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Experimental investigation on dual fuel operation of acetylene in a DI diesel engine

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ABSTRACT

Depletion of fossils fuels and environmental degradation have prompted researchers throughout the world to search for a suitable alternative fuel for diesel engine. One such step is to utilize renewable fuels in diesel engines by partial or total replacement of diesel in dual fuel mode. In this study, acetylene gas has been considered as an alternative fuel for compression ignition engine, which has excellent combustion properties.

Investigation has been carried out on a single cylinder, air cooled, direct injection (DI), compression ignition engine designed to develop the rated power output of 4.4 kW at 1500 rpm under variable load conditions, run on dual fuel mode with diesel as injected primary fuel and acetylene inducted as secondary gaseous fuel at various flow rates. Acetylene aspiration resulted in lower thermal efficiency. Smoke, HC and CO emissions reduced, when compared with baseline diesel operation. With acetylene induction, due to high combustion rates, NO_x emission significantly increased. Peak pressure and maximum rate of pressure rise also increased in the dual fuel mode of operation due to higher flame speed. It is concluded that induction of acetylene can significantly reduce smoke, CO and HC emissions with a small penalty on efficiency.

1. Introduction

The enormous growth of the worlds population during the last decade, technical developments and increase in standard of living in the industrial nations have led to an intricate twin crisis of fossil fuel depletion and environmental degradation ranging from local air pollution to global dimensions of global warming, climatic changes and sea level rise. The search for an alternative fuel that promises a harmonious correlation with sustainable development, energy conservation and management, efficiency and environmental preservation has become imperative in the present context. Therefore, any attempt to reduce the consumption of petroleum based and to replace it with other fuels derived from non-petroleum based will be most welcome.

One approach in this direction is to utilize gaseous fuels like biogas, LPG (liquefied petroleum gas), LNG (liquefied natural gas), hydrogen and acetylene gas. They have a high self-ignition temperature; hence they cannot be used directly in diesel engines. Diesel engines however can be made to use a considerable amount of gaseous fuels in dual fuel mode without incorporating any major changes in engine construction. It is possible to trace the origin of the dual fuel engines to Rudolf Diesel, who patented an engine running on essentially the dual fuel principle. Here, gaseous fuel called primary fuel is either inducted along with intake air or injected directly into the cylinder and compressed but does not auto-ignite due to its very high self-ignition temperature. Ignition of homogeneous mixture of air and gas is achieved by timed injection of small quantity of diesel called pilot fuel near the end of the compression stroke. The pilot diesel fuel auto-ignites first and acts as a deliberate source of ignition for the primary fuel–air mixture. The combustion of the gaseous fuel occurs by flame initiation by auto-ignition of diesel pilot injection at unspecified location in the combustion chamber. This ignition source can develop into propagation flame, similar to spark ignition (SI) engine combustion [1]. Thus, dual fuel engine combines the features of both SI and CI (compression ignition) engine in a complex manner.

The work of Karim [2,3] on utilization of gaseous fuels such as methane, propane, acetylene, ethylene and hydrogen in diesel engine reveals that the maximum amount of gas consumption is limited to the onset of knock. He also reported that in dual fuel engines at low load, when gaseous fuel concentration is low, the ignition delay period of the pilot fuel increases and some of the homogeneously dispersed gaseous fuel remains unburned and results in poor performance. Pilot fuel quality, injection timing and intake temperature are important variables affecting the performance of dual fuel engine. Karim [4] has done extensive research to establish the nature of the combustion process in the dual fuel engine. He has used variety of gases like methane, ethane, propane, butane, hydrogen, ethylene and acetylene as the primary fuel. It is generally accepted that the performance of the dual fuel engines, irrespective of the type of gaseous fuel

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Nomenclature

BSU	Bosch smoke unit
CI	compression ignition
CO	carbon monoxide
DI	direct injection
HC	Hydrocarbon
LNG	liquefied natural gas
LPG	liquefied petroleum gas
NO_x	Oxides of nitrogen
SI	spark ignition

employed, is better at medium and at high loads. However, it has been reported that at low outputs, efficiency is marginally inferior to the baseline diesel engine. Researchers have stressed the need to control the quantity of both pilot and gaseous fuels depending on the load conditions for better performance.

