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Effect of nozzle and combustion chamber geometry on the performance of a diesel engine operated on dual fuel mode using renewable fuels

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A B S T R A C T

Renewable and alternative fuels have numerous advantages compared to fossil fuels as they are biodegradable, providing energy security and foreign exchange saving and addressing environmental concerns, and socio-economic issues as well. Therefore renewable fuels can be predominantly used as fuel for transportation and power generation applications. In view of this background, effect of nozzle and combustion chamber geometry on the performance, combustion and emission characteristics have been investigated in a single cylinder, four stroke water cooled direct injection (DI) compression ignition (CI) engine operated on dual fuel mode using Honge methyl ester (HOME) and producer gas induction. In the present experimental investigation, an effort has been made to enhance the performance of a dual fuel engine utilizing different nozzle orifice and combustion chamber configurations. In the first phase of the work, injector nozzle (3, 4 and 5 hole injector nozzle, each having 0.2, 0.25 and 0.3 mm hole diameter and injection pressure (varied from 210 to 240 bar in steps of 10 bar) was optimized. Subsequently in the next phase of the work, combustion chamber for optimum performance was investigated. In order to match proper combustion chamber for optimum nozzle geometry, two types of combustion chambers such as hemispherical and re-entrant configurations were used. Re-entrant type combustion chamber and 230 bar injection pressure, 4 hole and 0.25 mm nozzle orifice have shown maximum performance. Results of investigation on HOME-producer gas operation showed 4–5% increased brake thermal efficiency with reduced emission levels. However, more research and development of technology should be devoted to this field to further enhance the performance and feasibility of these fuels for dual fuel operation and future exploitations.

1. Introduction

Power production from diesel engines are getting more popular because of their higher brake thermal efficiency, power output, reliability, less fuel consumption, lower emissions and durability as well. Hence diesel engine technology plays a vital role in transportation, agricultural and power generation applications. In the present energy scenario, life of conventional fossil fuels has become limited, while the demand for energy is growing at a faster rate. Due to rapid depletion of conventional fuels, increasing prices of crude petroleum and stringent environmental legislations, use of environment friendly fuels (biofuels) in partial or complete replacement for diesel engine applications is the need of the hour. Major emissions from diesel engines include nitric oxide (NOx) and smoke. These pollutants can be overcome by dual fuel concept. However, a diesel engine using biodiesel-producer gas combination operating on dual fuel mode results in a higher hydrocarbon (HC) and carbon monoxide (CO) emissions [1,2]. Energy conservation with high efficiency and low emissions are important topics for research in engine design and development. For enhancing thermal efficiency of producer gas fueled dual fuel engine and controlling emissions, various biomass feed stock, increased compression ratio,

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addition of hydrogen, blends with ethanol and intake air pressure boosting are being applied [1,3–5]. Biofuels such as biodiesel and producer gas derived from biomass are being considered as better alternative fuel in order to ensure both food and energy security in the prevailing situation of scarcity of fossil fuels. However, in both transport and power generation applications, newer emission legislations have been started to enforce limits on the emission levels [6]. For achieving better thermal efficiency with lower emission levels, many investigators have focused their interest on the domain of fuel related and engine modification techniques. Therefore an effort has been made to curtail negative effects and it is now important to investigate the effects of combustion chamber designs and injection nozzle geometry on the performance and emission characteristics of diesel engine.

Utilization of gaseous fuel along with injected fuel in a dual fuel engine leads to combustion with more complexity because it involves two fuels with different properties and is burnt simultaneously inside the engine cylinder. Therefore, heat release rate of dual fuel combustion is the result of three combustion stages [7–9]. In case of dual fuel engine, injection of liquid fuel is performed with an in-cylinder injection system. These engines can operate unthrottling, with load regulated by admitting gaseous fuel along with air through induction manifold. Substantial research on producer gas fueled dual fuel engine and its effect on performance and emission levels has been reported in the literature [4, 10–17]. Dual fuel engines are known for good liquid fuel saving with decreased smoke and nitric oxide (NOx) emissions. Some of the investigators have reported lower performance, increased HC/CO and lower NOx/smoke levels under producer gas dual-fueling [2, 4, 11–18]. Some researchers have reported decreased power output of engine, whereas others have not mentioned. Loss of thermal efficiency compared to diesel operation has been reported in the literature. In view of this, several investigators have made an effort for achieving comparable efficiencies [8, 11, 13]. Biomass energy conversion technologies to achieve prominence for developing energy for rural as well as industrial sectors are required to improve the quality of life [4, 12, 13, 15, 18]. Different types of gasifier and their advantages and disadvantages, applications, current status, challenges, potential scope and economic analysis of the gasifier-engine system have been investigated [1, 2, 19, 20]. Performance of an engine depends on the two factors such as, properties of fuel used and basic engine design. Majority of the research work is focused on the utilization of compressed natural gas (CNG) and liquefied petroleum gas (LPG) in engines operated on both single and dual fuel mode and developed many new technologies. Many published literatures have reported with reference to fuel properties and their influence on dual fuel operation. However, very few literatures have been reported on basic engine modifications. Therefore, use of producer gas in engines still needs more detailed studies, as this area is less investigated. Improvement in performance with decreased exhaust emissions of producer gas dual-fuel engine needs more detailed investigation with respect to both fuel properties and basic engine design modification.

