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Effect of Alternative Fuels and Operating Conditions on the Performance and Emissions of a Gas Turbine

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Abstract: *In this paper we have covered different potential liquid and gaseous alternative fuels such as bio-diesel, pyrolysis wood gas, biogas of methanisation for gas turbine, their properties and composition and their effect on its emission and its combustion performance. There is a good progress for the clean combustion of low calorific value fuel such as biomass and hydrogen enriched fuels by using gasification and lean premixed combustion, which gives low emission particularly NOx. After analysing these alternative fuels, it has been found that the bio-diesel is the best suited alternative for an existing gas turbine and its performance will be compared on various parameters i.e. thermal efficiency, power output, Emission, Specific fuel consumption etc. The effect of operating conditions such as water or steam injection on emission formation and performance will also be studied with the different combinations of alternating fuels. The wet compression consists of injecting atomised water into the compressor inlet air stream, this water evaporates and cools the inlet air so it reduces compressor work and increases mass flow rate.*

Keywords: *gas turbine, bio-fuel, alternative fuels, water injection, emission.*

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I. INTRODUCTION

Many performance and emission tests have been carried out in reciprocating diesel engines that use bio fuel over the past years but very few in gas turbine engines. The gas turbine develops steady flame during stationary operation. This favorable feature gives a wide range to the different alternative fuels and their properties for clean combustion designs. That’s why gas turbines have essence access to a broad range of primary energies such as natural gas, petroleum distillates, *gasified coal* or *biomass, gas condensates, alcohols, ash-forming fuels* etc.

The use of liquid and gaseous fuels from biomass will also help to fulfill the Kyoto targets concerning Global warming emissions. In addition, to make industrial processes more environmentally friendly, waste gases could be used as a potential gas turbine fuel.

In this paper we have tried to review the main primary energies accessible to stationary gas turbines, accessing its performance changes with the fuel, and the effect of fuel properties on NO*x* emission.

Gas turbine performance also depend on environmental conditions, particularly air temperature, the environmental conditions differs widely from nominal operative conditions, for instance during summer months. Some methods can improve the performance under these adverse conditions such as ‘‘evaporative cooling’’, “wet compression”, ‘‘fogging’’, ‘‘absorption chillers’’ and ‘‘thermal energy storage’’. In all these methods air is conditioned at the compressor inlet and make gas turbine operative parameters almost independent of environmental conditions. When properly applied, all these methods are safe and recover the lost power due to the fluctuating ambient temperature and maximize the plant output and efficiency.

II. COMBUSTION PERFORMANCE

The most important aspects of combustion performance are combustion efficiency, flame stabilization and pollutant emissions.

2.1. Combustion Efficiency

Combustion efficiencies below 100% represent a waste of fuel and also give rise to the presence of undesirable or harmful pollutant emissions in the engine exhaust gases. In practice, high levels of combustion efficiency are achieved over most of the engine operating range by ensuring that the primary combustion zone provides sufficient time and temperature to fully evaporate the fuel, mix the fuel vapor with air and re-circulating combustion products, and allow combustion to proceed to completion.

2.2. Flame Stabilization

For any particular combustion chamber there is both a rich and a weak limit to the air/fuel ratio beyond which the flame is unstable. Usually the limit is taken as the air/fuel ratio at which the flame blows out, although instability often occurs before this limit is reached. Such instability takes the form of rough running, which not only indicates poor combustion, but sets up aerodynamic vibration which reduces the life of the combustor and causes blade vibration problems. The range of air/fuel ratio between the rich and weak limits is reduced with increase of air velocity, and if the air mass flow is increased beyond a certain value it is impossible to initiate combustion at all.

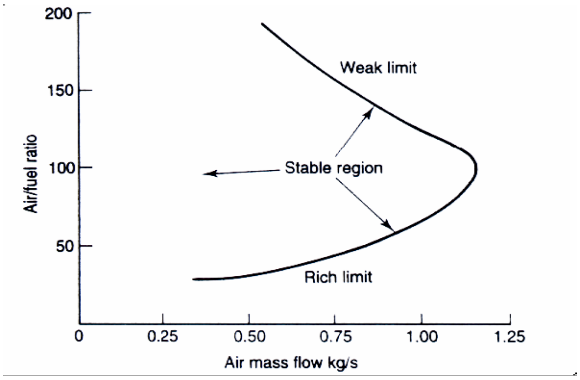

Figure 1: Stability loop

2.3. Pollutant Emissions

Smoke is the most obvious pollutant from gas turbine engines because it can be seen with the naked eye. Other pollutants of importance are carbon monoxide (CO), unburned hydrocarbons (UHC) and oxides of nitrogen (NOx).

