Design and Construction of Gas-Fed Burners for Laboratory Studies of Flame Structure

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Abstract
The study of buoyant convection for diffusion flames in wildland fires is critical to understanding heating and cooling dynamics related to particle ignition. Studies based on solid biomass fuels are made difficult by short flame residence time associated with fine fuels. An alternative is to use artificial fuel gas rather than relying on pyrolysis of solid fuels to produce the gas products for combustion. This paper reports on the design, construction, and testing of gas-fed burners used for the study of flame characteristics.

Keywords: , Turbulence, Vertical Burner, Cylindrical Burner, Wall Fire

1. Introduction

The study of buoyant convection from diffusion flames in wildland fires is critical to understanding heating and cooling dynamics related to particle ignition (Baines 1990, Weber 1990, Beer 1995, Finney et al. 2010a). Studies based on flames from the burning of solid biomass fuels, however, are complicated because the rate of mass-conversion to volatile gases is not controllable and the duration of fine fuel burning is relatively short. An alternative is to directly use artificial fuel gas rather than relying on wood pyrolysis to produce the combustible gas products. The challenges, however, are to devise methods of delivering pure gas for producing diffusion flames that are appropriately analogous to wildland fuel configurations. The use of a stationary vertical and cylindrical fuel source was thought to be useful for gaining understanding of the convective environment at the ignition interface (Finney et al. 2010a). Gas-panel burners have been used previously to study vertical flame structure and heat transfer to interior walls and buildings (de Ris and Orloff 1975, Ahmad and Faeth 1979, Wang et al. 2002). The primary interest of these studies has been the mean temperature and velocity profiles extending up and away from the wall (Delichatsios 1982, Bertin et al. 2002) and for the upward spread rates and burning rates of solid fuels on the walls (Quintiere et all, 1986). The purpose of the wall burner is to generate diffusion flames attached to a vertical fuel source, analogous to a cross-section through a fuel bed burning in the absence of wind. The cylinder burners are intended to represent combustion of a three-dimensional fuel bed that can be subjected to cross-flow in a wind tunnel to study wind effects on flames. This paper describes the design, construction, and testing of gas-fed burners and use in wildland fire research.

2. Methods

A vertical wall burner and cylindrical tube burner array were developed to study diffusion flame geometry and turbulence. The wall burner and cylinder burners have some common design features and both use ethylene (C_2H_4) for consistent flame generation; however, both designs proved to be challenging from an engineering perspective.

Vertical flame burner

The rectangular vertical burner was constructed from tubular 0.3175cm steel tubing that measures 5.08 x 15.24 cm with inside dimensions of 0.61 m wide, 1.83 m tall and 0.15 m deep (**Figure 1**).

