

Further Development of Low Pressure Drop Duct Burners

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Purpose

One of the major objectives of this fellowship period was to develop strategies to improve the startup emissions of FlexEnergy Inc's FP250 turbine system and initiate the performance testing of FlexEnergy Inc's next generation of microturbine. The FP250 is a 250kWe gas-turbine generator that utilizes FlexEnergy Inc's proprietary Flex Oxidizer™ system to generate electrical power from a wide variety of gaseous fuels. Pollutant emissions are less than 1 ppm of NO_x, CO and UHC while operating in "Flex" mode. The next generation of FlexTurbine™ is designed to improve performance characteristics while maintaining the low emissions levels characteristics of FlexEnergy Inc's current microturbines. Due to the proprietary nature of the next generation of FlexTurbine performance and operation, it's testing will not be discussed in this report.

Background

During startup, two duct burners are utilized to provide high temperature, vitiated gas to the FP250. For applications using propane as a fuel source, a low pressure drop bluff-body stabilized burner was designed. The burner consists of a gutter with a centered fuel manifold with metering holes to inject fuel into the air stream, see Figure 1. Within the duct, the burner is normal to the direction of flow with the v-gutter pointing upstream. The recirculation behind the gutter provides conditions for fuel-air mixing, flame anchorage, and ignition. Studies performed during the summer of 2011 established a number of parameters related to the ignition and operation of these burners at atmospheric pressure using commercial propane as fuel. Burners of this type have since been included in another FP250 installation. For future installations of the FP250 system it is desired to expand the operation of the duct burners to natural gas as well as reduce their emission of controlled pollutants focusing on oxides of nitrogen (NO_x). Results of these studies are discussed qualitatively in this report.

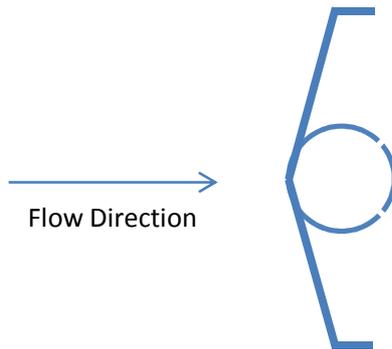


Figure 1. Schematic of the duct burners with current fuel metering pattern

Duct Burners for Natural Gas

To increase flexibility in site planning for future FP250 installations, it has been determined that adding natural gas as a possible start-up fuel is desired. The operational characteristics (e.g., ignition, stability, and turndown) of the current burners are desirable. Thus, changes to offset the difference in Wobbe Index of the two fuels should be limited to the size and pattern of the metering holes. A two-step numerical process was used to adjust the metering holes for natural gas. First, a simple one-dimensional model of the individual jets was used to approximate the conditions required to achieve the same energy increase across the burners with three fuels: propane, a mixture of gases representing typical natural gas, and methane. Second, Fluent (ANSYS, Inc., Canonsburg, Pa) was used to evaluate the effect some of the design changes.

The one-dimensional model used compressible flow relations for flow across an orifice to estimate jet-penetration and mass flow rate from each jet. The manifold tube was treated as a pressurized plenum, as was the region immediately downstream of the gutter. Measurements of fuel feed pressure, fuel flow rate, air flow rate, and duct pressure from operating FP250 installations using propane were used as a baseline for the design of the natural gas burners. Two different approaches were studied: a change in metering hole size and a change in fuel feed pressure. Included in the comparison is fuel feed pressure, hole size, number of holes, fuel mass flow, energy flow rate, and the maximum possible flow (i.e., choked condition). The results are shown in Tables 1 and 2 relative to the propane baseline.

