Low NO_x Emission with improved performance of the Gas Turbine Engine

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ABSTRACT - *A Combustor is a heart of an internal combustion engine. The design and operating conditions have has major role in the performance of a gas turbine engine. We cannot ignore the emissions of the engine due to their toxic properties to the living creatures. NO_x reacts with volatile organic compounds in the presence of sunlight to form Ozone. Ozone can cause adverse effects such as damage to lung tissue and reduction in lung function mostly in susceptible populations (children, elderly and asthmatics). On the other hand NO_x destroys ozone in the stratosphere. Ozone in the stratosphere absorbs ultraviolet light, which is potentially damaging to life on earth. The formation of nitrogen oxide (NO_x) and carbon monoxide (CO_x) in the exhaust are challenging for the designers. This paper produces a combustor design which minimizes the formation of these pollutant emissions without affecting the efficiency of system. At high temperature the combustor improves turbine performances and also minimise the CO_x emission, but the formation of the NO_x will be increased. In this paper we tried to reduce NO_x less than 6 ppm and CO_x less than 2 ppm, but the turbine efficiency should be unaffected or at maximum. NO_x is formed by oxidation of nitrogen during the combustion process. The presence of H_2 leads to increase the flame stability such that the combustor can be operated at lower temperature and produces less thermal NO_x. A water gas shift convertor is used here to modify coal gas composition and natural gas leads to put increment a catalytic partial oxidation reactor to convert part of the natural gas feed to a syngas or synthesis gas (a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide) before fed back into the combustion chamber.*

KEYWORDS: *NO_x emission, H_2-enriched fuel, Thermal NO_x reduction, diffusion and premixed combustor.*

I. INTRODUCTION

Last some decades many development and improvement are introduced in gas turbine engine combustion technology, especially in the field of NO_x emission reduction by using the coal as a derived synthesis gas. These developments are considered with a small reduction in overall engine performances. The objective of this paper is to develop a gas turbine system which is capable of achieving the goal near zero (2 ppm) NO_x emissions, fuel flexibility and engine operation with consistency and correctness to run both the ultra modern and other existing gas turbine engines.

II. NO_X EMISSION CONTROL FOR THE MODERN GAS TURBINE ENGINES

The production of NOx emissions are noticed by the following main parameters.

1. Formulation of thermal NO_x emission at elevated temperature
2. Rapid NO_x
3. The transformation from $N_2O \rightarrow NO$

As we know the major problem in almost all combustor is the thermal NOx formation. The development in the reduction of thermal NO_x emission is concerned; designers are trying to produce an engine where the combustion chamber temperature can be controlled by the modern methods. These methods are briefed as

i. Addition of diluting agent

Steam, CO_2, N_2 or other diluents are added to the combustion zone of a diffusion combustor. Since

NO_x formation is related to the combustion temperature, the additions of diluents lower the temperature to reduce NO_x.

ii. Premixed fuel lean combustion

Typical premixed combustion mixes the fuel and oxidant upstream of the burner. Premixed combustion allows leaner fuel mixtures that reduce the flame temperature, and therefore thermal NO_x formation.

iii. Combustion with Catalyst

Lean premixed combustion is also the basis for achieving low emissions from catalytic combustors. These systems use a catalytic reactor bed mounted within the combustor to burn a very lean fuel air mixture. The catalyst material stability and its long term performance are the major challenges in the development of an operational catalytic combustor.

iv. Post combustion management

NO_x can be removed from the gas turbine exhaust by injecting ammonia that converts NO_x to molecular nitrogen.

This paper is focused on concept development of a fuel flexible combustor, a fuel processor scheme capable of working with coal derived fuel gas and hydrogen/natural gas blend. The results of the above discussed concepts are summarized in the following order.

i. Fuel processor scheme.
ii. Conceptual combustor design and integration of the combustor with the fuel processor.

The overall objective of this paper is to produce gas turbine engine designs that would be capable of generating less than 2 ppm of NO_x emission while fired on coal synthesis gas or natural gas. This new gas turbine combustion system must also cost significantly less than the conventional engine. The solution presented herein involves the modification of the fuel supply to the gas turbine in terms of the hydrogen content. The presence of H_2 in the fuel increases the reactivity of the system leading to higher flame speeds and increased flame stability. By adding H_2 to natural gas or modifying the H_2 content of a coal synthesis gas, the combustor may be operated at a lower temperature, thus producing less thermal NO_x, and the increased reactivity of the fuel also allows complete combustion. The hydrogen content of the fuel supply to the gas turbine will be modified depending on the fuel source. In the case of a coal synthesis gas unit, a water gas shift converter would be utilized to adjust the H_2 content to the desired level. For either a coal gas or natural gas fired unit, the combustor would be based on a lean premixed system with minor modifications to the fuel nozzles.

