Clean Combustion of Liquid Biofuels in Gas Turbines for Renewable Power Generation

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ABSTRACT

A Lean, Premixed, Prevaporized (LPP) combustion technology has been developed that converts liquid biofuels, such as biodiesel and ethanol, into a synthetic natural gas. This LPP gas can then be burned with low emissions in virtually any combustion device in place of natural gas, providing users substantial fuel flexibility. A DLE gas turbine utilizing LPP combustion technology to burn biofuels creates a low emissions power plant with no net greenhouse gas emissions.

This technology provides a clean and reliable form of renewable energy using liquid biofuels that can be a primary source for power generation or be a back-up source for inconsistent renewable energy sources such as wind and solar. The technology allows for the clean use of biofuels in combustion devices without the use of post-combustion pollution control equipment and can easily be incorporated into both new and existing gas turbine power plants. No changes are required to the DLE gas turbine combustor hardware.

Keywords: biofuel, biodiesel, carbon neutral, clean combustion, ethanol, gas turbine, Kyoto protocol, global warming, renewable energy.

1 Introduction

Traditionally, spray diffusion combustors (Figure 1) have been employed in gas turbines that operate on liquid fuels, including conventional fuels such as fuel oil #1 and fuel oil #2, also renewal fuels such as ethanol or biodiesel. However, this diffusion mode of operation tends to produce unacceptable levels of NO_x emissions. The current technology for burning liquid fuels in gas turbines is to use water and/or steam injection with conventional diffusion burners. Emissions levels for a typical "state of the art" gas turbine, such as a GE 7FA burning fuel oil #2 in diffusion mode with water/steam injection, are 42 ppm NO_x and 20 ppm CO [1]. Water/steam injection has a dilution and cooling effect, lowering the combustion temperature and thus lowering NO_x emissions. But at the same time, water/steam injection is likely to increase CO emissions as a result of local quenching effects. Thus, the "wet" diffusion type of combustion system for liquid fuels must trade off NO_x emissions for CO emissions.

In recent years, stringent emissions standards have made lean, premixed combustion more desirable in power generation and industrial applications than ever before, since this combustion mode provides both low NO_x and CO emissions without water addition. Lean, premixed combustion of natural gas avoids the problems associated with diffusion combustion and water addition. Thus, lean, premixed combustion is the foundation for modern Dry Low Emissions (DLE) gas turbine combustion systems. When operated on natural gas, DLE combustion systems provide NO_x and CO emissions of 25 ppm or less with no water addition. However, these systems cannot currently operate in premixed mode on liquid fuels because of autoignition and flashback within the premixing section.

Figure 1: Conventional liquid fuel spray diffusion flame (left) and typical lean, premixed natural gas flame (right)

In this study, vaporization of the liquid fuel in an inert environment has been shown to be a technically viable approach for LPP combustion. As described in this paper, a fuel vaporization and conditioning process [2] was developed and tested to achieve low emissions (NO_x and CO) comparable to those of natural gas while operating on liquid fuels, without water or steam addition. Tests conducted in both atmospheric and high pressure test rigs utilizing typical swirl-stabilized burners (designed for natural gas) found operation similar to that achieved when burning natural gas [3]. Emissions levels were similar for both the LPP gas fuels (fuel oil #1 and #2) and natural gas, with any differences in NO_x emissions ascribed to fuel-bound nitrogen present in fuel oil #2. Also, tests showed that the LPP combustion system helps to reduce the NO_x emissions by facilitating stable combustion even at very lean conditions when using liquid fuels. Extended lean operation was found for the liquid fuels due to the wider lean flammability range for these fuels compared with natural gas. An added advantage of the fuel vaporization and conditioning process is the ability to achieve fuel-interchangeability of a natural gas-fired combustor with liquid fuels. This was described in much greater detail in recent papers [3,4].

