Combustion of Alternative Syngas Fuel in Gas Turbine Combustor

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ABSTRACT

Over the past decades domestic and imported oil was used for transportation, and domestic coal and natural gas have been used as the primary fuels for power generation systems. Today the emission regulations for power plant have become more stringent. The concern today with the combustion of fossil fuels is the new emission regulations for power plant with regards to carbon dioxides (CO_2) and nitrogen oxides (NOx). Nitrogen oxides (NOx) are responsible for smog and acid rain, and the carbon dioxides (CO_2) are one of the main greenhouse gases responsible for global warming. Another concern with fossil fuels is the high cost of imported oil. Alternative fuels that can be produced using local feed stocks, burn efficiently, and produce low emissions are needed. With the development of advanced technologies, coal, biomass, or waste products can be used in power generation systems to produce low emissions comparable to the ones obtained with natural gas fuel. This can be achieved through the Integrated Gasification Combined Cycle (IGCC). Different types of gasifies are used to gasify the solid fuels (coal, biomass or waste products) and produce synthetic gas. The syngas is then cleaned and burned in gas turbine and the hot exhaust gas is used to produce steam for steam turbine. Future power generation systems using Integrated Gasification Combined Cycle (IGCC) will have a higher efficiency and generate lower carbon dioxide and nitrogen oxides emissions. The IGCC systems are used to produce syngas fuel with different compositions from solid fuel feed stocks using different gasification process technologies. The aim of this study is to understand the effect of the variability in the alternative fuel composition and heating value on combustion performance and emissions.

Keyword : - *Syngas , Combustion, Gasification, Emission*

1. INTRODUCTION

Syngas, or synthesis gas, is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide. The name comes from its use as intermediates in creating synthetic natural gas (SNG)[1] and for producing ammonia or methanol. Syngas is usually a product of gasification and the main application is electricity generation. Syngas is combustible and often used as a fuel of internal combustion engines.[2][3][4] It has less than half the energy density of natural gas.

Syngas can be produced from many sources, including natural gas, coal, biomass, or virtually any hydrocarbon feedstock, by reaction with steam (steam reforming), carbon dioxide (dry reforming) or oxygen (partial oxidation). Syngas is a crucial intermediate resource for production of hydrogen, ammonia, methanol, and synthetic hydrocarbon fuels. Syngas is also used as an intermediate in producing synthetic petroleum for use as a fuel or lubricant via the Fischer–Tropsch process and previously the Mobil methanol to gasoline process.

Production methods include steam reforming of natural gas or liquid hydrocarbons to produce hydrogen, the gasification of coal, biomass, and in some types of waste-to-energy gasification facilities.

The global energy landscape is experiencing major changes as current economic issues evolve. There is worldwide pressure to secure and make more gas and oil available to support global power needs. With constrained fuel sources and increasing environmental focus, the quest for higher efficiency and lower emissions targets in the context of security over fuel supplies seems straightforward. As Natural Gas Combined Cycle (NGCC) plants provide very high efficiency, there will be increasing demand for natural gas, which will continue the push for increased availability of Liquefied Natural Gas (LNG). At the same time, countries will continue to look at available natural resources, such as liquid fuels and coal, as ways to increase energy stability and security. Solutions for reducing CO_2

emissions can be as simple as leveraging increasing energy conversion efficiency or switching to more carbon neutral fuels. Finally, these pressures are drivers for many industries and refiners to examine the potential inherent value within process off-gases or process waste streams as a way to maintain or reduce energy operating expenses for themselves and regional power generators. This paper focuses on the role that gas turbines play in this changing environment that requires greater flexibility to burn a wider range of fuels, which is a crucial factor to the next generation of gas turbine power plants. Leveraging more Addressing Gas Turbine Fuel Flexibility than 50 years of fuel experience, GE has developed gas turbine technology that is proven and a more efficient alternative to other technologies, while burning the widest range of alternative gas and liquid fuel.