The performance of a diesel engine is significantly affected by injector type. The performance of a diesel engine is largely influenced by fuel spray characteristics that are produced using relatively high injection pressures. Highest injection pressure that can be used in the diesel engine is 205 bar, whereas, modern CI engines are equipped with common rail direct injection (CRDI) technology. This will employ very high injection pressures (2000 bar). In this injection system, fuel injection pressure can be regulated by controlling the fuel rail pressure [21, 22]. Fuel injection is an important operating parameter which affects the fuel vaporization; distribution and mixing of fuel within the combustion chamber which is in turn responsible for the overall performance of a diesel engine. Appropriate droplet size, fuel distribution, and penetration lead to more efficient combustion and thus lower emissions [24]. Some of modern diesel engines use micro-orifices having various orifice designs and affect engine performance to a great extent. Several investigators have investigated the effect of dynamic factors on injector flow spray, combustion and emission levels from a diesel engine [23, 25]. Experimental studies involving the effects of nozzle orifice geometry on global injection and spray behavior has been reported [23, 26–28]. Smaller injector nozzle hole diameter produces smaller droplet size and results into reduced spray tip penetration due to the low spray momentum [29]. Air and fuel mixing depends on the number of nozzle holes and diameter. Adverse effect on combustion and emissions has been reported when number of holes exceeds a certain threshold value. This could be due to lack of the air entrainment required for the achievement of a stoichiometric mixture [30].

Effective air and fuel mixing is significantly affected by mainly spray characteristics and air flow inside the engine cylinder. Modification of combustion chamber by suitable piston bowl can significantly affect the different phases of heat release i.e., it affects the shape and magnitude of the heat release rate profile, by affecting bulk airflow and turbulence, thus affecting air-fuel mixing rates. Effective control and manipulation of the heat release rate is important to limit peak cylinder pressure, combustion noise and emission levels. A good combustion chamber provides better squish, forcing the air to the centre of the combustion chamber [8]. This causes turbulence even when the fuel is injected into the cylinder. Present diesel engines use hemi-spherical combustion chamber and results into better performance for the diesel fuel. However, it may not be good for alternative liquid and gaseous fuels; hence it is necessary to design different combustion chambers for alternative fuels [31–34]. The effect of combustion chamber configuration on the engine performance is very complex to analyze due to its influence on the flow field and air-spray interaction [35,36]. The shape of piston bowl controls the movement of air and fuel as piston moves up during compression stroke. Suitable changes in the in-cylinder flow field or swirl results into vortex inside the piston bowl before combustion takes place, creating a better mixture formation. Swirl is used to promote rapid mixing of inducted air and fuel at the end of the compression stroke. However, fuel-air mixing is predominantly governed by fuel injection characteristics and air-swirl. Rapid mixing is essential, because small DI diesel engines operating at high speed have a very short time-window over which combustion must occur. This is necessary in order to limit formation of soot in the expansion phase, and minimize specific fuel consumption [31]. This fact results into better and more efficient combustion, leading to enhanced power output. Therefore the behavior of fuel injected in the combustion chamber and its interaction with air is important as far as combustion and emissions are concerned. It is well known that nozzle geometry and cavitations strongly affect evaporation and atomization processes of fuel. Hence, the combustion chamber of an engine plays a major role during combustion of wide variety of fuels. At fixed compression ratio and newly developed piston, researchers have observed increased swirl at TDC, less smoke, comparable HC and NOx levels. In this context, many researchers have performed both experimental and numerical studies on the use of various combustion chambers and analyzed its effects on the engine performance [8, 9, 35, 37–43]. Improvement in air entrainment with increasing swirl and injection pressure has been reported in the literature [44,45]. Optimum combustion chamber geometry of engine must be considered to have a better engine operation, performance and emission levels. Suitable combustion chamber geometry helps to increase squish area and proper mixing of gaseous fuel with air [35, 46]. Designing the combustion