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Modern Gas Turbine with High Fuel Flexibility-A Review

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Abstract—*Fuel supply is one of the most critical factor governing the reliability and operability of gas turbine. The supply of fuel that does not meet gas turbine combustion requirements can result in serious operability and maintenance problem. Due to depletion of fossil fuel, bio fuels have generated a significant interest as an alternative fuel for future. The use of bio-fuels to fuel gas turbine seems a viable solution for the problems of decreasing fossil-fuel reserves and environmental concern. In recent years, the desire for energy independence, foreseen depletion of nonrenewable fuel resources, fluctuating petroleum fuel costs, the necessity of stimulating agriculture based economy, and the reality of climate change have created an interest in the development of bio-fuels. Environmental friendly, gas turbine driven co-generation plants can be located close to energy consumption sites, which can produce their own fuel such as waste process gas or biomass derived fuels. Since gas turbines are available in a large power range, they are well suited for this application. Current gas turbine systems that are capable of burning such fuels are normally developed for a single specific fuel (such as natural gas or domestic fuel oil) and use conventional diffusion flame technology with relatively high levels of NOx and partially unburned species emissions. Recently, great progress has been made in the clean combustion of natural gas and other fossil fuels through the use of dry low emission technologies based on lean premixed combustion, particularly with respect of NOx emissions. This paper comprehensively covers gas, liquids and new alternative fuels for gas turbine and explains the interrelationships of fuel system design, fuel properties and gas turbine operability in terms of dry low Nox/dry low emission (DLN/DLE) combustion.*

Keywords*: Alternative fuels, gas turbines, synthetic fuels, liquid synthetic fuels.*

1. INTRODUCTION

Advantages that gas turbine engine have over internal combustion engine is that they can operate with a larger selection of alternative fuels. This is especially an advantage if it can be done without major modifications in the engine and with fuels that can be derived, at a relatively low cost, from domestic sources. Nowadays, the air transportation is more popular and growth faster to respond the opening business and travel. The worldwide commercial jet fleet increases around 110% for a period of 20 years. In 2008, there were 15900 jets operating in the world and the number of jet is forecasted to be 33500 jets in 2028, corresponding to a yearly average growth rate of 4.7% [1]. The increase in the number of aircraft leads to increasing in demand of fuel. In a report, the world fuel consumption of jet fuel has been increased from 189.1 million gallons per day in 2001 to 198.3 million gallons per day in 2008 and world jet fuel demand is predicted to increase by about 38% during the period of 2008 to 2025 [2]. In contrast, the resource of fossil fuel is depleting and will be finished in a near future. Consequentially, the price of jet fuel has been increased rapidly from $0.93/gallon (Feb, 2004) to $2.97/gallon (Feb, 2014) in 10 years [3]. Statistically, fuel has represented about10-15% of airline operating cost [4], therefore the costly fuel affects strongly to their commercial strategy and profits The overall objective of this study is to develop the data and understanding necessary to consider the following:

- Relaxing fuel specification to increase availability.
- Use of non-petroleum crude stocks to make "synthetic fuels"
- Temporary use of non-specification fuels in emergency situations.

Further goals are the development of design guidelines for engines which are more fuel tolerant, and the development of prophetic reference fuels to be used in the specification and qualification of power plants.