2 LPP Process

In this approach, liquid fuel is vaporized in an inert environment to create a fuel vapor/inert gas mixture, called LPP gas, with combustion properties similar to those of natural gas (Figure 2). Premature autoignition of the LPP gas was controlled by the level of inert gas added during the vaporization process. Tests conducted in both atmospheric and high pressure test rigs utilizing typical swirl-stabilized burners (designed for natural gas) found operation similar to that achieved when burning natural gas. The atmospheric and high-pressure rigs (up to 16 atm) were operated at inlet air temperatures typical of gas turbines (500K or higher). Both emissions and combustion dynamics were found to be the same or lower than operation on natural gas. This development is more fully described in Gokulakrishnan et al. [3].

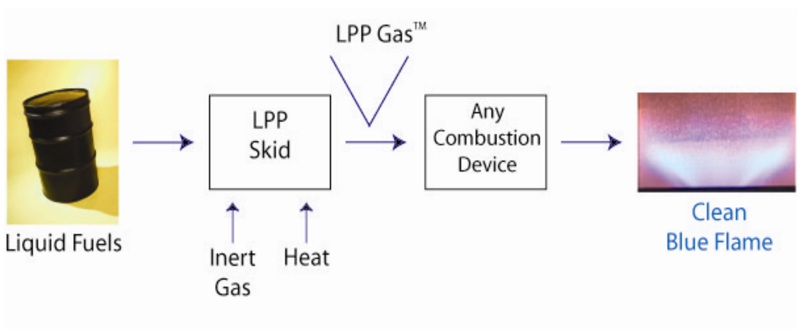

Figure 2: LPP Combustion Process Diagram

3 Biofuels Testing

Biofuels testing of the LPP Combustion System was performed in an atmospheric pressure combustor rig using a Solar Turbines Centaur 50 natural gas nozzle. The same commercial gas burner hardware was used for both natural gas and liquid biofuels, as LPP gas, without any modification (Figure 3). The biodiesel used for testing was soy-oil based soy-methyl-ester (SME). Figure 4 shows the atmospheric pressure test facility used to evaluate various fuels using the LPP Combustion Technology.

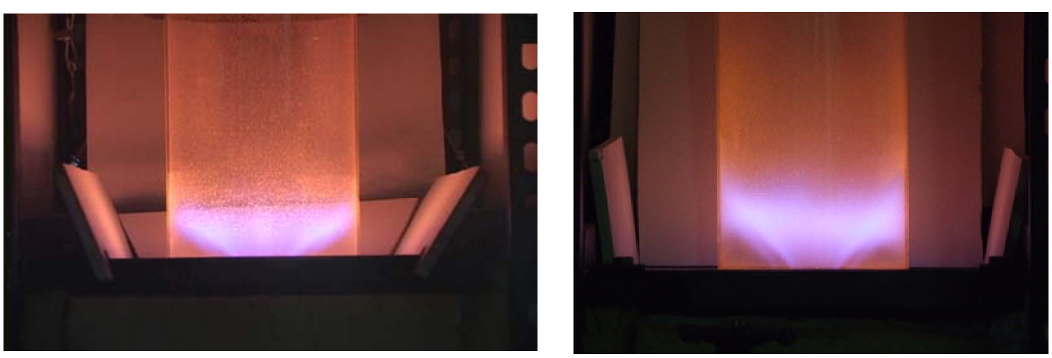
Figure 3: Lean, premixed natural gas flame (left) and lean, premixed, prevaporized biodiesel flame (right)

Combustor inlet temperatures were maintained at typical compressor discharge temperatures of 600 K to 630 K. Figure 3 shows a photograph comparing the biodiesel flame and the natural gas flame using the same burner. The Figure shows that the biodiesel burned as a lean, premixed LPP Gas also produces a clean, light blue flame similar to natural gas with low emissions.