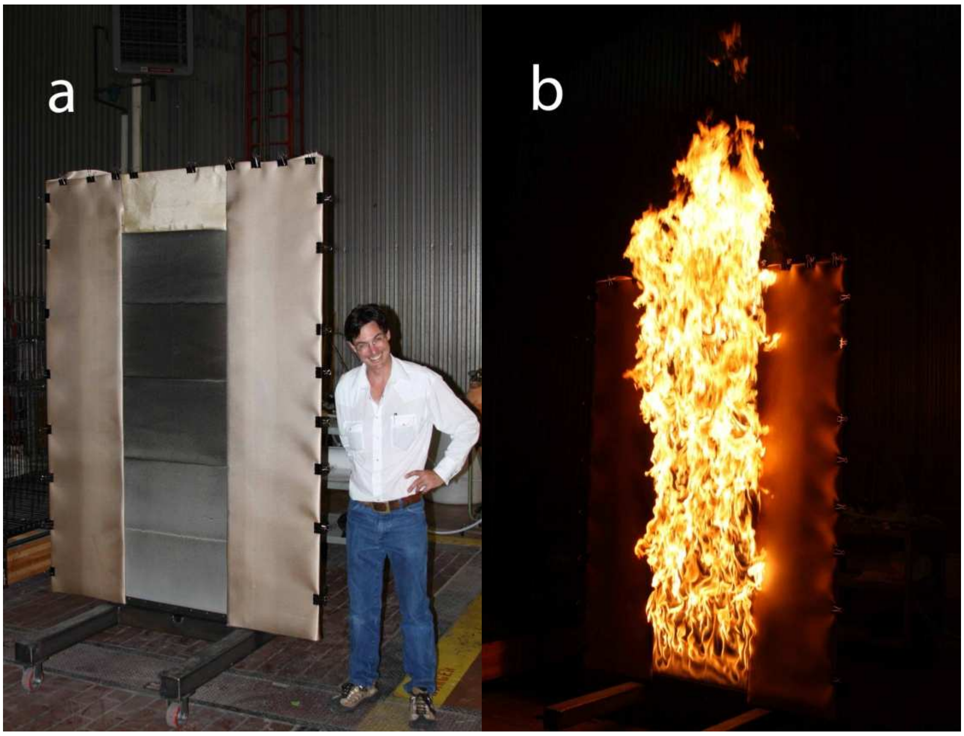

Figure 1. Photographs of flame wall apparatus showing (a) vertical ceramic surface with high temperature fiberglass cloth boarders, (b) flame wall in operation.

The burner frame was mounted to allow the entire burner to rotate 90 degrees into a horizontal position for providing access to the burner's components for maintenance. The burner support was constructed of the same rectangular steel tubing as the burner frame and mounted on four 7.62 cm casters, making the entire system portable (**Figure 2.)** The interior volume of the vertical burner was enclosed at the back by a 0.3175 cm steel plate and a three layer diffuser at the front burner surface. To produce uniform gas flow the

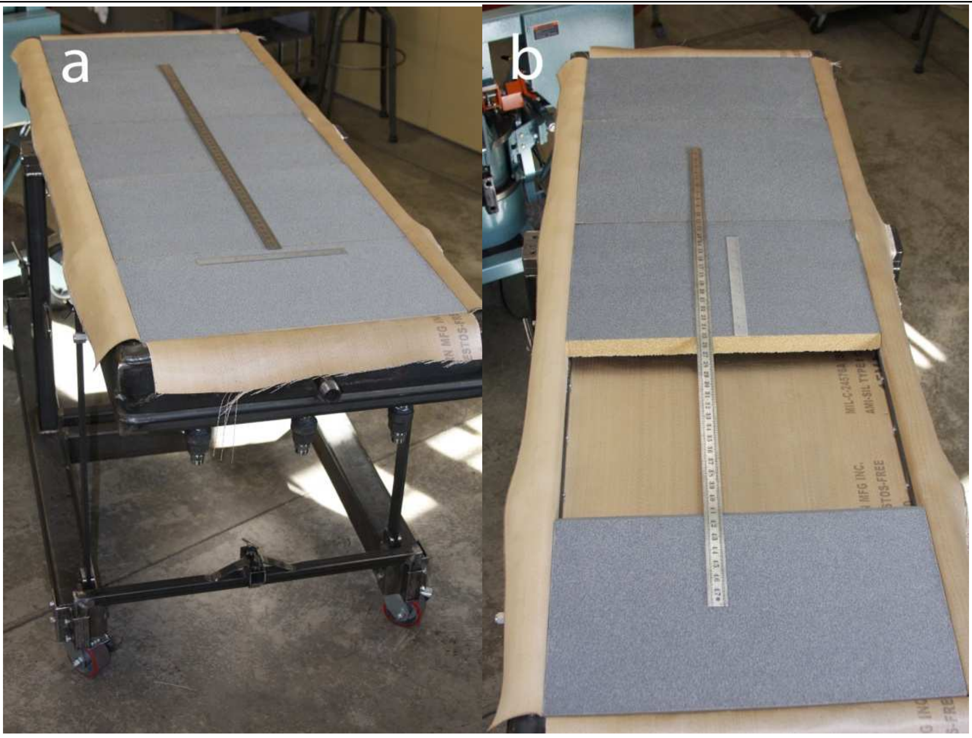

Figure 2. Photographs of flame wall apparatus showing (a) support frame and wall burner in horizontal position, (b) assembly of ceramic tiles with high temperature fiberglass cloth diffuser.

diffuser was composed of an interior layer of fiberglass cloth, a middle layer of fiberglass batting, and an exterior surface layer of ceramic foam 2.5cm thick (17.7 pores per centimeter (45 pores per inch or ppi)) (**Figure 3**). The fiberglass cloth is a silica based high temperature (1260 C) material and acts as the initial gas diffuser. The cloth measures 0.06cm thick, 68.58cm wide and 190cm long and stretched tight throughout the interior surface using steel strap (**Figure 3**). The fiberglass batting is a silica based material cut to fit the void space between the silica cloth and ceramic foam board and acts as a secondary diffuser. Cordierite ceramic foam (Sud-Chemie Hi-Tech Ceramics[1]) is used for the burner exterior surface due to the low thermal expansion coefficient and thermal shock tolerance. The ceramic foam provides a rigid surface that will not deform during extended periods of burner operation. The burner face is constructed of five separate ceramic panels, four that measure (35 x 62.5) cm and one that measures (40 x 62.5) cm. This configuration gives a flat panel wall burner surface measuring (180 x 62.5) cm contained within a steel construction housing measuring (190 x 70 x 15) cm.