2. LITERATURE REVIEW

Maria Cristina Cameretti and Raffaele Tuccillo [1] examined in this paper the response of a micro gas turbine (MGT) combustor when supplied with gaseous fuels from biomass treatment or solid waste pyrolysis or from an anaerobic digestion process. They have paid a special attention to a satisfactory compromise between the expected CO_2 reduction and the possible increases in pollutant emissions, like carbon and nitric monoxides. For serving this purpose, flameless regime was induced by either an external exhaust gas recirculation (EGR) or by an appropriate choice of the pilot injector location for exploiting a sort of internal EGR. They had analyzed combustion when low LHV fuel is supplied to MGT. The authors evaluated the combustion model impact on the accuracy of result of numerical simulations of turbulent reactive flow by using two numerical codes i.e. the Sandia Flame implementing a 3D RANS integration of the Navier-Stokes equations using the EDM, and a 1D one, where the reaction of diffusion equations are numerically integrated only along the radial direction. S. Taamallah et al. [2] studied fuel flexibility, stability and emissions in premixed hydrogen-rich gas turbine combustion. Their objective was to review the progress made in understanding the effects of fuel composition on premixed gas turbine combustion, with a special emphasis on system stability and emissions, for hydrogen-rich synthetic gas (syngas) mixtures. This is driven by the rising interest in the use of hydrogen blends and syngas in combined cycle power plants, as an alternative to standard natural gas. Typical applications where such mixtures are used include the recycling of hydrogen by-product from industry as well as promising pre-combustion carbon capture methods like fuel reforming or gasification integrated with gas turbine combined cycle plants. Syngas is mainly a mixture of H_2, CO and CH_4; its composition can vary due to fluctuations in the process's conditions but can also dramatically change if the feedstock is modified like coal or biomass grades in gasification. Due to the substantially different chemical, transport and thermal properties that distinguish the syngas components, especially H_2, when compared with conventional hydrocarbon fuels, these non-standard fuels pose several challenges in premixed combustion. These challenges are reviewed in this paper along with the combustion fundamentals of these fuels. A survey of available technologies able to handle syngas and hydrogen-rich fuel in general is provided reflecting the difficulties encountered while using these fuels in real large scale commercial applications. Munzer S.Y. Ebaid et al. [3] had done thermo economic analysis OF PV and hydrogen gas turbine hybrid power plant of 100 MW power output. The design of a PV-hydrogen gas turbine hybrid power plant is proposed to generate 100 MW electrical loads. This electrical power is supplied directly from PV solar panels, and in the case of shortage or lack of solar radiation, it is supplied by a gas turbine power plant working on hydrogen fuel which is produced through using electrolysis of water by a PV generator. The hydrogen produced is stored directly in gas tanks under appropriate pressure. In the case of inability in supplying the load from PV generator, hydrogen fuel will be used through gas turbine. It is found that the price of the electricity produced is 0.12 $/kWh for worst case scenario, and 0.16 $/kWh for the average scenario. The payback period is 13 years and 15 years for the worst and the average scenarios respectively based on 8% interest rate. Attila Kun-Balog and Krisztián Sztanko [4] studied the combustion characteristics of crude rapeseed oil. Their studies were aimed at reduction of pollutant emissions from a rapeseed oil fired micro gas turbine burner. The experiments were performed on a burner test rig, which allowed to modify the factors affecting fuel atomization and to measure the emission of pollutants from a gas turbine burner equipped with an air blast atomizer selected for the purposes of the experiment. Measurement results confirmed that by preheating the rapeseed oil and performing the atomization using steam instead of air, the burner can easily be changed to burning crude rapeseed oil instead of diesel oil without increasing the emission of pollutants. The preliminary analysis showed that the viscosity and the surface tension of sufficiently preheated vegetable oils are similar to that of the diesel oil at room temperature. If the temperature of rapeseed oil is at least 80 °C and atomization takes place with superheated steam instead of air at gauge pressure of 0.95 bar, the emissions of unburned hydrocarbons and carbon monoxide are equal and the emission of nitric oxides is lower by 60%, than that of diesel oil firing with air blast atomization at the same gauge pressure.Xiuqin Zhang et al. [5] evaluated performance and parametric optimum design of a syngas molten carbonate fuel cell and gas turbine hybrid system. A novel model of the molten carbonate fuel cell (MCFC) and gas turbine (GT) hybrid system with direct internal reforming is established where the fuel cell and the auxiliary burner are taken as the heat reservoirs of the gas turbine. Expressions for the power output and efficiency of the hybrid system are derived by considering various irreversible losses resulting from the overpotentials in the MCFC, the heat leakage in the auxiliary burner, and the finite-rate heat transfer and compression, expansion, and regeneration processes in the