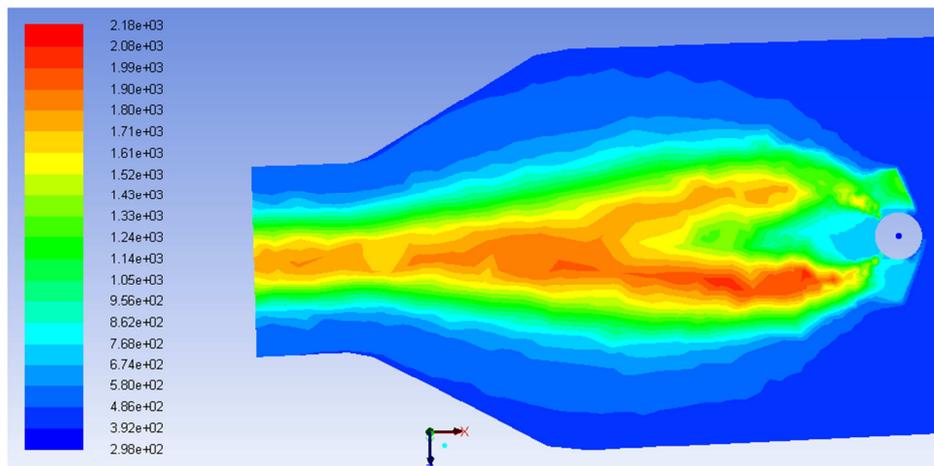
Table 1. Hole size relative to that for propane required for reaching same energy rate on natural gas or methane

Fuel	Fuel P	Meter Hole Diameter	# holes	Fuel Flow	Energy Rate	Choke Flow
C3H8	1.00	1.00	1.00	1.00	1.00	1.00
Natural Gas	1.00	1.06	1.00	0.70	1.00	0.74
Methane	1.00	1.04	1.00	0.66	1.00	0.71

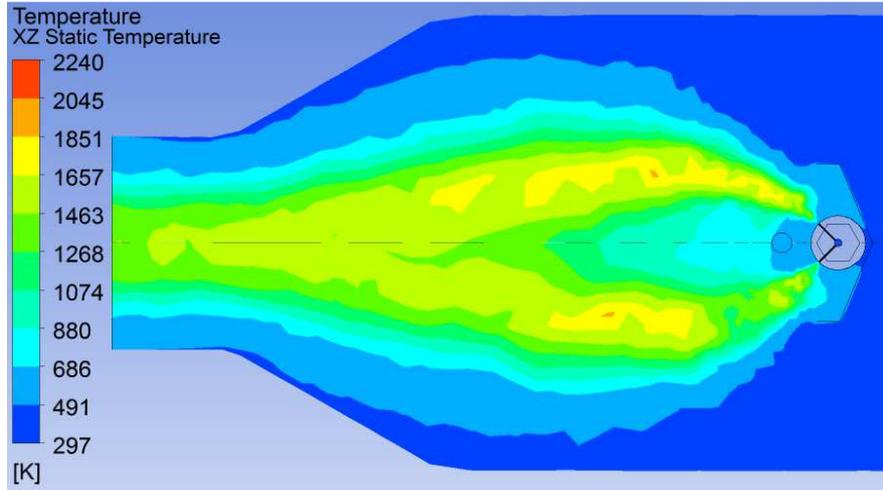
Table 2. Required pressure change relative propane required for operation on natural gas and methane

Fuel	Fuel P	Meter Hole Diameter	# holes	Fuel Flow	Energy Rate	Choke Flow
Propane	1.00	1.00	1.00	1.00	1.00	1.00
Natural Gas	1.08	1.00	1.00	0.70	1.00	0.68
Methane	1.06	1.00	1.00	0.66	1.00	0.67