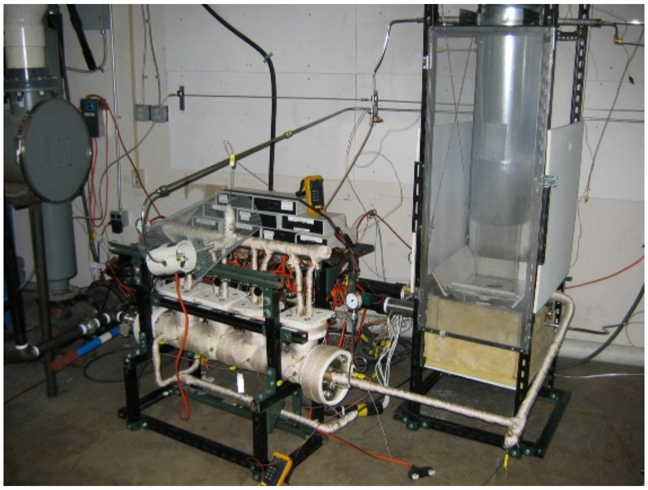

Figure 4: Atmospheric pressure combustor test facility used to evaluate emissions for various fuels using LPP Combustion Technology.

Figure 5 shows a comparison of NO_x emissions obtained for biodiesel and ethanol with those of natural gas, fuel oil #1 and fuel oil #2. As can be seen in the Figure, the biodiesel and ethanol emissions are similar to those obtained from natural gas and fuel oil #1 and are lower than the NO_x emissions obtained from fuel oil #2 which contained some fuel bound nitrogen. The results for the biofuels is to be expected since both biodiesel and ethanol contain no significant fuel-bound nitrogen.

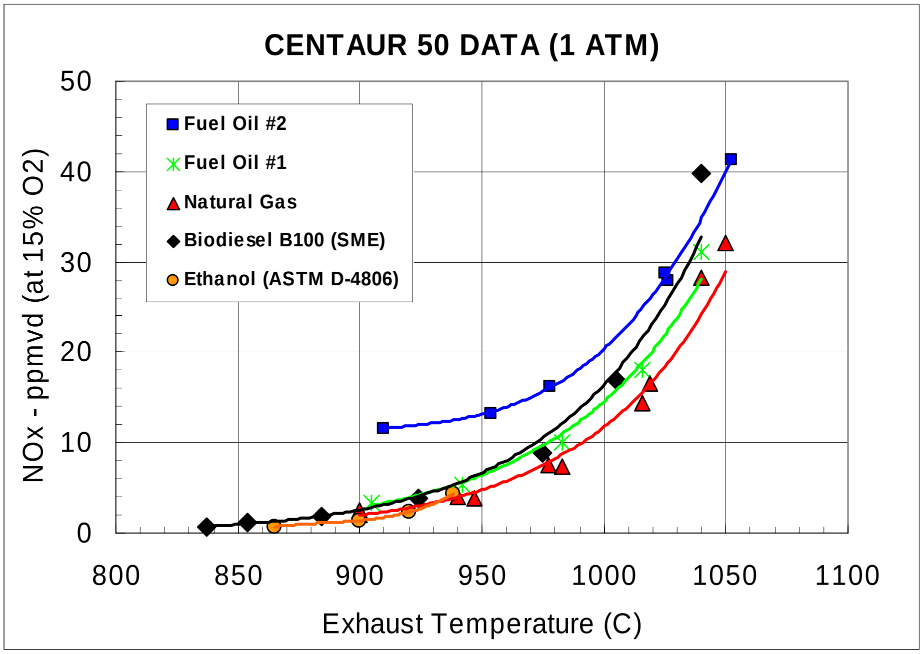

Figure 5: Comparison of NO_x emissions for natural gas, fuel oil No. 2, fuel oil No. 1, biodiesel (soy methyl ester, SME) and ethanol (ASTM D-4806).