The fuel gas for all of the experiments is CP grade bottled ethylene (C_2H_4) and was supplied by means of six inlets (3 on top and bottom) connected internally by perforated 2.5cm steel tubing as a manifold. The six inlets are plumbed into the burner through the back steel plate. Ethylene was chosen because its molecular weight (28.05 g/mol) is buoyancy neutral allowing for optimal gas diffusion through the ceramic burner surface thus providing an ideal diffusion flame. The gas flow rate is precision controlled using an Omega, Inc. Mass Flow controller (FMA-2600A)[2]. Gas flow rates range from 100-400

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liters/minute and is supplied to each burner configuration through 1.9 cm Teflon PTFE tubing. The pressure drop across the ethylene tank regulator reduces the gas temperature low enough to effect flow controller function. This is avoided by using 15 meters of coiled tubing submersed in a water bath. This warms the gas prior to reaching the Omega mass flow controller (**Figure 4**). The entire burner is purged with CP grade bottled nitrogen (N_2) prior to each experiment to eliminate any oxygen (O_2) from the system.

Figure 3. The flame wall burner assembly cross section showing fiberglass cloth (back), fiberglass batting (middle), and porous ceramic plate (front).

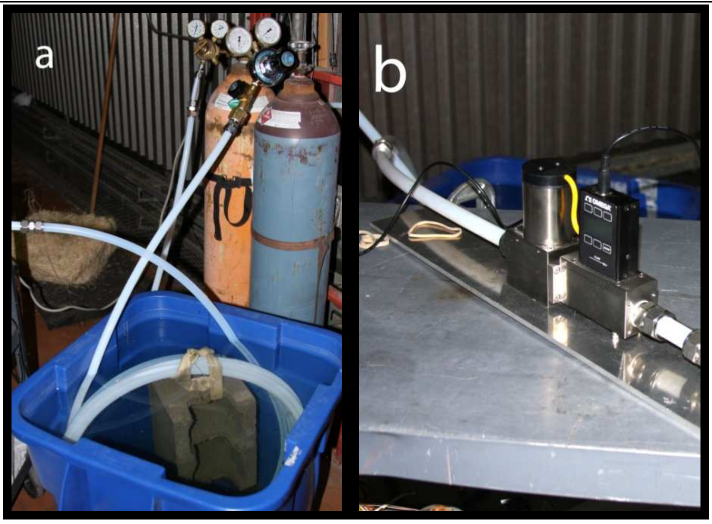

Figure 4. The gas feed system with (a) water bath heat exchanger and (b) Omega Inc. mass flow controller.

Cylindrical flame burners

The cylindrical burners are constructed in an array consisting of 13 rows with up to 17 individual burner ports per row. This design allows for several experimental configurations with varying cylindrical burner spacing and density, both of which we believe contribute to the flame dynamics. Each horizontal row support is constructed of 2.5cm steel square tubing with 3.175mm wall thickness that functions as both the array support and the gas feed manifold to the individual cylindrical burners. The entire support is (180 x 3.75 x 3.75) cm and is housed within a frame (191 x 240 cm) constructed of 5.0 cm angle iron steel. The assembly is attached to a mechanical screw which enables the array to tilt up to 60 degrees in the positive or negative horizontal direction from perpendicular. Each Cordierite ceramic cylinder is 30 cm long with 5 cm OD and 2.875 cm ID. By stacking the ceramic cylinders, the burner height can vary. The burner design provides for a fuel bed array ranging in size and density as well as height and a full range of motion to align the fuel rods into different wind flow regimes in order to precisely represent flaming of a three-dimensional fuel bed.