Giles et.al. [5] investigated NOx emission characteristics of counter flow syngas diffusion flames with airstream dilution. The syngas produced through the gasification process consists mainly of hydrogen (H_2) and carbon monoxide (CO) and inert gas such as nitrogen (N_2), water vapor (H_2O), and carbon dioxide (CO_2). Syngas has also less energy density (kJ/Kg) than natural gas. The main characteristics of the syngas fuel are the lower heating value, the H_2/CO ratio, and the fraction (up to 50%) of noncombustible such as steam, carbon dioxide, and nitrogen. For syngas fuels combustion, the effect of hydrogen content is very important. The burning velocity increases with the hydrogen content because the density of the mixture is very low compared to the density of natural gas. The replacement of methane with syngas with high hydrogen content will help to reduce the CO_2 emissions. The gas turbine can combustor is designed to burn the fuel efficiently, reduce the emissions, and lower the wall temperature. Syngas mixtures with different fuel compositions are produced through different coal and biomass gasification process technologies. Although its composition may vary significantly, it generally contains CO and H_2 as the dominant fuel components with varying amount of methane and diluents. Due to its wide flexibility in fuel sources and superior pollutants characteristics, the syngas is being recognized as a viable energy source worldwide, particularly for stationary power generation. There are, however, gaps in the fundamental understanding of syngas combustion and emissions, as most previous research has focused on flames burning individual fuel components such as H_2 and CH_4, rather than syngas mixtures. This paper reports a numerical investigation on the effects of syngas composition and diluents on the structure and emission characteristics of syngas non-premixed flames. The counter flow syngas flames are simulated using two representative syngas mixtures, 50%H_2/50%CO and 45%H_2/45%CO/10%CH_4 by volume, and three diluents, N_2, H_2O, and CO_2. The effectiveness of these diluents is characterized in terms of their ability to reduce NOx in syngas flames. Results indicate that syngas non-premixed flames are characterized by relatively high temperatures and high NOx concentrations and emission indices. The presence of methane in syngas decreases the peak flame temperature, but increases the formation of prompt NO significantly. Consequently, while the total NO formed is predominantly due to the thermal mechanism for the 50%H_2/50%CO mixture, it is due to the prompt mechanism for the 45%H_2/45%CO/10%CH_4 mixture. For both mixtures, CO_2 and H_2O are more effective than N_2 in reducing NOx in syngas flames. H_2O is the most effective diluent on a mass basis, while CO_2 is more effective than N_2. The effectiveness of H_2O is due to its high specific heat that decreases the thermal NO, and its ability to significantly reduce the concentration of CH radicals, which decreases the prompt NO. The presence of methane in syngas reduces the effectiveness of all three diluents.

Chaouki Ghenai [6] carried out three-dimensional CFD analysis of syngas fuel combustion in gas turbine can combustor. Five Syngas fuel mixtures with different fuel compositions (H_2/CO = 0.63 to 2.63) and low heating values (8224 kJ/m^3 to 12492 kJ/m^3) were tested in this study. The syngas fuels are produced by different gasification processes using different feed stocks (coal, biomass, waste). The k-ε model was used for turbulence modeling, mixture fractions/PDF model for non-premixed gas combustion and P-1 for radiation modeling. The effect of the syngas fuel composition (H_2, CO, CO_2, CH_4, N_2, H_2O) and fuel heating values on syngas flame shape, gas temperature, carbon dioxide (CO_2) and nitrogen oxides (NOx) emissions was determined in this study (i) Baseline fuel (methane) combustion: the results of the gas temperature, velocity field, swirling strength and CO_2 and NOx emissions show that gas turbine can combustor burns the fuel efficiently, reduces the emissions, and, lower the wall temperature. The predicted maximum temperature of methane fuel combustion compares well with the theoretical adiabatic flame temperature. (ii) The gas temperature for the all five syngas shows a lower gas temperature compared to the temperature of methane. The gas temperature reduction depends on the lower heating value and the combustible constituents (hydrogen, carbon monoxide, and methane) and non-combustibles (inert) constituents in the syngas fuel. (iii) The results show a reduction (30% to 49%) of CO_2 mass fraction at the exit of the can combustor when methane is replaced with syngas fuel that produces less power (20% to 55% power reduction with syngas fuel). The reduction of CO_2 concentrations depends on the carbon monoxide and methane volume fractions in syngas fuel. For the same power generated by the methane and syngas fuels combustion, the results show a higher mass of CO_2 emitted per unit of energy generation (kg/KJ) for Exxon Singapore, Tampa, and PSI syngas fuels compared to methane fuel. Schwarze Pumpe was the only syngas fuel that shows a reduction of about 12% of the average mass of CO2 emitted per unit of energy generation (kg/KJ) compared to methane fuel. (iv) With the same fuel mass flow rate but less power generated for the syngas fuel, the results show a reduction (11.5% to 97.6%) of the average NO mass fraction for synags fuel compared tomethane. Syngas is used in non-premixed combustion to control the NOx emissions by diluting the synags gas with nitrogen, carbon dioxide, and steam. The diluents reduce the flame temperature and consequently the formation of NOx. For the same power generated by the methane and syngas fuels combustion, the results show a reduction of the mass of NO per unit energy generated for syngas fuel compared to methane fuel only when the primary and secondary air mass flow rates were increased according to the increase in the fuel mass flow rate to keep the same power. The results obtained in this study show the change in gas turbine can combustor performance (temperature, flame shape, CO_2 emissions, and NO emissions) when natural gas or methane fuel is replaced by syngas fuels with lower heating value and fuel compositions.

