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LIQUID FUEL COMBUSTION USING POROUS INERT MEDIA

(Grant/Contract Number DAAD 190210082)

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SUMMARY/OVERVIEW:

Combustion using porous inert media (PIM) offers benefits such as high power density, stable operation over a wider turndown ratio, homogeneous product gases, lower combustion noise and reduced emissions of NOx, CO, particulates, etc. Much of the previous research using PIM has focused on combustion of gaseous fuels, whereby the reactants are preheated by upstream transfer of heat from the flame region. In case of the flame stabilized within the PIM, the heat transfer is dominated by radiation and conduction from the reaction zone. The focus of the present study is to achieve lean premixed combustion (LPM) of liquid fuels using PIM. In particular, we seek to recirculate energy released in the reaction zone to pre-vaporize the liquid fuel and preheat the fuel-air mixture upstream of the combustor. Further, a PIM section is used upstream of the combustor section to promote fuel-air mixing and hence, to achieve uniform combustion without the fuel-rich or fuel-lean regions that tend to increase the emissions of particulates, CO, NOx, and UHCs. Two test facilities were developed in this project; (i) a non-reacting set up with controlled heat input to the PIM to simulate upstream heat transfer, and (ii) a combustor set up capable of providing emissions data over a range of operating conditions. The experiments are complemented with computational fluid dynamic analysis to model the fuel vaporization, fuel-air premixing and reactant preheating. Combustion experiments were conducted using a commercially available injector and a custom designed two-fluid atomizer. Results show that a finite fuel-air premixing region upstream of the PIM section is necessary for complete mixing, and hence, to achieve low-emissions with liquid fuel combustion. The length of the premixing section can be reduced significantly through injector design. The study has resulted in a combustor concept with an annular heat recirculation zone to further increase the heat recirculation by minimizing the heat loss through the combustor wall.

TECHNICAL DISCUSSION

Combustion in porous inert media is based on excess enthalpy concept in which thermal energy from the reaction zone is recirculated upstream to preheat the fresh fuel-air mixture via solid radiation and conduction[1]. Much of the research on PIM combustion in the past has focused on gaseous fuels[2-3]. One of the first studies using liquid fuel (heptane) in PIM was conducted Kaplan and Hall[4]. They found that the combustion stabilized over the equivalence ratio (ϕ) range of 0.57-0.67. The burner stability was dependent upon the droplet size and the distance between the PIM and fuel injector. Emission measurements indicated complete combustion with single digit CO emissions and NOx emissions ranging between 15-20 ppm. Jugjai et. al.[5] showed that strong energy feed-back by radiation from the flame enabled evaporation of kerosene. The liquid kerosene supplied at normal temperature experienced preheating when it came in contact with the high temperature porous surface of the burner at the top. The burner acted not only as a pre-heater but also as a distributor for the liquid fuel. The evaporation of kerosene occurred within the porous burner to result in lean premixed (LPM) combustion.

PIM combustor consists of a fine pore region followed by a coarse pore region, where the flame is stabilized. The fine pore region serves as the pre-heater by facilitating upstream heat transfer by conduction and it also prevent flashback into the premixing region. An important requirement to achieve low pollutant emissions in liquid fuel combustion is that the fuel is fully pre-vaporized and premixed with air, prior to reaching the reaction zone. If the injector is placed very close to the PIM, the fuel pre-vaporization and/or fuel-air premixing may be inadequate and hence, droplet combustion mode producing diffusion flames would ensue. Thus, the distance between the fuel injector and PIM (denoted as the premixing length) is an important parameter to maintain LPM combustion needed for low-emissions. From practical considerations, the premixing length must be minimized to yield a compact combustion system. The trade-off between the premixer length and completeness of fuel-air premixing depends upon the operating conditions such as the co-flow air temperature and geometric parameters including the PIM configuration affecting thermal feedback upstream of the combustion zone.

The test setup for combustion experiments shown in Fig. 1 consists of four sections, namely, the inlet plenum, the vaporization and mixing section, the PIM section, and the emissions shield. The combustion air entered through fittings mounted on the inlet plenum on the upstream end of the apparatus. The injector could be located at any axial position within the vaporization and mixing section. Two injectors were investigated in this study as shown in Fig. 2. The air-assist atomizer is commercially available product (Delavan, Type SNA) and the swirling-air atomizer

