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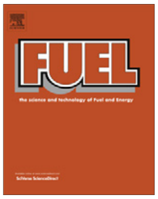

Technical applicability of low-swirl fuel nozzle for liquid-fueled industrial gas turbine combustor

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HIGHLIGHTS

- ▶ Potentials of a liquid-fueled low-swirl burner are reported for the first time.
- ▶ Flow field of the current implementation is that of the typical low-swirl flow.
- ▶ The burner stabilize flames under higher velocity conditions with kerosene fuel.
- ▶ The combustor is operable over the entire operating range of a test engine.
- ▶ The combustor has a big advantage for preventing overheating issues.

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ABSTRACT

In this study, potentials of the liquid-fueled low-swirl burner technique for industrial gas-turbine combustor application are reported for the first time. A low-swirl fuel nozzle, which is a new implementation of the basic low-swirl burner design, is configured by the velocity measurement of methane–air open flames under atmospheric pressure and a low velocity (~3 m/s) condition. Flow properties, such as the axial stretch rate and virtual origins, are compared with the previously reported values with the axial vane type low-swirl injector, and it is confirmed that the flow field generated from the current implementation is of the typical low-swirl flow. Then, it is shown that the configuration successfully stabilize the lifted flame under much higher velocity (~50 m/s) condition with kerosene fuel injected by a typical pressure atomizer. Finally, the fuel nozzle is installed in a 290 kW simple-cycle liquid-fueled gas turbine engine and is found to be operable over the entire operating range. The combustor inlet wall temperatures are shown to be within an acceptable range, even without the cooling air that was required for conventional combustors. This is an advantage of the lifted flame stabilized by the low-swirl technique. Although our focus is not on low emissions characteristics, NOx emissions is also found to be below maximum levels of current Japanese regulations (<84 ppm@15% O_2). In sum, the proposed fuel nozzle design shows promise for the application of liquid-fueled industrial gas turbine engines.

1. Introduction

Gas turbine engines for standby generators generally use liquid hydrocarbon fuels due to their robust, rapid engine startups capability. In these gas turbines, burning of the liquid hydrocarbon fuel spray often results in significant heat radiation from the flames that can occasionally damage the fuel nozzle and/or combustor wall. Overheating can also corrode the combustor wall surface to the extent that aggressive cooling treatments have been applied to the combustor wall of liquid-fueled gas turbine engines. For example, the systems developed by Niigata Power Systems [1–3], use cooling air supplied to the heated region to prevent overheating. While this provision improves the durability of hot parts and extends maintenance cycles, it has several disadvantages, including lower engine efficiency and unburned hydrocarbon emissions. Thus, preventing overheating with less or no cooling air would generate a critical advantage, as well as reducing emissions of pollutants such as NOx and soot.

This study examines the adaptation of the low-swirl burner technology, developed for ultralow emissions gas-fuel combustors (<5 ppm NOx and CO), to a liquid-fueled industrial gas turbine combustor. The low-swirl burner was developed at the Lawrence Berkeley National Laboratory [4,5] for lean premixed combustion of gaseous fuels. It has been widely adopted for fundamental

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Nomenclature

A_{EP}	area of the swirl flow passage in the x–r cross-plane
M	ratio of mass flow rate through inner tube to mass flow rate through swirl orifices ($M \equiv \dot{m}_x/\dot{m}_\phi$)
$\dot{m}_x$	mass flow rate through inner tube
$\dot{m}_\phi$	mass flow rate through swirl orifices
Q_f	fuel volume flow rate
R	ratio of inner tube radius to nozzle radius ($R = R_1\ R_2$)
R_1	inner radius of the inner tube in C-C cross section (Fig. 1)
R_2	inner radius of the outer tube in C-C cross section (Fig. 1)
r	radial distance
S_g	geometrical swirl number
U_0	bulk flow velocity
U	axial velocity
x	axial distance from injector exit
x_0	virtual origin of divergent flow
E.R.	equivalence ratio
φ	orifice diameter

studies, since this burner generates a detached flame that is a close approximation of a freely propagating planar turbulent premixed flame. The flame configuration is considered the most fundamental for elucidating basic turbulent flame processes. From a practical perspective, many studies have been devoted to the adaptation of the technology to gas turbines. Flow field and emissions characteristics have been reported for various gaseous fuels, including natural gas, hydrogen, and syngas [6–8]. Testing of a prototype low-swirl injector for a 7 MW gas turbine showed that the absence of heating of the nozzle tip due to the detached flame to be an attribute of this technology in addition to its ultra-low emissions capability [9].