III. PROCESSING OF SOLID (COAL) FUEL GAS

Table.1. Solid fuel gas

Ingredient (dry)	substance Gasifier	Air Gasifier
H_2	31.3	23
Carbon monoxide	62.7	7
Carbon Dioxide	1.5	20
N_2	4.5	47
Methane		3

The above table represents some compositions of coal gas which is currently available. It is noticed that in the above table the coal gas contains considerable amount of hydrogen and ample amount of CO as well. It is also observed that there is a significant variability in the gas composition. As discussed earlier, the main aim to process the fuel is to provide the combustion chamber with a fuel which is containing steady hydrogen. This can be skilled by shifting part of CO with a water gas shift reactor. The water gas shift reactor functions similar to the general reaction which is produce CO2 and H2 from the reactants of CO and steam.

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

The water gas shift reactor is working between the temperatures of 200-400^0 C at high pressure along with a catalyst. The catalyst selection is based on the requirements of the desired composition and operating conditions.

IV. PROCESSING OF FUEL GAS (NATURAL GAS)

In this paper H_2 is taken as the main constituent of the fuel. For supplying the H_2 to the combustor it is necessary to establish an economical method and also the content which is available with the fuel should be under control. The production of pure H_2 as a fuel additive is an expensive to continue with turbine engine. The table gives the capacity of the gas turbine engine with the progressive content of H_2.

Table 2: Hydrogen requirements for the various capacities of the gas turbine engine

GT Capacity (MW)	NG (Nm^3/h)	Volume H_2 (Nm^3/h)		
		5 vol. % H_2	10 vol. % H_2	20 vol. % H_2
5	1363	68	136	205
25	6817	341	682	1023
40	10907	545	1091	1636
80	21813	1091	2181	3272
100	27267	1363	2727	4090

In the present days the production of syngas is possible by the following methods.

1. Steam methane reforming (SMR)
2. Non catalytic partial oxidation (POX) and
3. Auto thermal reforming (ATR).

SRM is the most widely used technology for the production of H_2. In a steam reforming process roughly around 20% of the methane gas is used and burned to generate adequate amount of heat to improve the remaining fuel with the steam. The result of it has noteworthy effects in NO_x and CO_2emissions.

Table 3: Hydrogen production technology assessment

process	H_2: CO	Steam Requirement	Residence time	O_2 required	Catalyst required	N_2 present
SMR	3-6:1	high	sec	No	Yes	No
POX	1.8:1	moderate	sec	Yes	No	No
CPOX	2.0:1	none	ml sec	no	yes	no

V. FUEL FLEXIBLE GAS TURBINE COMBUSTION CHAMBER PERCEPTION

Fuels those are rich in hydrogen content having substantial different combustion characteristics than hydrocarbon based fuel (Natural gas). When fuel is added with H_2, it changes various attributes including the physical nature of the flame, stability of the flame, combustion efficiency and NO_X emissions. The remarkable effect on the combustion process due to the addition of H2 is due to the increase reactivity of H_2 compared to the other fuel gases. The stoichiometric ratio of H_2 and air flame speed is roughly around 2m/s, compared to the equivalent methane/air mixture having the flame speed of 0.4m/s. The radical pool of a flame is also changed by the H_2 content in the fuel. Thus the rate of oxidation process of the other fuel classes will also be changed.

The addition of H_2 to the gas turbine engine fuel has a mainly two advantages .First the lean blow out limit is shifted to lower equivalence ratio. Second it increases the rate of CO oxidation due to this it reduces the CO emission. The above explained advantages allow the combustor to work at low temperature, thus it minimize the production of the thermal NO_X emission. The addition of H_2 to the fuel steps up the energy locally through the improved concentration of the intermediate energetic OH- radicals. Even this has no any large effects on NO_X emission, but it has countable effects on flame stability improvements and also the reduction in CO formation. At a glance it is said that the reduction of flame temperature has major role in the reduction of NO_X emission. But in other hand as the flame temperature is reduced the portions of combustion reaction freezes and remain incomplete to produce mild amount of CO. The H_2 addition to the fuel reduces CO due to the increased intensity of the local heat release, thus allowing a reduction in flame temperature and reduces the percentage of NOx production at the engine exit.

VI. COMBUSTION AUGMENTATION

The combustion chamber of the gas turbine is now divided into two general categories; these are Diffusion and Premixed designs [1]. In the diffusion system design the fuel and the air injected separately into the combustion chamber where they mixed and burnt while in the area of premixed system design, fuel and air is mixed outside the combustor and then air fuel mixture is injected into the combustion chamber for the ignition. Stabilized flame is the main advantage which is observed by the diffusion system design of a gas turbine combustor, thus liquid fuels and gaseous fuels with high flame speeds (e.g., coal gas) can be burned in such a system. The drawback of diffusion based systems is that the flame zone temperature is inherently higher than a premixed system, and substantial quantities of NO_x are produced. The flame temperature is decreased by injecting diluents, such as steam, into the flame region to promote mixing.