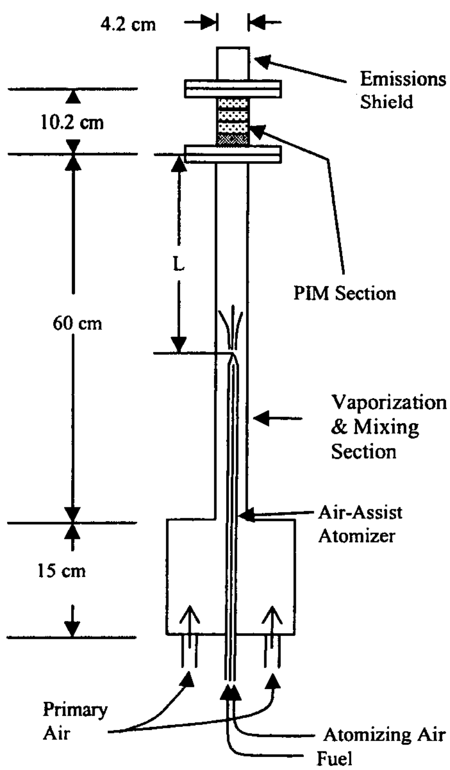

Figure 1. Schematic Diagram of the Combustor Setup

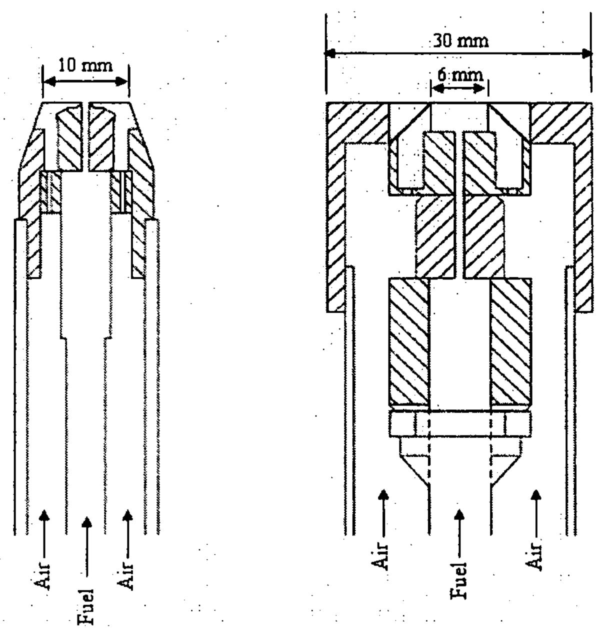

Fig. 2 (a) Air-assist atomizer (left), and (b) Swirl-air atomizer (right) provided by Parker Hannifin.[6] PIM is placed in the preheating section and the combustion section. The flow cross-section of both of these sections is 4.2 cm x 4.2 cm. Several PIM configurations were tested as shown in Fig. 3. In the baseline configuration C1 (or 26/4-4-4), the preheating section was a 2.5 cm thick, 26 pores per cm (ppcm) porous piece and the reaction zone consisted of three 4 ppcm porous pieces occupying the 7.5 cm length downstream of the preheating zone. Each porous piece fit tightly into the test section. Product gas was sampled by quartz probe with a tapered tip to quench the reactions. The cooled sample was passed through water traps prior to measuring the CO and NOx emissions by electrochemical analyzers.

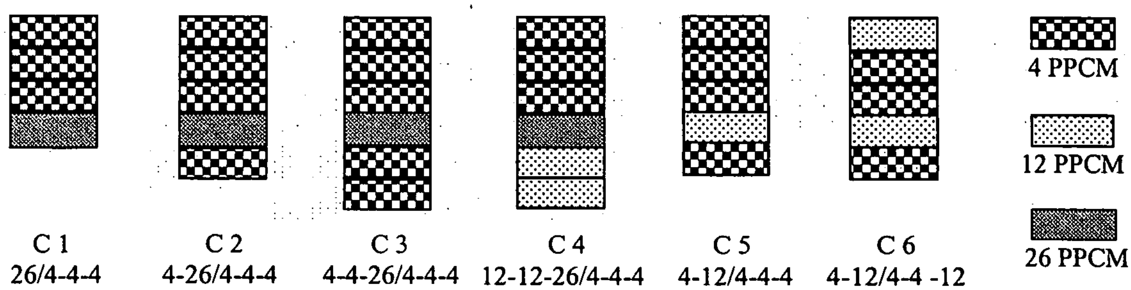

Figure 3. Porous Media Configurations

Base line conditions were established as equivalence ratio (Φ) of 0.67, primary inlet air temperature (T_{in}) of 475 K and heat release rate (Q) of 3.3 kW and air flow rate of 135 standard liters per minute (slpm). Measurements were taken at the center of the emissions shield to determine the variation in emissions in the streamwise direction. Results showed that the reactions occur mainly within the porous inert media. The effect of the injector location on CO and NOx concentration is shown in Fig. 4 (a) and (b) for both the air-assist atomizer and the swirling-air atomizer. The CO and NOx concentrations are nearly the same for L = 60 cm to about 40 cm suggesting that the fuel is fully vaporized and premixed with air. For L = 35 cm to about 25 cm, there is a slight increase in the CO and NOx concentration for the air- assist atomizer. However, the CO and NOx concentration for the swirling-air atomizer are lower indicating improved premixing of fuel and air within the injector. For L < 17.5 cm, soot emitting orange flamelets signifying droplet combustion in diffusion mode were visually observed.