The cylindrical burners contain a 0.94 cm tubular 304-stainless steel manifold with a wall thickness of 0.75 mm. The tubular manifold also serves to structurally support the ceramic burner. Size 56 holes (1.16 mm) are drilled every 1.25 cm on four sides symmetrically for initial uniform gas distribution (**Figure 5**). The tubular steel manifolds vary in 30 cm lengths from 30 to 90 cm depending on the height of the array being tested. The gas diffuser is a perforated stainless steel tube (Perforated Tube Inc.) measuring 2.45 cm OD 304-stainless steel tubing with 1.56 mm pore size by 0.235 cm staggered centers. The diffuser tube is wrapped in a heat-treated class 240C fiberglass sleeve (SPC Technology[3]) to enhance gas diffusion. The diffuser fills the void space between the stainless steel manifold and the inside diameter of the cylindrical Cordierite ceramic burner (**Figure 6**).

The fuel gas for all of the experiments is CP grade bottled ethylene (C_2H_4) and was supplied by means of 0.95cm Teflon PTFE tubing at each end of the tube support manifold to ensure even flow distribution throughout the entire tube array.

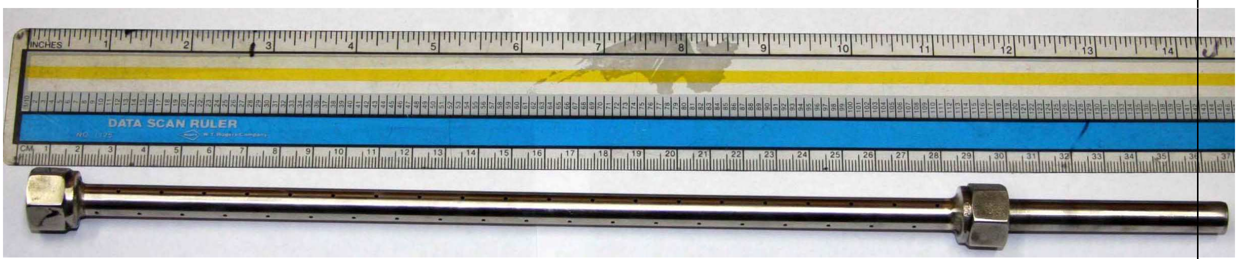

Figure 5. Cylindrical burner tubular gas manifold with size 56 holes (1.16 mm) drilled every 1.25 cm symmetrically on four sides to uniformly feed ethylene gas from the manifold to the Cordierite ceramic burner surface.

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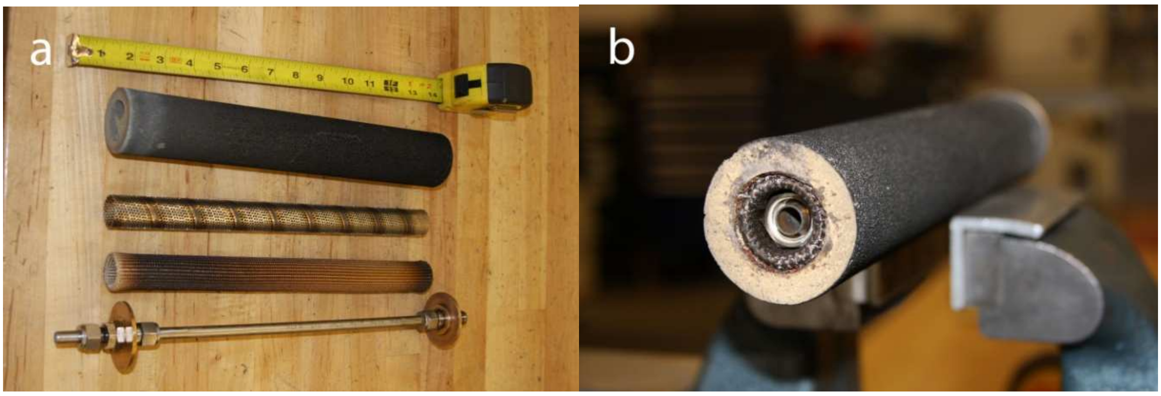

Figure 6. (a) Components of the cylindrical burner include from right to left, the tubular gas manifold with end caps, fiberglass sleeving, perforated tube diffuser, Cordierite ceramic burner tube. (b) Cylindrical burner components assembled without the end cap.

3. Performance

We tested the wall and cylinder burners with ethylene gas with flow rates controlled by a mass flow meter. Flame structure generated by the wall (described by Finney et al. 2010b) was found to be repeatable as measured by thermocouples and heat flux sensors (**Figure 7a).** The cylindrical burners have only yet been tested for functionality with no performance measurements available at this time. **Figure 7b** shows flames produced by a linear array of the cylindrical burners during a feasability test.

Figure 7. Examples of flame structure produced by gas-fed burners for a) the wall section 1.8 meters tall and b) the 30cm tall cylinder burners.

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