2. FUEL CLASSIFICATION

Fuel classification the potential fuels to be utilized on high efficiency gas turbines are very large, and in this changing energy landscape, there is a growing interest in turning to non-traditional fuels, capitalizing on the

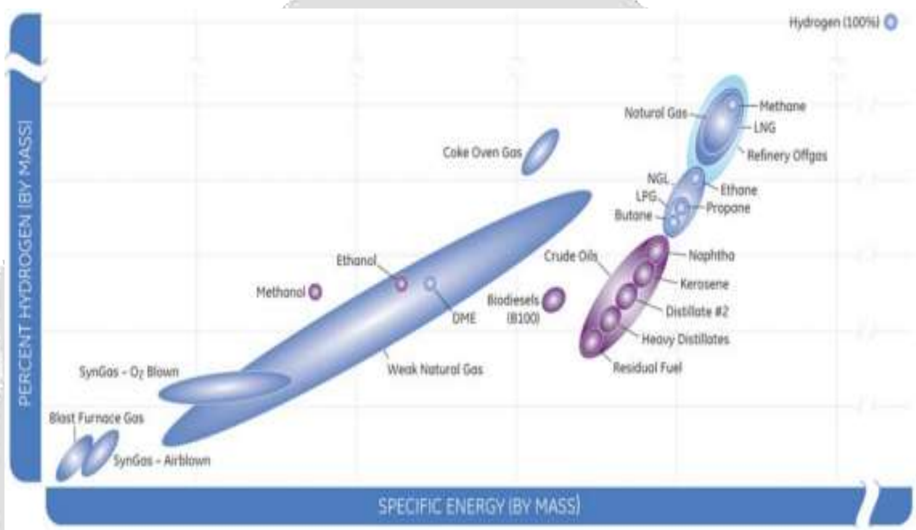

Fig -1: Fuel used on high efficiency gas turbines [7]

experience gained during the past five decades. As continuous flow machines with robust designs and universal combustion systems, gas turbines have demonstrated distinctive capabilities to accept a wide variety of fuels. GE gas turbines, in particular, have been operating with most of these fuels (see Figure 1). The most common way to classify fuels is to split them between gaseous and liquid fuels, and within the gaseous fuels, to split by their calorific value. Table 1 shows such a classification of fuels.

2.1 Natural gas: This is mainly methane with some small amounts of volatile hydrocarbons and inert gases. • High calorific value gases: These are made of volatile hydrocarbons with minor fractions of inert gases, which are usually very clean and perform well in gas turbines. It may typically be propane, butane or a mixture of the two. They often contain some amounts of hydrogen and are usually available as refinery by-products

Table -1: Fuel classification [7]

	Typical composition	Lower Heating Value kJ/Nm3 (Btu/scf)	Typical specific fuels
Ultra/Low LHV gaseous fuels	H_2 < 10% CH4 < 10% N_2+CO > 40%	< 11,200 (< 300)	Blast furnace gas (BFG) Air blown IGCC Biomass gasification
High hydrogen gaseous fuels	H_2 > 50% CxHy = 0-40%	5,500-11,200 (150-300)	Refinery gas Petrochemical gas Hydrogen power
Medium LHV gaseous fuels	CH4 < 60% N_2+CO_2 = 30-50% H_2 = 10-50%	11,200-30,000 (300-800)	Weak natural gas Landfill gas Coke oven gas Corex gas
Natural gas	CH4 = 90% CxHy = 5% Inerts = 5%	30,000-45,000 (800-1200)	Natural gas Liquefied natural gas (LNG)
High LHV gaseous fuels	CH4 and higher hydrocarbons CxHy > 10%	45,000-190,000 (1,200-5,000)	Liquid petroleum gas (butane, propane) Refinery off-gas
Liquid fuels	CxHy, with x > 6	32,000-45,000kJ/kg	Diesel oil Naphtha Crude oils Residual oils Bio-liquids