gas turbine. The effects of some key parameters including the molar fraction of the oxygen in the oxidant, the utilization factor of the hydrogen in the MCFC on the performance of the hybrid system are revealed. It is found that the efficiency of the hybrid system will be increased by adding the utilization factor of the hydrogen, and the maximum power output of the hybrid system will be achieved when the utilization factor of the hydrogen is equal to 0.78. Moreover, the flowing rates of the syngas and oxidant and the molar fraction of the oxygen in the oxidant are determined under the optimal efficiency or maximum power output of the hybrid system.Mukund H. Bade and Santanu Bandyopadhyay [6] analyzed gas turbine integrated cogeneration plant through process integration approach. A methodology is proposed to integrate gas turbine and regenerator with process plant directly at minimum fuel consumption. In addition to this, thermodynamic analysis of GTCP with regeneration is presented on gas turbine pressure ratio versus power to heat ratio diagram.It is interesting to note that though the contour plots of energy utilization factors and fuel energy saving ratios differ significantly, loci of the maximal energy utilization factor and the maximal fuel energy saving ratio are identical. It is noted that GTCP with regeneration is thermodynamically efficient at lower pressure ratios. The proposed analysis (maximum EUF and FESR plot on pressure ratio vs. R) can be used for retrofitting and grassroots design to select optimal configuration of GTCP. In grassroots design of GTCP, for a given R, optimal pressure ratio can be selected based on maximum EUF and FESR. The retrofitting case, for known pressure ratio, there are two values of R. Optimal R can be decided based on the objective of designer such as operating cost to be minimum or fuel energy savings (societal benefits) to be maximum. The shift of pinch point influences the sizing of GTCP. At very high R, GTCP plant behaves similar to gas turbine plant with regeneration. Mohammad Saghafifar and Mohamed Gadalla [7] analysed maisotsenko open gas turbine bottoming cycle. Electricity has an essential role in our daily life. However, with ever increasing cost of fossil fuels and natural gases, improved power generation with higher efficiency and lower capital cost is of high demand. Conventional combined cycles which include a gas turbine topping cycle and a steam turbine bottoming cycle is the most efficient combined power plant system. Nevertheless, it is not the most economically justified cycle for smaller scale power plants because of the presence of the condenser and the heat recovery steam generator (HRSG) in its bottoming cycle. It is reported that conventional combined power cycles are not the most economical alternative for power plants with 50 MW or lower capacities Maisotsenko gas turbine cycle (MGTC) is a recently proposed humid air turbine cycle. An air saturator is employed for air heating and humidification purposes in MGTC. In this paper, MGTC is integrated as the bottoming cycle to a topping simple gas turbine as Maisotsenko bottoming cycle (MBC). A thermodynamic optimization is performed to illustrate the advantages and disadvantages of MBC as compared with air bottoming cycle (ABC). Furthermore, detailed sensitivity analysis is reported to present the effect of different operating parameters on the proposed configurations' performance. Efficiency enhancement of 3.7% is reported which results in more than 2600 tonne of natural gas fuel savings per year. L. Aichmayer et al. [8] done thermo economic analysis of a solar dish micro gas-turbine combined-cycle power plant. A novel solar power plant concept is presented, based on the use of a coupled network of hybrid solar-dish micro gas-turbines, driving a centralized heat recovery steam generator and steam-cycle, thereby seeking to combine the high efficiency of the solar dish collector with a combined-cycle power block. The optimal design has a predicted solar electricity cost of 231 USD/MWhr, 46.1% higher than from a contemporary molten-salt tower CSP plant. At the same time, emissions are 1.7% higher than from a standard unmodified combined-cycle power plant, making the micro gas-turbine combined-cycle appears to be both economically and environmentally unattractive with current technology. A key challenge when drawing conclusions from this work lies in the fact that both the hybrid solar combined cycle concepts analyzed are currently prototype systems, and considerable effort is needed to bring them to maturity. Significant cost reductions have been observed for central receiver systems in recent years as deployment has accelerated, and it is likely that mass production would yield similar costs reductions for solar dish systems. Furthermore, advances in solar micro-turbine technology, such as closer receiver integration, will increase power block performance and bring down costs, allowing the true potential of hybrid solar dish micro gas-turbine combined-cycle power plants to be unlocked, especially in high solar-share configurations. As such, in addition to being ideally suited for small-scale stand-alone and off-grid applications, hybrid solar dish micro gas-turbines also have great potential for utility-scale power production. Future studies will seek to further refine and optimize the design of these hybrid systems and identify the most efficient and cost-effective solutions. Valera-Medina A, [9] studied about alternative fuel for gas turbine. Ammonia has been identified as a