Energy 67 (2014) 162–175

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Assessment of maximum available work of a hydrogen fueled compression ignition engine using exergy analysis

Venkateswarlu Chintala, K.A. Subramanian*

Engines and Unconventional Fuels Laboratory, Centre for Energy Studies, Indian Institute of Technology, Delhi, New Delhi 110 016, India

ARTICLE INFO

Article history:
Received 6 August 2013
Received in revised form
23 January 2014
Accepted 26 January 2014
Available online 16 February 2014

Keywords:
Energy
Exergy
Hydrogen
Dual-fuel engine
Maximum available work
Irreversibility

ABSTRACT

This work is aimed at study of maximum available work and irreversibility (mixing, combustion, unburned, and friction) of a dual-fuel diesel engine (H_2 (hydrogen)–diesel) using exergy analysis. The maximum available work increased with H_2 addition due to reduction in irreversibility of combustion because of less entropy generation. The irreversibility of unburned fuel with the H_2 fuel also decreased due to the engine combustion with high temperature whereas there is no effect of H_2 on mixing and friction irreversibility. The maximum available work of the diesel engine at rated load increased from 29% with conventional base mode (without H_2) to 31.7% with dual-fuel mode (18% H_2 energy share) whereas total irreversibility of the engine decreased drastically from 41.2% to 39.3%. The energy efficiency of the engine with H_2 increased about 10% with 36% reduction in CO_2 emission. The developed methodology could also be applicable to find the effect and scope of different technologies including exhaust gas recirculation and turbo charging on maximum available work and energy efficiency of diesel engines.
© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Diesel fuel consumption per capita for automotive diesel engines in the world increased drastically from 91.5 kg (oil equivalent) in 2003 to 125.5 kg in 2010 [1]. World demand for diesel engines is projected about 6.7% per year [2]. However, it emits high level of PM (particulate matter) and NO_x (oxides of nitrogen) emissions which are mainly due to the engine combustion with heterogenous air–fuel mixture. NO_x which forms at high temperature could decrease by reducing in-cylinder temperature but it decreases maximum available work resulting in increase in PM emission. EPA (Environmental Protection Agency) emphasized the emission regulation of diesel engine's PM that shall be evaluated based on diesel particulate size and count. The EPA emission regulations for Total Suspended Particles for $PM_{2.5}$ (fine particles indicator) and PM_{10} (coarse particles indicator) are 15 μg/m^3 and 100 μg/m^3 [3]. In case of European Countries, Euro-V emission regulation for PM emission of automotive diesel engines is 0.02 g/kWh which needs to be reduced further for Euro-VI emission regulation [4]. The future emission regulation for CI (compression ignition) engines targets CO_2 (Carbon dioxide) emission reduction along with other regulated emissions (CO (carbon monoxide), HC (hydro carbon), NO_x and PM (particulate count and size)). For example, European Union sets CO_2 emission regulation of 95 g/km by 2020 [5]. Environmental Protection Agency implemented CO_2 emission regulation (820 g/kWh) for light, medium and heavy duty vehicles for next three years (2014–16) [6]. The CO_2 emission from diesel engine can be reduced by energy efficiency improvement and carbon content reduction in fuel. The current technology for reducing emission from diesel engines is based on either temperature reduction (EGR (exhaust gas recirculation), retarding injection timing, etc.) or physical and chemical methods (selective catalytic reduction, diesel oxidation catalyst, etc). These technologies generally need energy input for their function resulting in reduction in maximum available work of the engine. Hence, green environment (less emissions of PM, and CO_2) and energy efficiency improvement are sustainable indicators of CI engines.

Utilization of H_2 (Hydrogen) in CI engines under dual-fuel mode could provide solutions to improve energy efficiency along with carbon-based emission reduction (CO, HC, PM and CO_2) as the engine with H_2 reduces the degree of heterogeneity ensuing to less PM emission (including its size and count) along with energy efficiency improvement and CO_2 emission reduction. Some studies reported the effect of H_2 on emissions (PM and CO_2) reduction and energy efficiency improvement of dual-fuel diesel engines. For example, Tsolakis reported that total particle number and total particle mass decreased from 0.55 cm^{-3} and 98.66 mg/cm^3 with

* Corresponding author.
E-mail addresses: subra@ces.iitd.ernet.in, subra@ces.iitd.ac.in (K.A. Subramanian).

0360-5442/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.energy.2014.01.094

diesel to 0.37 cm^{-3} and 77.64 mg/cm^3 with 20% H_2 added EGR in a 8.6 kW direct injection diesel engine under dual-fuel mode at 1500 rpm and indicated mean effective pressure of 4.5 bar [7]. Wu et al. reported simultaneous reduction of CO_2, NO_x, and smoke emissions from a diesel engine (9.2 kW at 2400 rpm) under dual-fuel mode (diesel-gasoline) [8]. Miyamoto et al. reported CO_2 emission decreased from 688 g/kWh with base diesel fuel to 425 g/kWh with 10% H_2 (by volume) in a common rail direct injection diesel engine under dual-fuel mode [9]. Chintala and Subramanian reported energy efficiency of a diesel engine (7.4 kW) under dual-fuel mode increased about 5.4% with H_2 [10].