2.2 Medium calorific value gases: These fuels are either weak natural gases made of methane with high fraction of inerts (CO_2, N_2), process gases, or gasified coal. Process gas is a broad classification of byproduct gases, with wide range of composition, mainly containing methane, hydrogen and carbon monoxide. Also called "syngas" and mostly derived directly from abundant fossil carbon (refinery residuals, coal, lignite, tar sands, and shale oil), they represent great potential for the carbon-constrained economy, provided they are subjected to carbon capture. A subset of these syngas fuels is made up of the high hydrogen gaseous fuels, where hydrogen makes up more than 65% of the total gas volume. These fuels are made either by methane reforming or oxygen-blown gasification of coal.

2.3 Low calorific value gases: Often called "low-BTU" gases, they contain carbon monoxide and hydrogen diluted with a large fraction of inert components, namely nitrogen and carbon dioxide. Derived from the chemical, oil and gas, or steel sectors, many of these fuels cannot be transported or stored, and their essential appeal will be to reduce fuel supply in industrial plants in the carbon-constrained environment. Within the liquid classification, one can distinguish three main categories:

2.4 True distillate fuels: These are refined products essentially free of ash-forming components. Most common ones are naphtha, kerosene, and diesel fuels, which normally can be used as is or with minor cleanup.

2.5 Oils: Includes crudes and other refined residuals that are heated to acceptable levels to enable the needed viscosity for gas turbine combustion.

2.6 Bio-liquid fuels: More evenly distributed around the world, they are of prime interest due to their overall neutral carbon balance. All these categories represent potentially abundant energy sources.

3. PRODUCTION CHEMISTRY

The chemical composition of syngas varies based on the raw materials and the processes. Syngas produced by coal gasification generally is a mixture of 30 to 60% carbon monoxide, 25 to 30% hydrogen, 5 to 15% carbon dioxide, and 0 to 5% methane. It also contains lesser amount of other gases.

The main reaction that produces syngas, steam reforming, is an endothermic reaction with 206 kJ/mol methane needed for conversion. The first reaction, between incandescent coke and steam, is strongly endothermic, producing carbon monoxide (CO), and hydrogen H_2 (water gas in older terminology). When the coke bed has cooled to a temperature at which the endothermic reaction can no longer proceed, the steam is then replaced by a blast of air. The second and third reactions then take place, producing an exothermic reaction—forming initially carbon dioxide and raising the temperature of the coke bed—followed by the second endothermic reaction, in which the latter is converted to carbon monoxide, CO. The overall reaction is exothermic, forming "producer gas" (older terminology). Steam can then be re-injected, then air etc., to give an endless series of cycles until the coke is finally consumed. Producer gas has a much lower energy value, relative to water gas, due primarily to dilution with atmospheric nitrogen. Pure oxygen can be substituted for air to avoid the dilution effect, producing gas of much higher calorific value. When used as an intermediate in the large-scale, industrial synthesis of hydrogen (principally used in the production of ammonia), it is also produced from natural gas (via the steam reforming reaction) as follows:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

In order to produce more hydrogen from this mixture, more steam is added and the water gas shift reaction is carried out:

$$CO + H_2O \rightarrow CO_2 + H_2$$

The hydrogen must be separated from the CO_2 to be able to use it. This is primarily done by pressure swing adsorption (PSA), amine scrubbing, and membrane reactors.

4. CONCLUSIONS

An analysis of emerging fuels shows that the power generation community will face major challenges. The predictability of fuel resources and environmental commitments will weigh heavily on long-term plans. As a result, there is a need to explore all sustainable alternative energy channels. Any sensible utilization of alternative fuels, including process streams from industrial plants such as refineries, petrochemical plants, iron plants and steel plants, can generate economic and environmental benefits. In a carbon-constrained environment, the technology trend is for combustion systems capable of burning syngas and hydrogen-rich fuels in combination with delivering the required operability. In this new context, the strong operational experience gained by gas turbines with a wide variety of fuels creates favorable prospects, both for robust E-class machines and for F-class machines that deliver high performance.

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