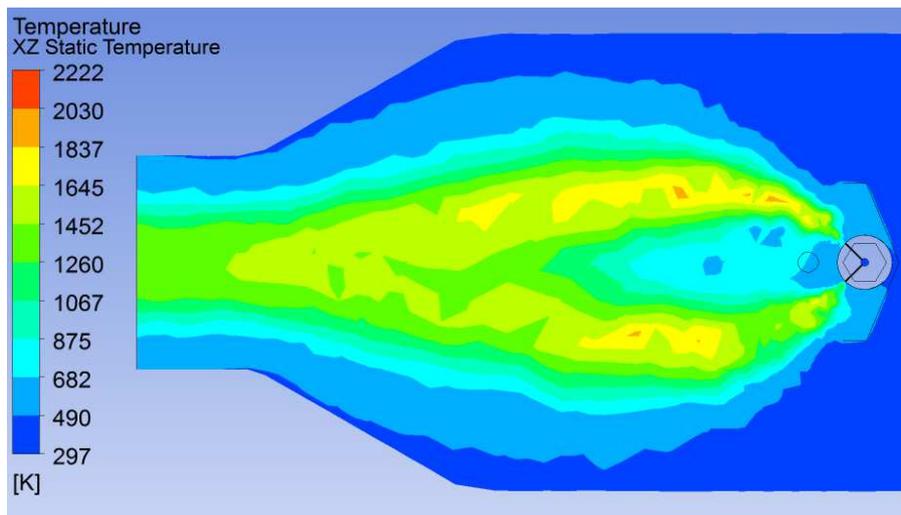
Based on the results of the one-dimensional model, a series of CFD simulations were used for qualitative and limited quantitative validation. Again, simulations using propane were used as a baseline for comparison. The three-dimensional, steady-state CFD simulations use a coupled solver with realizable $k-\epsilon$ with standard wall functions for turbulence and a non-premixed combustion model with an equilibrium PDF model including 26 species. Simulations at two different operating points were performed. Results from simulations of the larger burner with fixed hole size at one operating point are presented here.



(a) Propane



(b) Natural Gas



(c) Methane

Figure 2. Static temperature contours along the duct centerline for the three different fuels tested

Results typical of the temperature profile for portion of the computational domain along the duct centerline for the three fuels are shown in Figure 2. The fuel flow rate in all three simulations was adjusted to achieve the same area-averaged exit temperature. Qualitatively the temperature profile of the propane flame has a narrow high temperature core whereas the natural gas and methane flames have a cooler wider core. The result is an improved temperature distribution at the exit of the domain. Table 3 includes some of the factors important to the operation of the duct burners as predicted by the CFD simulations. The general fuel pressure trend predicted by the one dimensional model was validated by the CFD. However, the magnitude of the change was greater. This is likely due to additional flow losses through the small tubes used in the CFD geometry. In the one-dimensional model, the jets were

simple orifices. The actual pressure increase required for operation on natural gas will be determined experimentally.

Table 3. Some operating parameters of the duct burners as predicted by the CFD simulation of the larger burner. Boundary conditions were controlled to match exit temperature.

	Natural Gas	Methane
Fuel Pressure	1.49	1.51
Inlet Temp	1.00	1.00
Outlet Temp	1.00	1.00
ΔT	1.00	1.00
Duct ΔP	1.03	1.03

The results of the redesign study led to two options. First, if the additional fuel pressure is available, use the current burner. Because the orifices are not operated near their choking condition, even under extreme conditions, it is possible to keep the current hole diameter with higher feed pressure to account for an increase in losses due to the change in fuel. Second, increase the hole size by ~5% to allow for the greater volume flow rate required by natural gas. This is an option for circumstances where additional fuel pressure is not available. In both cases the geometry of the burner is essentially maintained.