Figure 6 shows a similar comparison of CO emissions obtained for biodiesel and ethanol with those of natural gas, fuel oil #1 and fuel oil #2. This Figure shows that the biofuels also produces very low CO emissions when burned lean, premixed and prevaporized using the LPP Combustion technology. Unlike some combustions systems where NO_x and CO emissions are traded-off with each other, the LPP Combustion technology simultaneously achieves both low NO_x and CO emissions when burning liquid fuels.

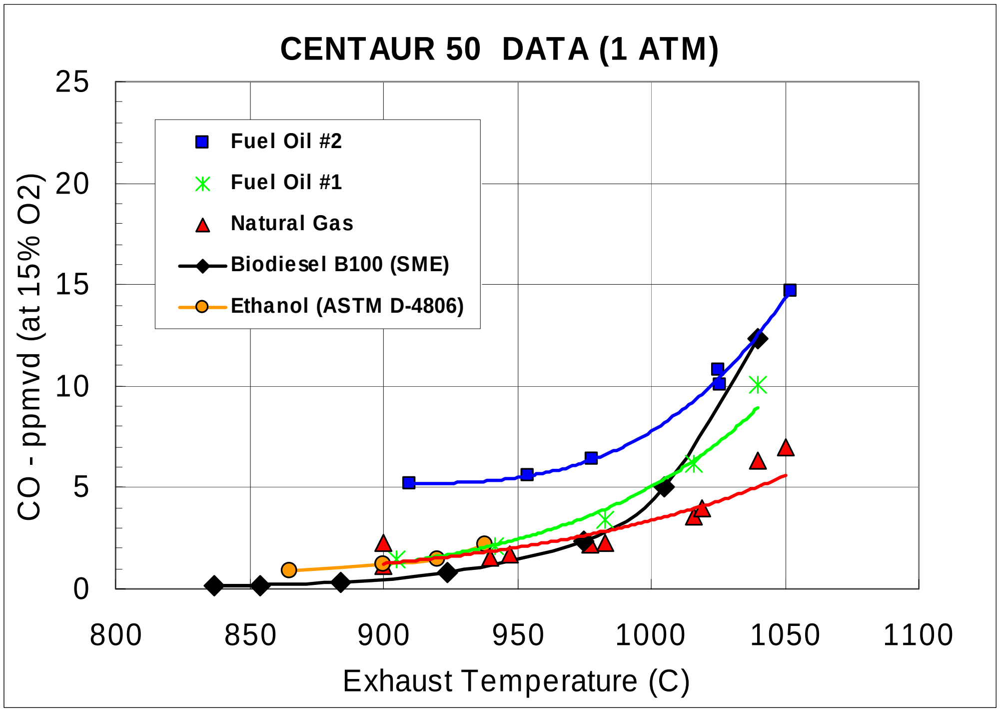

Figure 6: Comparison of CO emissions for natural gas, fuel oil No. 2, fuel oil No. 1, biodiesel (soy methyl ester, SME) and ethanol (ASTM D-4806).

These results demonstrate that the LPP Combustion System is capable of burning biodiesel and ethanol, both renewable fuels, in a gas turbine combustor with NO_x and CO emissions similar to those obtained from operation on natural gas. These results were obtained using a commercial DLE gas turbine nozzle designed for lean, premixed combustion of natural gas with no modifications to the nozzle hardware. The pollutant emission levels achieved are much lower than can be obtained when using these fuels in conventional manners, such as how liquid fuels are used today in gas turbines or reciprocating engines (without extensive post-combustion cleanup).

4 Summary of Results

The emissions and operational characteristics of the Lean, Premixed, Prevaporized (LPP) combustion technology results described in this paper represent a new and clean way of burning a wide range of liquid fuels including renewable biofuels. The LPP technology focuses on changing the characteristics of the fuel rather than trying to change the combustion hardware. Since the LPP Combustion system utilizes burners designed for natural gas, no changes to the DLE gas turbine combustor hardware were required. The LPP Combustion system provides the capability to cleanly burn liquid fuels and achieve natural gas level emissions without the need for post combustion pollution control equipment.