The single most important factor affecting the formation of NOx is the flame temperature; this is theoretically a maximum at stoichiometric conditions and will fall off at both rich and lean mixtures. Unfortunately, while NOx could be reduced by operating well away from stoichiometric, this results in increasing formation of both CO and UHC

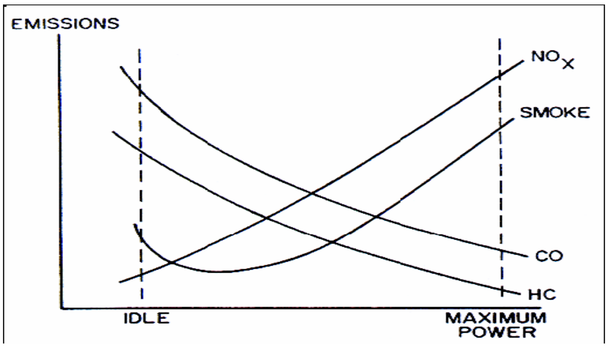

Figure 2: Emission characteristics of gas turbine engines

III. COMMONLY USED GAS URBINE FUELS

3.1. Kerosene

It is a friction of crude oil primarily comprising a band of hydrocarbon with an average composition of C12H23.5 and molecular weight of 167.7. There are numbers of commercial grades available such as JP4, JP5, Jet A1 and AVTUR, which are refined to a tight specification. Aero engine exclusively use kerosene as its high calorific value, minimising fuel weight, and free of corrosive elements such as sulphur.

3.2. Diesel

Diesel fuel is a heavier fraction of crude oil than kerosene, comprising a band of hydrocarbons with an average composition of C12.9H23.9 and molecular weight of 178.6. It is less refined having small percentage of corrosive agents like sulphur. Diesel is almost exclusively used for marine engines and in military applications

3.3. Natural Gas

Natural gas comprises over 80% methane with minor amount of ethane, propane, butane etc. The land based power generation turbines usually burn natural gas with a backup liquid fuel capability to guard against interrupted gas supply. The use of natural gas is due to its competitive cost and negligible content of corrosive elements. The other benefits include lower emission of carbon-di-oxide. It is because lighter hydrocarbon contains more hydrogen and produces more water, this leads to higher power output and higher thermal efficiency.

IV. ALTERNATIVE FUELS FOR GAS TURBINE

4.1. Bio Diesel

Vegetable oils due to its properties very close to diesel fuel may be a promising alternative for its use in gas turbine. High viscosity interferes the fuel atomization and contributes to incomplete combustion. Poor volatility makes vegetable oil difficult to vaporise and ignite this result thermal cracking and carbon deposits in the combustion chamber.

High viscosity and poor volatility can be reduced drastically by transesterification. It can be blended with diesel in various proportions and can also be used in 100% satisfactorily. Abundant source of vegetable oil in India and its ease of conversion to bio diesel may help to save large expenditure on import of petroleum and economic growth of the country. Bio-diesel generates huge rural employment and degraded lands can be restored due to the plantation of oil plants, which again help in reducing pollution.

4.2. Biogas of Slow Pyrolysis Wood Gas

Pyrolysis consists in heating solid biomass (generally waste or wood) in the absence of air to produce solid, liquid or gaseous fuels. Slow pyrolysis produces a high yield of gas and solids. In this process the reactor used is a rotary kiln with indirect heating.

Monica Rodrigues [1] has shown that the biomass integrated gasifier gas turbine/combined cycle gives efficiency around 40%, where as biomass electricity generation based on steam cycle gives efficiency about 20%. Anuradda Ganesh [13] has shown that the economy of biomass pyrolysis- combine cycle is at par with biomass gasification combined cycle. Chan [8] has suggested the use of circulating fluidised bed for the gasification of biomass in pyrolysis process.

4.3. Biogas of Methanisation

Anaerobic digestion occurs naturally when high concentrations of wet organic matter accumulate in the absence of dissolved oxygen. Anaerobic micro-organisms digest the organic material producing carbon dioxide and methane that can be collected and used as fuel (biogas). The stabilized solid residue, which averages 40–60% by weight of the feedstock, can be used as soil conditioner material (compost). Anaerobic digester systems, also called fermentation or methanisation, use closed reactors to control the anaerobic process and to collect all of the biogas fuel produced. The yield of biogas depends on the composition of the waste feedstock and the conditions within the reactor. For example, the rate of anaerobic digestion can be increased by operating in certain temperature ranges. The modern anaerobic digestion treatment processes are engineered to control the reaction conditions to optimize digestion rate and fuel production.

