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Research article

Flow stabilized porous heterogeneous combustor. Part II: Operational parameters and the acoustic emission

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ABSTRACT

Heterogeneous combustion is an advanced combustion technique, which incorporates a highly porous ceramic media into the combustion chamber, and enables the flame to propagate within the pores of the ceramic media. Heat exchange between the solid and gas phases within the combustion chamber can enable a flame to exist that is highly resilient to momentary disruptions in reactant flow rates while also enabling localized temperatures to be in excess of the adiabatic flame temperature, a phenomena known as superadiabatic combustion. While beneficial to performance, the incorporation of the solid into the combustion chamber greatly complicates observations and understanding of the combustion phenomena occurring within the voids and on the surface of the solid media, therefore, development of non-invasive and low cost instrumentation is always a priority to get a better understanding of the phenomena occurring within the combustion chamber. Within this work, a novel instrumentation technique, acoustic emission profiles obtained by collecting the noise during heterogeneous combustion, is used to measure characteristics of the flame, in addition to the optical characterization by CCD camera and the thermal characterization by thermocouples to characterize the performance of newly developed heterogeneous porous combustor.

1. Introduction

Energy conversion technologies are an important field of scientific study. Today more than ever there is a need for versatile, robust, and efficient energy conversion devices to maximize the use of often scarcely available or costly resources. One of such energy conversion technologies, which has undergone significant exploration in recent years, is heterogeneous combustion, where combustion of fuel and air mixtures occurs, within the pores of ceramic porous media housed within a combustion chamber [1–3]. Such heterogeneous combustion of hydrocarbons within porous media enables chemical reactions to progress through both gas and gas-solid reaction channels and allows for near theoretical combustion efficiency [4–7], and localized flame temperatures in excess of that of the adiabatic flame temperature of the unburned mixture [8]. The porous media immersed within the combustion chamber is used to support and regulate the flame and could be either catalytically inert or catalytically active [9]. If the media is catalytically inert, such as in the case of α-Al_2O_3 ceramics [6], then the combustion process is considered to be homogeneous and all reactions are assumed to occur in the gas phase. In this case, the media surface does not contribute to the chemical reaction pathways involved in the combustion process. However, by allowing the flame to propagate within the pore space of the media, the chemically inert media still serves as a means to store and redistribute heat within the flame enabling higher net reaction rates, an elongated flame, and improved flame stability [7]. Conversely, if the media is catalytically active, then in addition to whatever heat transfer the media enables, during the combustion process various gas phase species will adsorb onto the solid's surfaces. Adsorbates temporarily bound to the catalytically active solid phase, lower the partial pressures of their respective gas phase species, promoting certain chemical reaction pathways. Adsorbates bound to the catalyst may undergo additional reactions with other adsorbates within close proximity; or as a result of chemical bonds between the adsorbate and catalyst, the adsorbate may become significantly more reactive enabling other gas phase species to interact with the adsorbate [10]. In this case, as both gas and solid phases are active participants in the combustion process, and it can be said under such circumstances that the chemical reactions in the combustion chamber are heterogeneous.

Within the literature heterogeneous combustors have been shown to utilize multiple design schemes, and there are multiple review papers showcasing designs [11,12]. Such heterogeneous combustors designs incorporate several different types of porous media such as continuous

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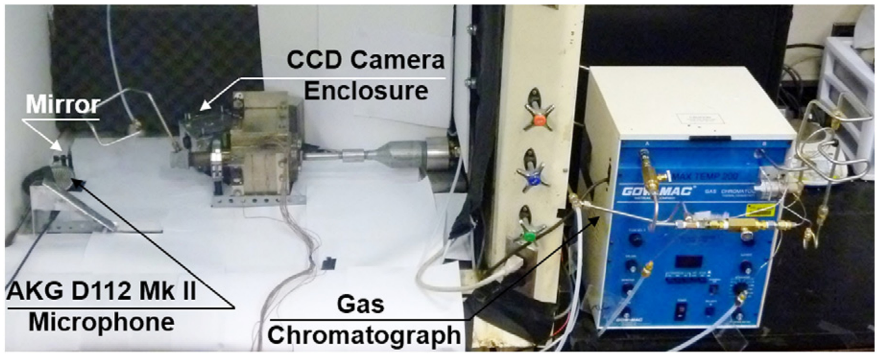

Fig. 1. Combustor setup including gas chromatograph, microphone, and CCD camera.

ceramic foams which have some external geometry with regularly spaced pores [13], packed beds of individual ceramic spheres [14,15], or a woven fiber media may be utilized [16]. Additionally, considerations of the fuel and reactant flow rate to be used in the combustor are necessary during design as to enable efficient operation [17,18].