The LPP technology demonstrated that natural gas level emissions can be obtained for biofuels including both biodiesel and ethanol. Figure 7 shows a summary of the NO_x performance for a range of fuels using LPP Combustion technology compared to both natural gas (DLE baseline) and fuel oil No. 2 burned as a spray diffusion with water addition (state of the art benchmark for liquid fuels).

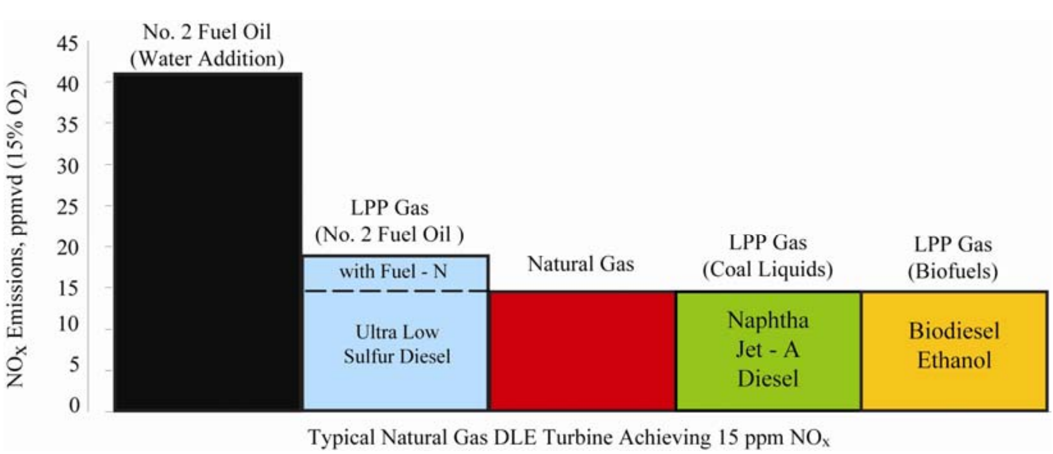

Figure 7: Summary of NO_x emissions performance for a range of fuels using LPP Combustion technology compared to a nominal 15 ppmv NO_x natural gas DLE fuel nozzle and conventional spray diffusion nozzle with water addition.

4.1 Carbon Emissions

The big benefit of burning biofuels, such as biodiesel or ethanol, is that the emissions are considered to be "carbon neutral" or "net zero" [5,6]. This designation takes into account the complete carbon cycle of the fuel including the growing cycle of the plant used as a feedstock to make the biofuel. As the plant grows, it consumes CO_2 from the atmosphere. When the plant is burned as a biofuel, the CO_2 is liberated back to the atmosphere as a "net" zero contribution to the atmosphere.

Conventional application of biofuels to gas turbines for the generation of renewable energy encounters the same emissions limitations on NO_x and CO as conventional petroleum fuels [7,8]. Water or steam addition is required in spray diffusion burners to achieved the "state of the art" benchmark level of 42 ppmv NO_x @15% O2. The emission results from burning liquid fuels using LPP Combustion technology presented in this paper and others [3,4] show that the LPP technology offers a significant improvement over the 42 ppm NO_x level for liquid fuel operation and that natural gas level emissions can be achieved. Gas turbine plants permitted for liquid fuel operation are typically restricted, based on emissions, to approximately 500 hours of annual operation. Since the LPP Combustion technology achieves natural gas level emissions for liquid fuels, this allows for significant additional run time under a plants existing air permit.