Reduced Emissions Duct Burners

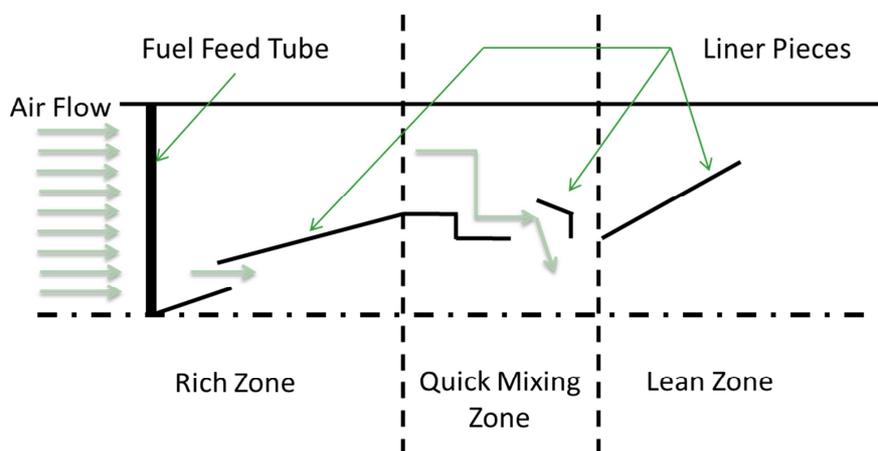


Figure 3. A sketch of the RQL concept duct burner for low emissions

Two different dry-low-NO_x approaches were investigated for the redesign of the duct burner for reduced emissions. The concept used a rich, quick-mixing, lean (RQL) method. In this design, sketched in Figure 3, a fuel rich zone is used to provide flame stability the effluent from this zone is mixed rapidly with fresh air and this fuel lean mixture is allowed to proceed towards complete combustion. This concept requires an additional liner which increases the complexity of its implementation. The second

concept uses a modified version of current duct burners to operate as a lean-premixed burner rather than as a diffusion controlled burner. The second concept is described in more detail in this report.

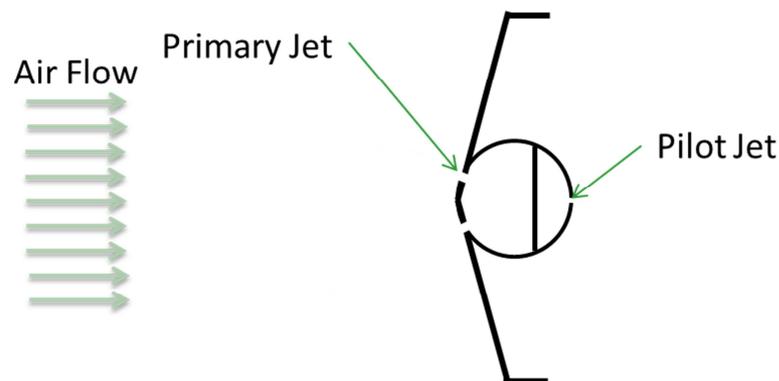


Figure 4. V-gutter burner with lean-premixed primary fuel and diffusion pilot

The modified v-gutter duct burner, sketched in Figure 4, uses the flow pattern behind the gutter for flame stabilization, but injects fuel in a different pattern to achieve a lean-premixed primary flame. A line of small holes on the downstream side of the manifold provide fuel for a diffusion pilot flame. These holes are designed to be choked at the pressure differential between the fuel feed and the duct. They are fed by an independent fuel circuit. Using choked orifices allows the fuel command for the pilot to be provided by a simple solenoid valve. The number of pilot holes is dependent on the minimum temperature rise required from the burner. Primary fuel is fed from a series of holes on the upstream side of the burner. These jets inject fuel against the air flow to promote mixing. The fuel lean mixture passes over the gutter and into the region of slow flow behind it where it is ignited either by autoignition or the pilot flame. The size of the primary holes is controlled by the necessary jet penetration for the specified region in the duct and to avoid autoignition of the gas upstream of the gutter. The location of the holes relative to the slots in the gutter may be adjusted control flame spread. Fuel for the primary feed jets is supplied by a control valve to adjust temperature rise across the burner.

Conclusions

A number of projects were undertaken during the period of the fellowship with FlexEnergy. Included among those were projects relating to duct burners used during the startup of the FP250 gas-turbine generator system. The first project investigated modifying the duct burners to run on natural gas. It was concluded that either an increase in feed pressure with the current geometry or a slight increase in the feed jet diameter could be used to operate on natural gas. The second project explored two options for

new duct burners with reduced pollutant emissions. A modification of the current duct burner design to use a lean-premixed approach was described for future testing.

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