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Liquid biofuels utilization for gas turbines: A review

Ibrahim I. Enagi[a], K.A. Al-attab[b], Z.A. Zainal[c,*]

[a] Department of Mechanical Engineering, School of Engineering Technology, Federal Polytechnic, P.M.B 55, Bida, Niger State, Nigeria
[b] Department of Mechanical Engineering, Faculty of Engineering, Sana'a University, Sana'a, Yemen
[c] School of Mechanical Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia

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ABSTRACT

The global demand for utilization of renewable fuels in gas turbines has been on the increase to secure a sustainable, and pollution free environment. In this paper, the reviewed studies were on different liquid biofuels production methods such as the catalytic conversion of biomass, gasification, pyrolysis and transesterification. The review also included different studies on directly fired gas turbine (DFGT) and externally fired gas turbine (EFGT) utilizing biomass and liquid biofuels. Furthermore, this study elucidated the use of biofuels in clean combustion methods scalable to gas turbines such as colourless distributed combustion (CDC), high temperature air combustion (HiTAC), moderate or intensive low oxygen dilution (MILD) combustion and catalytic combustion. The discussion included the effect of different input parameters associated with the clean combustion systems that have influence on the attainment of ultra-low emissions of NOx and CO under premixed and non-premixed modes. As for the fuel types, biodiesel is one of the most studied biofuel in gas turbine especially in small-scale micro gas turbine (MGT) engines. The materials for the path of hot gas, types of fuels, heat recovery and cogeneration techniques are the variables, found to be affecting the performance of the DFGT. As for the EFGT, the high temperature heat exchanger with its lower turbine inlet temperature of 700–900 °C is generally the main limiting factor for this technology. The paper concluded by highlighting relevant and recent findings, thereby proposes a further research to improve the versatility in the utilization of liquid biofuels in gas turbines.

1. Introduction

The high global demand of energy has increased expeditiously in the past decade with a reported ratio of annual increment of 2.3% in 2013 [1]. The depletion of fossil fuels and global warming concerns encouraged the development of new combustion technologies for alternative fuels utilization. These technologies should not only cover the demand for power, but also maintain high performance, conversion and efficiency without any environmental impacts [2]. The significance of biomass resources to energy production has shown that 75% of global renewable energy and 13% of world primary energy are from biomass, whereas up to 30% of global energy supply by 2050 is estimated to be from bio-energy contributions especially liquid biofuels [3,4]

Due to the increased diffusion of renewable energy sources in recent years, biomass has gained a growing interest in the combined heat and power (CHP) applications [5]. Using different energy conversion technologies, biomass is storable, programmable and can be utilised to meet a wide range of energy needs [5]. There are several thermo-chemical conversion processes of biomass into different biofuels that include gasification, pyrolysis, liquefaction and transesterification. Focusing on the thermochemical conversion systems, the process technologies for microalgae-to-biofuel production systems were extensively discussed [6] with the benefits of exploiting upstream microalgae biomass development for bioremediation. In addition, there is a recent progress in gasification techniques including important pathways for production of biofuels, socio-economic impacts of biofuel generation and process design [7]. The first generation or advanced biofuels in existing combustion engines are performing well as pure or blended additives. In addition, oxygenated biofuels produces lower NO and sooth emissions than hydrocarbon fuels. However, in order to improve fuel efficiency and reduce engine emissions several novel technologies are being developed [8]. High efficiency, fuel flexibility and ultra-low emission heat engines and fuel cell technologies will in future enable customers to switch to the cleanest fuel available at the lowest cost [8].

One of the major power generation technologies with a significant share in global carbon footprint is gas turbine. However, it is still lagging behind when it comes to renewable resources utilization. One of the European Union targets [9] for micro gas turbine (MGT) power generation is the CHP small scale distributed generation. Some of the advantages of gas turbine include; low pollutant emission, high

* Corresponding author.
E-mail address: mezainal@yahoo.com (Z.A. Zainal).

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reliability, high power to weight ratio, high flexibility and ability to produce both heat and power in a decentralised manner [10]. The utilization of liquid biofuels within a relatively robust burning characteristics of gas turbines is an added advantage [10]. Moreover, liquid biofuels have emerged as the most promising alternative renewable source of fuel [11]. It has been experimentally established that most biofuels can readily be burned in pure form and in standard or slightly modified combustor designs without any significant issues [10].

The indirectly or externally fired gas turbine (EFGT) is an interesting option for electricity and heat production. Flue gas coming from combustor through high temperature heat exchanger heats up the compressed air. The expansion of the resulting hot, compressed and clean air takes place at the turbine. Since the combustion takes place at atmospheric pressure outside the cycle, flue gases are not in direct contact with the turbine, allowing for the utilization of variety of fuels including solid biomass [12]. Hot clean air at turbine exhaust can be utilised directly for thermal applications with no additional heat recovery equipment. Thus, making the biomass EFGT configuration a preferable candidate for CHP applications with a positive contribution to the greenhouse emission reduction [13].