Hydrogen dual-fuel engine provides high fuel flexibility as it can operate in either conventional mode (diesel) or dual-fuel mode (diesel–H_2) depending on H_2 fuel availability. The existing NG (natural gas) infrastructure (storage, transportation and dispensing) could also be used for H_2 blended NG fuel. However, the existing system may need major modification for handling of H_2 (100%). For power generation and marine applications, the NG as main fuel is already being used in commercial dual-fuel diesel engines which are produced by diesel engine manufacturer including Cummins, Caterpillar and Wartsila. In the world, Delhi (India) is one of the largest vehicle fleet fueled with NG. The government of India is also taken further amendment by formulating fuel policy for implementation of H_2 blended natural gas (H_2: 18% by volume) as a fuel in IC (internal combustion) engines/vehicles [11]. National Hydrogen energy Roadmap (India) envisages road map for sustainable power generation and keeping air pollution free urban cities by utilization of H_2 as fuel for power generation (1000 MW aggregate capacity) and transport vehicles (one million) by 2020 [11]. A CI engine (at high compression ratio) could give higher energy efficiency with lesser CO_2 and PM emissions when it operates with H_2 fuel under dual-fuel mode as compared to spark ignition engine.

The energy efficiency of CI engine can be improved further by reducing the irreversibility and enhancing the available work from the system. In general, a CI engine produces irreversibility majorly due to combustion, air fuel mixing, wall heat transfer, exhaust gas, and friction. The literature status of these irreversibilities and available work from the engine systems is briefly described below.

1.1. Combustion irreversibility

Dunbar and Lior conducted a study of process irreversibility in an adiabatic combustion chamber and found one-third of the useful fuel energy is destroyed during combustion process [12]. Caton reported combustion irreversibility, which is mainly function of temperature, pressure and equivalence ratio, and it decreases with increasing combustion temperature [13]. But, Rakopoulos and Kyritsis reported the irreversibility is a function of fuel reaction rate as the combustion with lighter molecule fuels leads to decrease in irreversibility as compared to heavier molecule fuel [14]. Rakopoulos et al. reported that combustion process of the diesel engine fueled with H_2 (up to 10% by volume) produces less irreversibility under dual-fuel operation [15]. However, irreversibility produced during combustion in CI engines is not understood clearly so far.

1.2. Mixing irreversibility

Dunbar and Lior found the irreversibility of mixing of fuel with air is in the range of 8–10% of total reversibility [12]. Similarly, Jonathan and Dincer reported 9% of the total irreversibility which is produced by the mixing of fuel with air during suction stroke of a spark ignition engine [16]. As this mixing irreversibility is an important irreversible process, it needs to be studied for the dual-fuel diesel engine with H_2 fuel.

1.3. Wall heat transfer and exhaust gas losses

Taymaz reported that a diesel engine (136 kW at 2400 rpm) could decrease its heat transfer loss (through engine walls) from 27% without insulation to 23% with insulation. However, the heat loss increased through exhaust gases from 24% to 27% at higher load [17]. Information on irreversibility produced due to wall heat transfer and exhaust gas in CI engines is scanty in the literature. However, some researchers reported that the energy efficiency of the engine system could be improved by utilizing waste heat energy for application of combined heat and power (cogeneration) to industrial process because the energy losses typically through exhaust gas/cooling water from the engine. For example, Shu et al., studied the potential of waste heat recovery from a diesel engine using thermo-electric generator and organic cycle, and reported indicated thermal efficiency of the engine increased from 41% to 45.7% [18]. Ghazikhani et al., reported specific fuel consumption of multi cylinder direct injection diesel engine (85 hp at 2800 rpm) with exhaust gas recovery decreased about 10% [19]. Fu et al., reported energy efficiency improvement (about 6.3%) of a four cylinder CI engine (110 kW) using exhaust heat recovery. It is an interesting study that one cylinder (out of four) was operated by steam as working fluid which was generated using the heat input from waste exhaust gas energy of remaining three cylinders [20]. They also studied the potential of methanol as working fluid as well as fuel for combined cycle power plant (IC engine-ORC (organic rankine cycle)). Fu et al., reported methanol can be a working fluid for ORC system with efficiency improvement (3.9–5.2%) and subsequently, it is also utilized as fuel in IC engine for enhancing thermal efficiency (1.4–2.1%) [21]. Domingues et al., studied the potential of waste heat recovery from IC engine with ORC system with different working fluids (water, Hydrochlorofluorocarbons), and reported thermal efficiency and mechanical efficiency of the engine increased in the range of 1.4–3.52% and 10.16–15.95% [22]. The waste exhaust gas heat from IC engine was utilized for generating power (maximum net output of 2069 kW) in a ship using ORC with maximum energy and exergy efficiencies of 11% and 59% [23]. A diesel engine (20 kW) integrated with cogeneration system (heating, cooling and power) could significantly improve energy and exergy efficiencies [24]. Split cycle process was used for waste heat recovery from the marine engine and produced higher power output by 3.4% than conventional cycle [25]. Kalyan et al., concluded NO_x and CO_2 emission of a diesel engine with EGR decreased about 18% (on average) with ORC system [26]. ORC system with diesel engine (by combined cycle) has high potential to increase exergy (up to 21%) and energy efficiency (up to 6.1%) of the engine [27]. Sarabchi et al., studied utilization of waste heat from homogenous charge compression ignition for a tri-generation application (power, heating and cooling) and reported the second law efficiency of the tri-generation system is higher (about 5.19%) than the base engine [28]. It is clearly seen from the above discussion that the diesel engine with ORC/tri-generation system could enhance exergy efficiency of the engine but these systems (ORC/tri-generation) have limitation (additional system cost and complexity) on its usage in low rated power output system (automotive engine, and low and medium electrical power generation). Livio et al. reported that H_2 (8% by volume) blended NG fueled IC engine (65 kW rated power at 1500 rpm) with combined heat and power system could increase electrical efficiency significantly along with reduction of carbon monoxide and CO_2 about 27% and 9% [29]. There is no information in literature on wall heat transfer and exhaust gas energy loss of CI engines fueled with H_2.

Download English Version:

https://daneshyari.com/en/article/1732547

Download Persian Version:

https://daneshyari.com/article/1732547

Daneshyari.com