sustainable fuel for transport and power applications. Similar to hydrogen, ammonia is a synthetic product that can be obtained either from fossil fuels, biomass or other renewable sources. Since the 1960's, considerable research has taken place to develop systems capable of burning the material in gas turbines. Therefore, this work examines combustion stability and emissions from gaseous ammonia blended with methane or hydrogen in gas turbines. Experiments were carried out in a High Pressure Combustion Rig under atmospheric conditions employing a bespoke generic swirl burner. Results show that efficient combustion can be achieved with high power but at very narrow equivalence ratios using both hydrogen and methane blends. It has been shown that stable flames can be achieved with low emissions using strong swirling flows with both CH_4–NH_3 and H_2–NH_3 blends. Good correlation exists with experiments and numerical calculations. OH radical emissivity seems to be overwhelmed by other radicals, i.e. NH_2 molecules that keep reacting with NOx emissions. It is recognized that there is only a narrow equivalence ratio where high stability, low emissions and high temperature can be achieved, leaving a vast field of research on how to improve these parameters to obtain wider operational ranges. P. Klein et al. [10] done parametric analysis of a high temperature packed bed thermal storage design for a solar gas turbine. The development of a high temperature Thermal Energy Storage (TES) system will allow for high solar shares in Solar Gas Turbine (SGT) plants. In this research a pressurized storage solution is proposed that utilizes a packed bed of alumina spheres as the storage medium and air from the gas turbine cycle as the heat transfer fluid. A detailed model of the storage system is developed that accounts for transient heat transfer between discrete fluid and solid phases. The model includes all relevant convective, conductive and radiative heat transfer mechanisms and is validated against high temperature experimental data from a laboratory scale test facility. The validated model is further utilized to conduct a parametric design study of a nominal six hour TES (1:55MW hth) for a gas micro-turbine. The concepts of utilization factor and storage efficiency are introduced to determine the optimal storage design. The results of the study indicate that a storage efficiency of 88% and utilization factor of 85% can be achieved when combining thermal storage and hybridization with fossil fuels. A high temperature thermal storage system was proposed in order to increase the solar share of a SGT for off the grid power generation. A detailed model of the system was developed and solved using a finite element approach. The model was successfully validated against experimental data from a purpose built test facility. Alumina was identified as an effective high temperature storage material due to its low cost and high volumetric energy storage density. The validated TES model was used to conduct a parametric design study to determine the optimal storage configuration for a 7 m3 packed bed. The results showed that the inclusion of hybridization is important in order to increase the storage efficiency and utilization factor. For each analyzed storage configuration the level of stored energy increased with increasing the aspect ratio and decreasing the particle diameter. Saeid Barountian [11] presented a study of biodiesel from Jatropha Curcas and waste vegetable oil. In the research the author investigated the feasibility of utilization of cheap cost feedstock as an aviation alternative fuel. Several blends of biodiesel with Jet fuel were tested on physical properties to find the most suitable ratio base on the jet fuel specification. The authors concluded that the jet biofuel with 10 and 20% methyl ester contents have comparable properties with the commercial available aviation fuel. Alberto Llamas [12] and his colleagues studied on biodiesel from several kinds of plant oils. The idea of this research is taking fraction of fatty acid ethyl esters (FAMEs) containing the carbon chain length from C8 to C16 which is in order to those of Jet fuel, the remaining of biodiesel which contains long carbon chain length is studied to use as heating oil or lubricant oil. The feedstock was selected basing on carbon chain length range of Jet fuel. Regarding to the idea, Coconut, Palm, Babassu oils which contain dominantly fraction of carbon chain length within Jet fuel range, were used. Besides, Camellina was done in this research to find the feasibility to use inedible oil, which contains the large of fraction of carbon chain lengths mainly out of Jet fuel; the longer chain length was separated by distillation process. With the different manner, R. O. Dunn [13] used methyl soya ester (SME) to examine the feasibility of using biodiesel as a Bio Jet fuel. To improve the freezing point to satisfy requirement of standard, some solutions were done to increase volume percentage of SME.Blends of SME in 10-30% by volume with JP-8 were tested of cold flow properties to find that blends with as little as 10% by volume. SME may limit operation of aircraft to lower altitudes where ambient temperature remains warmer than –29 ºC. Treatment of SME with cold flow improver additives may decrease this limit to –37 ºC. Blends with winterized SME gave the best results, reducing the limit to as low as –47 ºC, a value that meets the standard fuel specification for JP–8.Nascimento [14] studied on biodiesel's effects on diesel micro-turbine engines. The