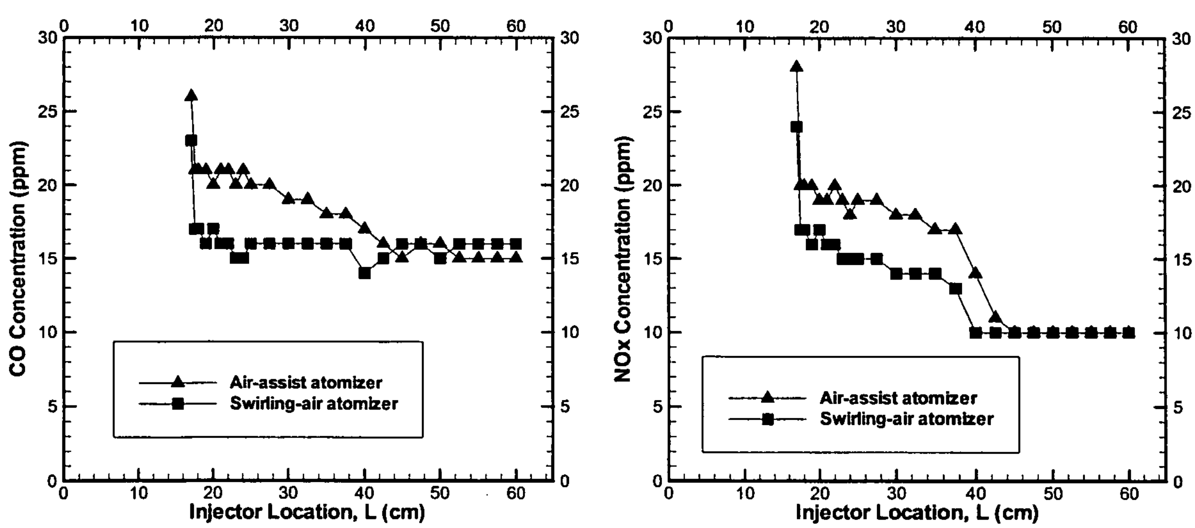

Figure 4. CO and NOx Concentration at Centerline for Baseline Conditions

Figures 5 (a) and (b) show the CO and NOx emissions versus injector location for the baseline configuration (C1) and modified configuration (C2). For each case, L was varied until combustion in droplet mode was visually observed. Results show that configuration C2 required a shorter premixing length (L = 9 cm) to avoid droplet combustion compared to configuration C1. The additional porous piece in configuration C2 increased the heat transfer from the combustion zone to the pre-vaporizing porous pieces. Results in Fig. 5 show that CO emissions decrease significantly with either one or two preheat pieces compared to the case with no preheat piece. However, the number of preheat pieces does not significantly affect the emissions.

The combustor used above is prone to significant heat loss from the walls. We have developed a combustor concept with an annulus to recover wall heat transfer to preheat the reactants. The concept shows excellent performance in both large and small scales combustion systems[7-8]. Experimental results with non-reacting set up are presented in detail in Ref. 9.

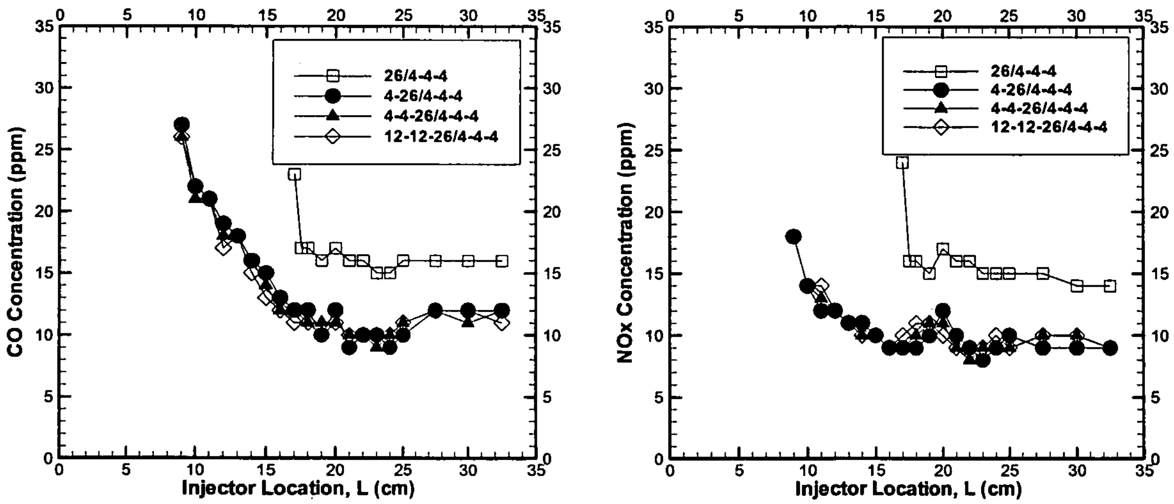

Figure 5. Effect of Preheat Section on (a) CO and (b) NOx Concentrations

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