To date, there has yet to be data published on burning liquid fuels with the low-swirl burner. For liquid-fueled combustors, the fuel atomization and evaporation processes, as well as the mixing process, play key roles in controlling combustion characteristics such as flame stability, flame size and pollutant emissions. Because the low-swirl burner was intended for gaseous fuel, for it to burn liquid fuels a fuel atomization and mixing system needs to be included in the design scheme. The goal of this study is to investigate the feasibility of a liquid-fueled low-swirl combustion system for gas turbine. Our approach is to integrate a simple hollow-cone type fuel atomizer into the basic low-swirl burner configuration.

The low-swirl burner principle is based on stabilization of a turbulent premixed flame in a non-recirculating divergent flow. For gas turbines, the swirler shown in Fig. 1a has been developed to produce a divergent flow in the combustor. The main difference between this swirler and those of conventional high-swirl design is the opening of a center channel through which a portion of the flow of reactants bypasses the swirl annulus. When the flow of reactants discharges into the combustor, the transverse gradient induced by the centrifugal forces of the swirling flow causes the center non-swirling flow to diverge. Flow recirculation is avoided because the unswirled center flow inhibits the propensity of its surrounding swirling flow to cause vortex breakdown. For a given swirler geometry, the rate of flow divergence it generates is controlled by the mass ratio of the swirled and unswirled flows. This ratio, also called flow split, can be varied by covering the center channel with a perforated plate. Because the interaction between the unswirled and swirled flow is a critical process, the low-swirl injectors developed for gaseous fueled gas turbines are fitted with small injection spokes upstream of the swirler to minimize the disturbance of the flow feeding into the swirler [9]. In adaptation to liquid fuel, a top issue is whether or not the liquid fuel atomizer can be fitted in the flow path without causing significant disruption of the divergent flow formation. Other significant issues are associated with optimizing the rates of fuel vaporization and mixing so to enable a flame in the combustor to burn in a partial or full prevaporized–premixed combustion mode. Once these design issues are addressed, performance parameters such as flame stability, turndown, and emissions can then be evaluated to access the feasibility of adapting low-swirl burners to liquid fueled gas turbines.

The experimental test series is divided into three phases to address the issues outlined above. First, we performed PIV measurements to verify that our new implementation of a low-swirl burner fitted with a fuel atomizer produces flow pattern that has the low-swirl divergent flow characteristics. Premixed gaseous flames were used in this phase of our development. The experiments also include a study on the effects of nozzle tip shape on flow patterns by comparing axial velocity profiles along the center line. Second, atmospheric combustion testing using kerosene is performed with a single-can type combustor to determine if the

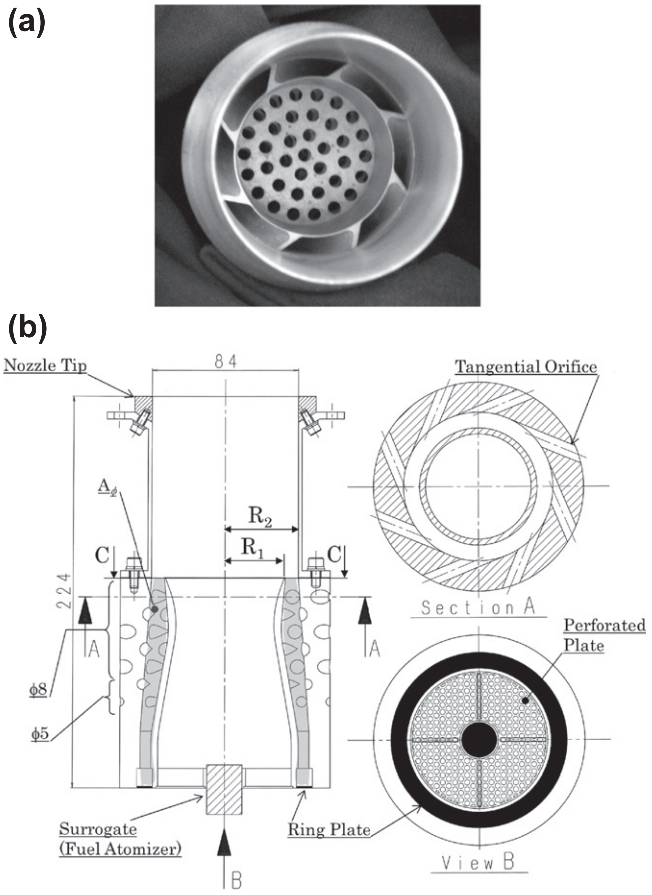

Fig. 1. (a) Vane-type low-swirl burner and (b) present low-swirl burner configurations.