However the mixing is incomplete, thus the flame temperatures cannot be lowered to the same level as a premixed system. Premixed systems can be operated at a much lower equivalence ratio such that the flame temperature throughout the system is decreased and thermal NO_x production is decreased compared to a diffusion system. The disadvantage of premixed systems is flame stability, especially at low equivalence ratios. Also, there is a tendency for the flame to flashback. The ability of the flame to flashback is increased as the flame speed of the fuel increases.

The main objective of this paper is to investigate the prospect of designing a fuel flexible gas turbine combustor that produces less than 2 ppm NO_x, and may operate on hydrogen enriched natural gas, or with minor modifications burn a coal gas based fuel. The gas turbine combustor that could achieve these goals will be operated as a premixed combustion system. However, two difficulties exist in implementing a premixed system that operates with both natural gas and coal gas. First, in order to achieve the low NO_x emissions level required, the system must operate leaner than machines currently operate. Second, as H_2 is added to the fuel, the tendency to flashback due to a higher flame speed is increased. The idea shows the effect of H_2 content on the laminar flame speed for hydrogen enriched methane and for coal gas with increasing amounts of diluents N2 (equivalence ratio of 0.7). Beyond this H_2 content the flame speed increases much more rapidly. The model coal gas considered in this paper (40% H_2, 51% CO, 8.5% CO_2, and 0.5% H_2O), has a laminar flame speed of approximately 48 cm/s in its raw form, but the flame speed drops considerably as diluents N_2 is added. At about 50% N_2 addition, the flame speed is comparable to that of pure methane which indicates that with sufficient diluents, the chance of flashback with natural gas may not be much different than pure natural gas.

VII. IMPROVED COMBUSTOR DESIGN

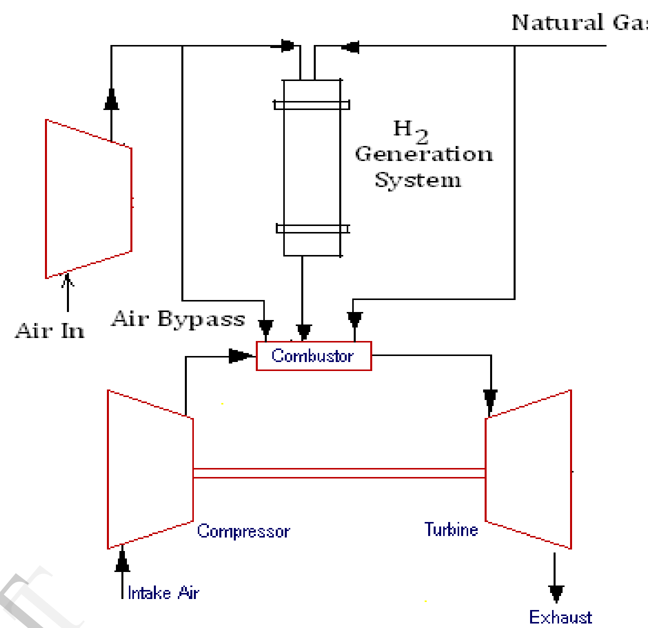

Figure.1. Low NOx gas turbine system capable of burning hydrogen enriched natural gas.

At present time series of global models are developed to study the effect of various H_2 containing fuels on gas turbine emissions. The models consist of a network of perfectly stirred reactors (PSR) and plug flow reactors. The chemical kinetics inside the reactors is represented by the natural gas combustion mechanism. Fuel and air are first mixed in a non-reacting chamber. The mixture is then introduced to the first PSR in which the mixture is ignited. The products move on to a second reactor where more air may be added, followed by a plug flow reactor to serve as a burn-out region. In order to fit the data for natural gas, the volumes of the reactors should be varied depending on the fuel-air ratio. This indicates that H_2 containing fuels have a direct impact on the shape and size of the flame in the combustor.

Methods for reducing NO_x emissions from a gas turbine process may be tackled either during combustion, post combustion by exhaust clean up, or with a combination of the two.

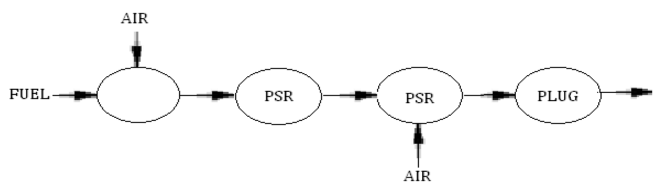

Figure.2. Simplified diagram of reactor network model of a gas turbine combustor having low emissions

RESULT AND DISCUSSION

The results from the process and study indicate that the fuel flexible combustor can bring values to produce gas turbine engine plants with low emissions and improved performances. Clearly it is an alternative to techniques that require significant modifications and chemical expense or methods those are only successful in reducing emissions.

CONCLUSIONS

Based on the technical analysis and literature survey on conceptual engineering works, the potential exists to develop a 2 ppm gas turbine combustor that will be capable of operating on either a blend of natural gas with hydrogen or a fuel typical of a coal derived fuel gas. However, significant work will be required to manage fuel composition and combustion aerodynamics.

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