One of the difficulties currently hindering the scientific exploration and widespread commercial implementation of heterogeneous combustion is the lack of truly non-invasive, fast, and low cost means of accurately characterizing combustor performance. Within studies of heterogeneous combustion, the standard method of analysis consists of temperature measurements via thermocouples placed at various locations along the combustion chamber [1,19]. However, the use of thermocouples leaves some ambiguity in the exact meaning of the reported temperatures, which is a result of the thermocouple bead exchanging heat with both the gas and solid phases within the combustion chamber and, thus, cannot be used to accurately measure temperature of each phase separately, unless specific precautions are taken [20]. Additionally, when the porous media has either large diameter or high linear pore density (low porosity) radial temperature measurements become difficult, if not impossible, as the media impedes concise thermocouple placement.

Previous non-invasive attempts to acquire information from heterogeneous combustion have incorporated a mirror and IR-CCD camera system to acquire IR images of the exhaust side of the porous media during operation [21]. Ex-situ chemical analysis of sampled exhaust gasses from heterogeneous combustion have been made through the use of a coupled gas chromatograph (GC) and sampling system [22], however these instruments are costly to implement into an experiment. More recently, in-situ spectroscopic measurements along the axis of the combustion chamber have been made using planar laser induced fluorescence (PLIF), though in order to implement the PLIF technique it was necessary to segment the porous media within the combustion chamber in order to create the necessary optical pathway [23], but such separation of the media disturbs heat transfer through the solid media and reactant dispersion in the vicinity of where the PLIF measurements are being taken. However, to the best of our knowledge, no research was previously reported where the acoustic signature of heterogeneous combustion would be analyzed to provide complementary information about the ongoing processes within the combustion chamber. Such acoustic information can non-invasively assist in the understanding of combustor operation, as both nominal azimuthal flow modes and vortex driven instabilities of the flame structure within the combustion chamber have been shown to be coupled with acoustic signatures [24–26]. Furthermore, the availability of acoustic emission measurements as a real-time combustion monitoring technique can be utilized as a component of feedback control systems [27,28].

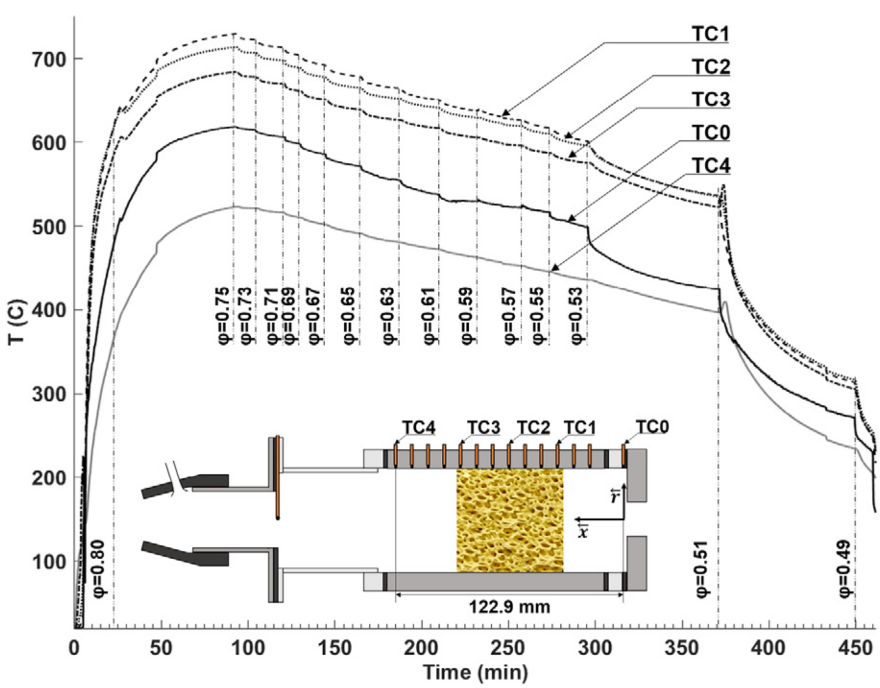

Fig. 2. Time evolution of selected thermocouples, shown with steady state burning delineations at each equivalence ratio.