4.4. Industrial Gases Rich in Hydrogen

The industrial gases are rejections from refineries or chemical industries. Instead of burning off these gases in flare stacks or in steam boilers, those gases rich in hydrogen could be used as fuels in industrial gas turbines. Such gases are: refinery flare gases, steam reforming fuel gas, Fisher–Tropsh fuel gas.

V. COMPARISON OF THE CHARACTERISTICS OF ALTERNATIVE FUELS

5.1. Low Heating Values of Liquid Fuels

The Low Heating Values of FT (Fisher–Tropsh) fuel, pure methyl ester (ME), ME 5%, ME 30% and oils are between 37,500 and 44,500 kJ/kg and are nearly equivalent to LHV of diesel oil. Methanol and flash pyrolysis oil have the lowest LHV

5.2. Viscosities of Liquid Fuels

The viscosities of ethanol, methanol, pure ME and ME 5% are lower than the viscosity of diesel oil. These low viscosities allow to spray the fuels more easily. The vegetable oils and the flash pyrolysis oil have a very high viscosity which can pose a problem to spray the oils in the combustion chamber of the gas turbine.

5.3. Densities of Liquid Fuels

The densities of most of the liquid fuels are ranging between 690 and 916 kg/m3, close to the density of diesel (equal to 830–840 kg/m3). The flash pyrolysis oil has a higher density (equal to 1200–1240 kg/m3) compared to those of the other fuels.

5.4. C/H ratio (w./w.) of Liquid Fuels

The high C/H ratio (high carbon content) of the flash pyrolysis oil from wood, the vegetable oils and the methyl esters may pose a problem of deposits in the combustion chamber of gas turbines.

5.5. Molar Weight of Liquid Fuels

The molar weights (MW) of hydrocarbon fuels are much lower than bio fuels. This property also influences the vaporization behavior of liquid fuels, where heavier fuels have lower vaporization rates. However, vaporization rates tend to similar values under high temperature conditions.

5.6. Comparison of Gaseous Fuel Characteristics

The LHVs of industrial gases (steam reforming gas, refinery gas and FT process off-gas and of wood slow pyrolysis gas) are higher than the LHV of natural gas. The reason for this is the high hydrogen content of these fuels (between 19 and 45% vol.).

On the contrary, the LHVs of waste methanisation gas is very low; also they are both generated at atmospheric pressure and need to be compressed before their use in gas turbines.

VI. EFFECT OF ATMOSPHERIC CONDITIONS ON GAS TURBINE PERFORMANCE

It is known that variations of atmospheric conditions, such as temperature, humidity and pressure, are important factors in gas turbine performance. The ambient temperature has the greatest effect on gas turbine performance. If it increases of 1^0 C the estimated power decrease is about 0.6–0.7%, and an efficiency decrease is about 0.2%.

An effective method of overcoming the problem of NOx, and improving the performance is pre-cooling of the inlet air. The increased density of the cooled air increases the mass flow through the engine, resulting in a significant increase in gas turbine power output, with a slight improvement in efficiency, and the NOx emission is reduced. A further consequence of pre-cooling of the inlet air is that maintenance costs are also reduced, as these depend heavily on the temperature of the hot section.

6.1. Methods of Inlet Air Cooling

There are few methods which can be used for cooling the inlet air.

6.1.1. Evaporative Cooling Methods

Evaporative methods are among the most widely used power augmentation techniques. This is primarily because the machinery is cheaper, and the installation and operating costs are also lower.

The first method is a media-based method in which the inlet air passes through a wet media causing the water to evaporate. The evaporating water needs to absorb its evaporation enthalpy, and the absorbed enthalpy decreases the dry bulb temperature of the air. The humidity ratio is increased.

Wet compression consists of injecting atomized water into the proximity of the compressor inlet air stream; The injected water quantity is larger than the one that can evaporate completely under environment conditions (temperature, pressure, relative humidity) of the plant installation site; therefore some water droplets are carried into the compressor stages by the air stream, because of the heating due to the pressure increase, evaporates and cools the air stream. Following the drop in the compressor discharge temperature, compressor work decreases and mass flow increases. Consequently, there is a significant enhancement of the gas turbine power output and efficiency & reduction of polluting emissions, particularly nitrogen oxides.

Fogging is another evaporative cooling method in which de-mineralized water is converted to the fog by means of high pressure nozzles. This fog cools the air down in a manner similar to the previous method. Evaporative cooling techniques are most effective in hot and dry climates but not so effective in humid climates.