engine performance was tested to determine the differences when the engine fueled by rapeseed biodiesel, and the blends of biodiesel with diesel and diesel which was used as a reference fuel in this experiment. An increase in CO and NOx emissions and fuel consumption were found when the engine was run on biodiesel blends. Furthermore, turbine nozzle and rotor presented significant fouling deposit and damage after using the biodiesel and its blends. Besides the studies on fuel properties, research on engine operation to evaluate effects of using biodiesel on performance and emission was done by many authors. Zehra Habib [15] run a 30kW gas turbine engine fueled with Jet A, soy methyl ester, canola methyl ester, recycled rapeseed methyl ester, hog-fat biofuel and their blends with 50% Jet A by volume. The engine was operated over a range of throttle settings. The study concludes that a reduction in static thrust and thrust-specific fuel consumption; increasing thermal efficiency; and CO and NO emissions were lower by adding of biofuel, no modification on engine was need to be done to use those fuels. The results suggest that an optimum mixture may be found that reduces pollutant emissions while producing the desired thrust. A. Rehman [16] performed a research with the same objective to test using biofuel on engine; however nonedible plant oil was used to make biodiesel. Blends of 15% and 25% biodiesel with diesel fuel by volume was run on IS/60 Rover gas turbine to find the differences on performance and emissions. The results showed that the fuel biofuel properties significantly affect to engine, especially viscosity, heating value and oxygen content presenting in biodiesel. Effect of using biodiesel from recycled waste canola cooking oil on an SR-30 gas turbine engine performance was done by French [17]. The results found that thrust when the engine was fueled biodiesel fuel was proportionately less than that of Jet A for all engine speeds. Ignition characteristic was insignificant different when the engine was run on biodiesel and Jet A. Exhaust jet color and size was indistinguishable by visual observation and the engine's angular acceleration using Jet A was higher than when using the biodiesel. David Chiaramonti [18] investigated of using first generation biofuels which are biodiesel or vegetable oils on a micro gas turbine engine (MGT) - Garrett GTP 30–67. The experiments demonstrated that the MGT can be successfully operated with these biofuels, with emissions comparable to the standard diesel oil. E. Gires [19] tested the performance characteristics of a small scale turbojet engine fueled by Jet A and a blend of palm oil methyl ester (PME) 20% with Jet A by volume. The result showed that the 20% PME blend with Jet A produced comparable results comparing with Jet A, particularly for thrust and thermal efficiency. The efficiency of combustor was improved with the addition of biodiesel while the other component efficiencies remained collectively consistent. Hashimoto et al [20] performed a study to determine the combustion characteristics of palm oil methyl ester (PME) in a diesel industrial gas turbine. It was found that combustion characteristic of PME are similar to those of diesel fuel, while NOx emissions were reduced as running with PME. In other the work of author, combustion characteristic of Jatropha methyl ester (JME) was investigated by conducting at atmospheric pressure employing an air-assist pressure swirl atomizer. It was found that the flame radiation intensity and the soot emission decrease with increasing mixing ratio of JME to diesel fuel. Krishna [21] performed research on the performance of a Capstone C30 micro-turbine on biodiesel blends. Soy-based biodiesel was blended with heating oil for stationary gas turbine engine in blends of 20, 50 and 100% by volume. The research found that lower SO2 and CO emissions, while NOx emitted was approximately the same for the baseline fuel and the biodiesel blends. There is no significant change in thermal efficiency

3. FUTURE SCOPE

Biofuel represents a feasible solution for the issues of the increase in fuel price and reducing GHG emissions. An aviation alternative fuel has to satisfy very strict requirement due to the high safety in commercial aviation industry, therefore researching and developing (R&D) on it needing many company investments, government policy, as well as high technology. Besides, choosing the production process should base on the domestic Conditions of natural, technology and socioeconomic situation. Biodiesel relates to simple production process, low cost and high efficiency. However from the literature available regarding the effects of biodiesel on gas turbine performance, it is due to the high viscosity and low heating value as well as high freezing point and presenting of oxygen. Bio-SPK and FT-SPK are produced by the advance production processes so that they are the promised biofuel for aviation in near future. As a consequence, the high technology and costly is the main barriers of Bio-SPK and FT-SPK for large volume production as well as manufacturing in the developing country such as ASIAN region.

Numerous other gaseous and liquid fuel alternatives are available for gas turbine application, ranging from refinery wastes and petroleum byproducts to biofuels produced from vegetable oils and natural sugars. Properties cover an extremely wide range and demonstrate the versatility of the combustion turbine in handling such different fuel qualities.

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