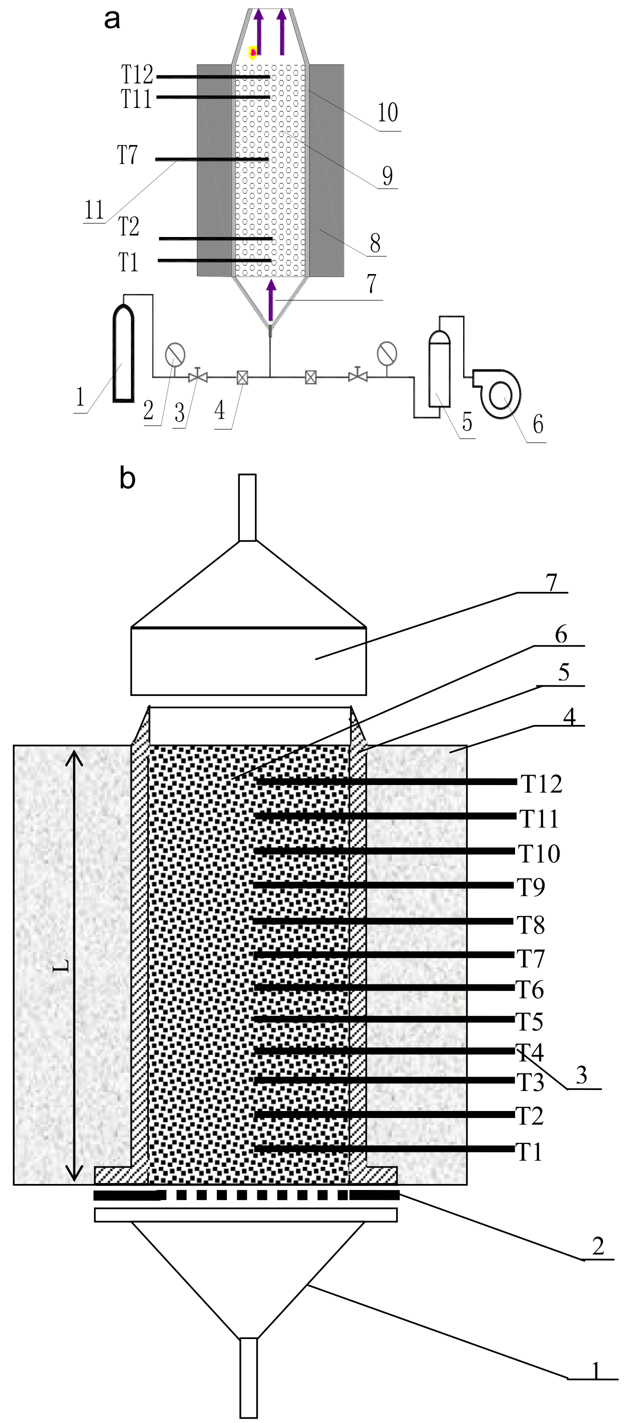

Fig. 1. a Experimental system. 1 – Fuel tank; 2 – Pressure gauge; 3 – Relief valve; 4 – Mass flow controller; 5 – Air tank; 6 – Air compressor; 7 – Mixer; 8 – Insulation; 9 – Porous media; 10 – Burner; 11 – Thermocouples. b Basic structure of the porous media burner with position of the thermocouples. 1 – Inlet chamber; 2 – Lattice; 3 – Thermocouples; 4 – High temperature insulation; 5 – Tubular burner; 6 – Porous media; 7 – Top cover.