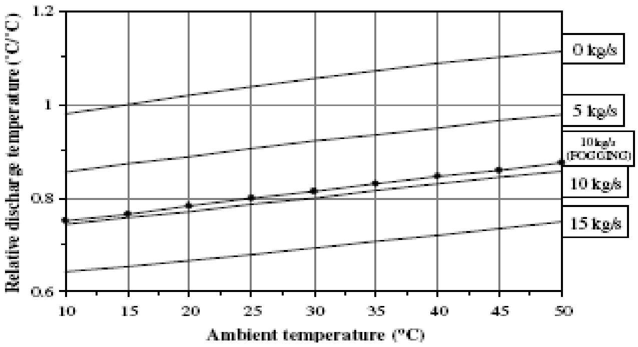

Fig. 3: Relative Compressor Discharge Temperature

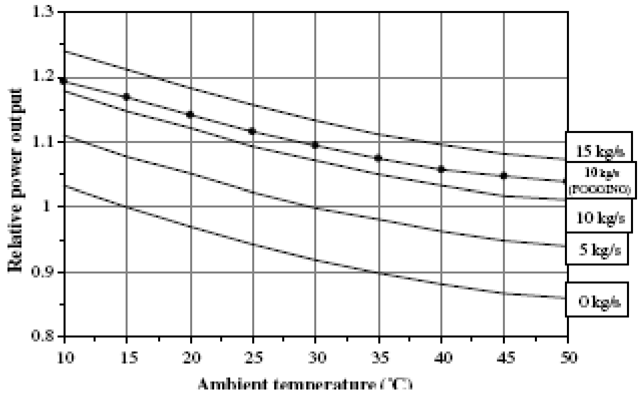

Fig. 4: Relative Power Output

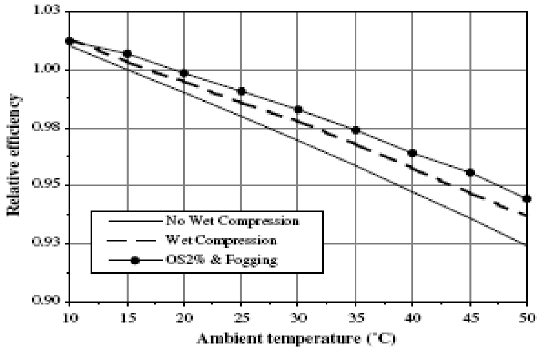

Fig. 5: Relative efficiency

6.1.2. Refrigerated Inlet Cooling Systems

Refrigerated inlet air cooling systems are more effective than evaporative cooling systems; because air dry bulb temperature is lower in these systems. However, the price of the machinery, and the installation, and operating costs are much higher. Two main subcategories of refrigerated cooling systems are mechanical refrigeration and absorption cooling. In mechanical refrigeration, a centrifugal, screw, or reciprocating compressor is utilized for compression of refrigerant vapor. These systems have extremely high power consumption and so many auxiliary equipments such as heat exchangers, pumps, compressors, and expansion valves are also needed. Chlorofluorocarbon refrigerants are normally used in these systems. In addition to environmental issues, high power consumption, high capital and maintenance cost, and poor part load performance are other deficiencies of mechanical refrigeration systems

Absorption chillers use the heat provided by gas turbine's exhaust for cooling the water which acts as a refrigerant. Lithium bromide is used as absorber in these systems. Depending on the specifics of the project, a combination of evaporative and refrigerating cooling systems might be the best choice. Possibility of such combination should be studied prior to selection of any particular type of inlet cooling system.

6.1.3. Thermal Energy Storage Systems

In these systems, extra power of off-peak hours is used for generating ice pieces to be used in peak hours. The inlet air is channeled through a path where it comes into contact with these ice pieces. This causes the inlet air to cool down. There are some problems associated with these systems, one of which is the need for auxiliary ice generating equipment and large insulated spaces for stocking of the ice.

VII. CONCLUSIONS

Water injection shifts the characteristics to higher mass flow ratio. A marginal thermal efficiency increase along with a substantial power boost has been predicted. The problems due to the wet compression technology and fogging are compressor blade erosion and turbine load-bearing structure distortion; generally, the surge margin diminishes as well. In order to reduce these disadvantages, water droplets injected into the air flow should very small have to evaporate in a short time: the spray nozzles, placed correctly with suitable drain systems, should assure small droplet diameters.

There is continuous work going on to enhance the total efficiency of the gas turbine power cycle and reduce its exhaust emission. It is suggested that

1. By cooling of inlet air through spraying of water in inlet air stream or by wet compression.
2. By using the alternative bio-fuels, both the objectives can be fulfilled.

The detail study is planned on the existing gas turbine (Rover IS 60) installed at MANIT, Bhopal, and from these alternative fuels bio-diesel will be tried and its performance will be compared, with inlet air cooling in different weathers.

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