Heterogeneous combustion is an advanced internal combustion technique, which enables heat recuperation within the flame by utilizing a highly porous ceramic media as a regenerator. Heat released within the gas phase convectively transfers to the solid media. This heat within the solid media then travels towards the inlet, enabling reactant preheating. Such heat redistribution enables stable burning of both ultra-lean fuel/air mixtures, forming a more diffuse flame through the combustion chamber, and results in reduced pollutant formation. To further enhance heterogeneous combustion, the ceramic media can be coated with catalytically active materials, which facilitates surface based chemical reactions that could occur in parallel with gas phase reactions.

Within this work, a flow stabilized heterogeneous combustor was designed and developed consisting of a reactant delivery nozzle, combustion chamber, and external instrumentation. The reactant delivery nozzle enables the combustor to operate on mixtures of air, liquid fuel, and gaseous fuel. Although this combustor has high fuel flexibility, only gaseous methane was used within the presented experiments. Within the reactant delivery nozzle, reactants flow through a tube mixer, and a homogeneous gaseous mixture is delivered to the combustion chamber. $\alpha$-alumina ($\alpha$-Al$_2$O$_3$), magnesia stabilized zirconia (MgO-ZrO$_2$), or silicon carbide (SiC) was used as the material for the porous media. Measurement techniques which were incorporated in the combustor include an array of axially mounted thermocouples, an external microphone, an external CCD camera, and a gas chromatograph with thermal conductivity detector which enable temperature measurements, acoustic spectroscopy, characterization of thermal radiative emissions, and composition analysis of exhaust gasses, respectively. Before evaluation of the various solid media in the combustion chamber the substrates and catalysts were characterized using X-ray diffraction, X-ray fluorescence, scanning electron microscopy and energy dispersive spectroscopy.

MgO-ZrO$_2$ porous media was found to outperform both $\alpha$-Al$_2$O$_3$ and SiC matrices, as it was established that higher temperatures for a given equivalence ratio were achieved when the flame was contained within a MgO-ZrO$_2$ matrix. This was explained by the presence of oxygen vacancies within the MgO doped ZrO$_2$ fluorite lattice which facilitated catalytic reactions. Several catalyst compositions were evaluated to promote combustion within a MgO-ZrO$_2$ matrix even further. Catalysts such as: Pd enhanced WC, ZrB$_2$, Ce0.80Gd0.20O1.90, LaCoO$_3$, La0.80Ca0.20CoO$_3$, La0.75Sr0.25Fe0.95Ru0.05O$_3$, and La0.75Sr0.25Cr0.95Ru0.05O$_3$; were evaluated under lean fuel/air mixtures. LaCoO$_3$ outperformed all other catalysts, by enabling the highest temperatures within the combustion chamber, followed by Ce0.80Gd0.20O1.90. Both LaCoO$_3$ and Ce0.80Gd0.20O1.90 enabled a flame to exist at $\phi = 0.45\pm0.02$, however LaCoO$_3$ caused the flame to be much more stable. Furthermore, it was discovered that the coating of MgO-ZrO$_2$ with LaCoO$_3$ significantly enhanced the total emissive power of the combustion chamber. In this work as acoustic spectroscopy was used to characterize heterogeneous combustion for the first time. It was found that there is a dependence of acoustic emission on the equivalence ratio and flame position regardless of media and catalyst combination. It was also found that when different catalysts were used, the acoustic tones produced during combustion at fixed reactant flow rates were distinct.

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