Figure 8 shows a comparison of various combustion technologies used for large scale power production. In order to combat global warming, California and other states have adopted an emissions performance standard (EPS) for carbon dioxide emissions of 1,100 lb CO_2/MWh [9]. Conventional boilers have low thermal efficiencies and produce significant carbon emission whether coal, oil or natural gas is used. Both natural gas and oil fired combined cycle gas turbines can meet the 1,100 lb CO_2/MWh. However, for practical purposes, conventional oil-fired gas turbines are severely restricted on annual hours of operation due to criteria pollutant emissions (primarily NO_x). This would also be the case for burning biofuels conventionally in spray diffusion burners. Since the LPP combustion technology achieves natural gas level emissions for criteria pollutants, a fuel oil No. 2 fired combined-cycle gas turbine could achieve the 1,100 lb CO_2/MWh EPS and not be restricted on annual operation.

Several clean coal technologies such as integrated gasification combined cycle (IGCC) and coal to liquids (CTL) derived from the Fischer-Tropsch process can achieve natural gas criteria pollutant levels, but still require carbon capture and storage (CCS) in order to meet the 1,100 lb CO_2/MWh EPS.

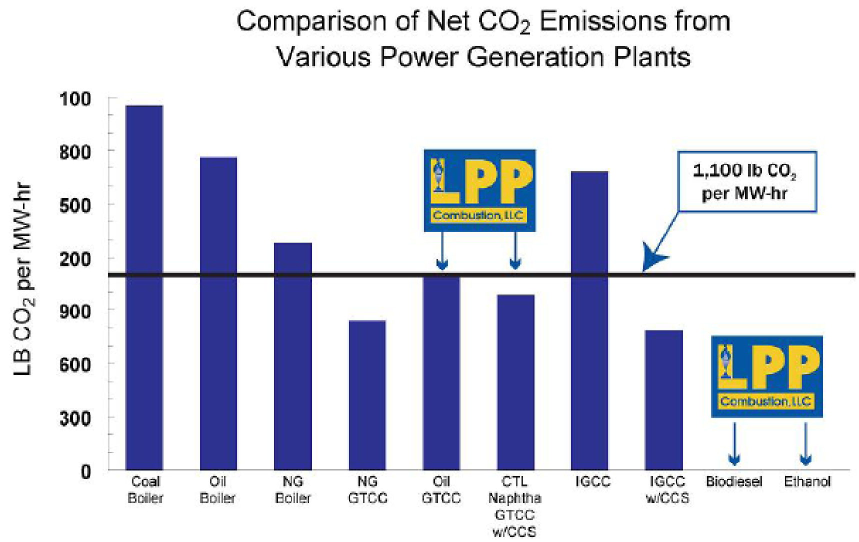

Figure 8: Summary of net CO_2 emissions from various power generation sources

Since the combustion of biofuels is considered to be carbon neutral, the amount of carbon in the earth's atmosphere remains unchanged, thus costly post combustion carbon capture and storage is not required. Burning biodiesel or ethanol using the LPP Combustion technology achieves both natural gas level emissions for criteria pollutants and no net carbon emissions and thus represents the cleanest use of renewable fuels for power generation.

5 Conclusions

The LPP Combustion technology presented in this paper represents the cleanest use of biofuels and achieves natural gas levels of criteria pollutants (NO_x, CO, SO_x & PM) and not "net" carbon emissions. Since the combustion of biofuels is considered to be carbon neutral, the amount of carbon in the earth's atmosphere remains unchanged, thus costly post combustion carbon capture and storage is not required. The LPP Combustion system provides the capability for tremendous fuel flexibility and low emission not previously attainable in modern DLE gas turbines with liquid fuels. The LPP Combustion technology provides fuel flexibility between natural gas and biofuels and enables the cleanest use of renewable fuels.

This technology provides a clean and reliable form of renewable energy using liquid biofuels that can be a primary source for power generation or be a back-up source for inconsistent renewable energy sources such as wind and solar. The technology allows for the clean use of biofuels in combustion devices without the use of post-combustion pollution control or costly carbon capture and storage equipment and can easily be incorporated into both new and existing gas turbine power plants. No changes are required to the DLE gas turbine combustor hardware. The clean combustion of biofuels achieved using LPP Combustion technology represents a solution to global warming for the power industry that is available today.

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