In the internally or directly fired gas turbines (DFGT), the hot combustion gases are in direct contact with the turbine blades. DFGT traditionally contain three main components namely: the compressor, combustion chamber and turbine. Fig. 1**a and b** show simple cycle of the DFGT and EFGT systems. Air pressure is elevated by the compressor commonly up to the range of 15 – 45 bar before entering the combustion chamber. Combustion flue gasses leave combustion chamber at high temperature in the range of 850 – 1200 °C to the expander or turbine, which is directly connected to the alternator for electrical power generation [14]. Numerous efforts on the utilization of various alternative fuels in existing gas turbine power plants are receiving attention. The properties and quality of these fuels are important as well as the necessity for a fuel flexible gas turbine combustors to attain the increasingly stringent regulations concerning the gas emissions [2]. Combustion engineers are facing challenges in the quest to develop an environmental friendly combustors producing ultra-low level pollutants such as soot, unburnt hydrocarbons, CO and NOx [15]. New combustor designs such as the high temperature air combustion (HiTAC) and colourless distributed combustion (CDC) for more uniform and stable combustion with ultra-low emissions are gaining more attention lately [15]. Recent researches on flameless combustion in power generation industry such as gas turbines have shown great potential. However, to improve its versatility in using liquid biofuels, further research is still needed on combustion mechanisms, comprehensive design methods, in-depth flows and advanced modelling and experimental development [16]. Other type of combustion enhancement technologies with gas turbines such as Moderate or intense low oxygen dilution [17] and catalytic combustion [18] have been widely investigated as well.

The current work aims at identifying the innovations and improvements on gas turbine systems with liquid biofuels to achieve complete combustion with low carbon footprint. The objectives of the review are to discuss new techniques for biofuel production, different biomass conversion technologies, biofuel co-firing with other fuels and new four combustion enhancement techniques: HiTAC, CDC, MILD and catalytic combustion.

2. Production process of liquid bio-fuels

This section discusses the major technologies on biomass conversion into liquid biofuels through catalytic, thermochemical and biochemical processes. Table 1 summarizes the proximate and ultimate analysis results of different types of raw biomass sources. From the analysis shown, fuels with high moisture content or low heating value, such as pine chip, cannot be co-fired or utilised directly with other fuels. Therefore, a pre-treatment such as torrefaction or carbonization is required to upgrade the raw materials for further conversion [19]. The properties of raw biomass such as low energy density, high bulk volume, high moisture content and hydrophilic nature are the major challenges for direct biomass utilization in power production. In addition, fouling and slagging issues increase with biomass due to the significant amount of alkali metal in biomass ash. Furthermore, milling difficulty for direct biomass co-firing in existing pulverised coal is among the drawbacks of direct biomass utilization [20]. On the other hand, biomass can be converted through a variety of methods into liquid biofuel while preserving the environmental advantages of biomass utilization. The role of biofuel co-firing is technically, economically, and environmentally the most realistic option for power plants and large CHP systems [21]. Biofuel co-firing plants can handle disruptions in biofuel supply, which makes their utilization suitable with perennial energy crops. Therefore, co-firing could serve as an important role in stimulating these perennial crops [21]. Co-firing of biofuels is in addition a good solution for a steady plant operation, so incorporating it in to CHP designs will permit a greater power production than the biofuel corresponding production capacity of a given site [22].

2.1. Catalytic conversion of biomass into liquid fuels

The catalytic process and development of catalysts play important role in the production of many liquid biofuels. Catalytic processes have the flexibility and capability to optimise and adjust performance in response to variations in feedstock and market demands. The major challenge is the development of catalyst that may facilitate a highly selective conversion of substrate to form desired products [23]. Catalytic analysis shows that Zeolite catalysts [ZSM-5] and mesoporous alumina silicates [Al-MCM-4] are utilised in many catalytic applications involving biomass conversion and upgrading processes, because of their

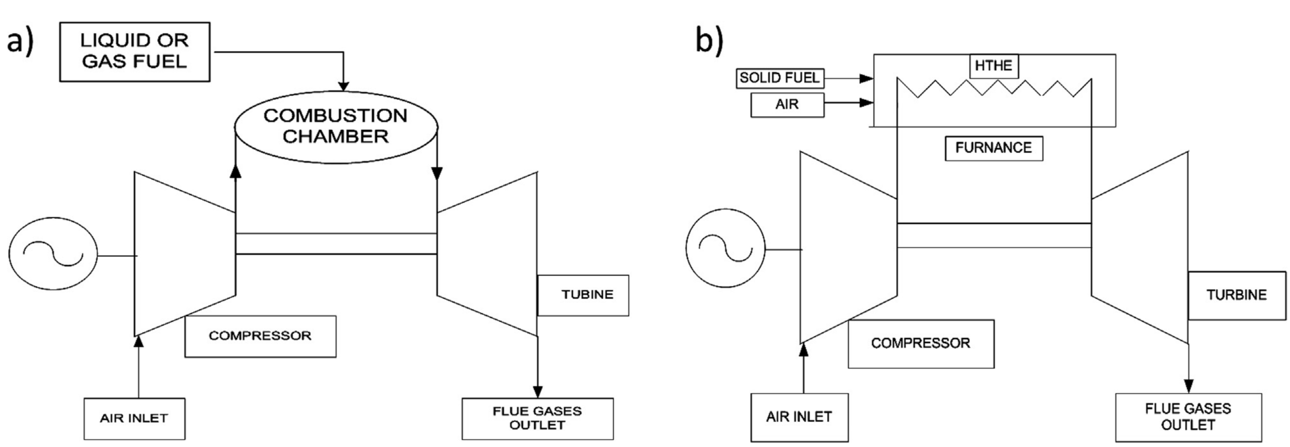

Fig. 1. A Simple sketch of (a) Directly fired gas turbine system; (b) Externally fired gas turbine system.