Liu and Karim [5] studied the effect of admission of gaseous fuels and diluents in the dual fuel diesel engine. They reported that gaseous fuels and diluents would change the physical and chemical processes of the ignition delay period. The extent of the ignition delay period depends strongly on the type of gaseous fuel used and its concentration. Rao et al. [6] investigated the performance of diesel engine in dual fuel mode by inducting a small quantity of hydrogen in the inlet manifold. At higher loads, the efficiencies attained were closer to diesel with a notable reduction in smoke, soot formation and exhaust temperature. NO_x emissions increased with increase in peak pressure. Das and Patro [7] conducted experiments in single cylinder, direct injection (DI) diesel engine in dual fuel mode by inducting hydrogen, and achieved improved knock limited power output by charge diluents techniques such as helium, nitrogen and water. Varde and Frame [8] conducted experiment with an objective to reduce smoke by aspirating hydrogen, and they concluded that reduction in smoke emission was prominent at part load than at full load. Very low concentration of hydrogen flow rate had an adverse effect on thermal efficiency, NO_x increased with increase in hydrogen. HC emission was not affected. Tomita et al. [9] investigated that by inducting hydrogen in the intake port of the diesel engine, NO_x emissions decreased because of lean premixed combustion. Hydrocarbon (HC), carbon monoxide (CO) and carbon dioxide (CO_2) decreased without exhausting smoke with marginal decrease in thermal efficiency.

Das [10] suggested that hydrogen could be used in both SI engine as well as in CI engine without any major modification in the existing system. He studied different modes of hydrogen induction by carburetion, continuous manifold injection, timed manifold injection, low-pressure direct injection and high-pressure direct injection and suggested to use manifold injection method for the induction of gases to avoid undesirable combustion phenomenon (back fire) and rapid rate of pressure rise. Razavi and Karim [11] conducted experiments on a four-stroke, single cylinder, DI diesel engine, fueled with natural gas. Tests were conducted with diesel as the pilot fuel having different cetane numbers in order to study the effects of pilot fuel quality on ignition delay. They concluded that the ignition delay of a dual fuel engine mainly depends on pilot fuel quantity and quality. High cetane number pilot fuels can be used to improve the performance of engines using low cetane value gaseous fuel.

Prabhukumar et al. [12] made comparative a study on the performance, fuel economy, combustion characteristics and smoke emission while using LPG and hydrogen as a primary fuel in dual fuel mode in diesel engine. They concluded that knock limited power output and percentage diesel substitution by LPG was higher compared to hydrogen diesel dual fuel engine due to its faster burning rate. Poonia et al. [13] have reported the performance of dual fuel engine with LPG as the primary fuel and diesel as pilot fuel and the influence of different variables. They reported that the part load efficiency was lower than diesel due to poor ignition and sluggish flame propagation. However at higher loads, it was better than diesel. It was also reported that the ignition delay was always greater than diesel. Wulff et al. [14] used a mixture of acetylene and alcohol to burn in spark ignition engine and in compression ignition engine in a controllable way in dual fuel mode. It exhibited higher efficiency than conventional engine with cleaner burning than fossil fuels. The combustion temperature was lower, which in turn would prolong the life expectancy of the engine. Ashok Kumar et al. [15] studied the suitability of acetylene in a SI engine along with EGR and reported that emission drastically reduced on par with hydrogen engine with a marginal increase in thermal efficiency. Swami Nathan et al [16] conducted experiments in a CI engine by using acetylene as a fuel in HCCI mode along with preheated intake charge. The efficiencies achieved were very near to diesel. NO_x and smoke level reduced drastically. However HC level increased.

Thus, the dual fuel mode of operation leads to smoother operation, lower smoke emission and thermal efficiency, which are almost comparable to the diesel version at medium and at high loads. However, major drawbacks with these engines are higher NO_x emissions, poor part load performance, higher ignition delay with certain gases like biogas and rough engine operation near full load due to high rate of combustion. Acetylene is chosen as the alternative fuel in the present work to study the performance and emission characteristics in an internal combustion engine. Acetylene posseses similar properties as that of hydrogen (Table 1). Acetylene was discovered in the year 1836 in England by E. Davy. Acetylene is a colorless gas with garlic smell, with very wide flammability range and minimum ignition energy required for ignition. It has higher flame speed, hence faster energy release and at stoichiometric mixtures acetylene engines could more closely approach thermodynamically ideal engine cycle efficiency. Flame cannot be quenched easily in the combustion chamber as it has lower quenching distance. Lower ignition energy, high flame speed, wide flammability limits and short quenching distance leads to premature ignition and undesirable combustion phenomenon called knock. These are the primary problems those are encountered in the operation of acetylene engines. In the present work, a single cylinder, DI, air cooled diesel engine was modified to work in the dual fuel mode with acetylene as the inducted fuel and diesel as the injected fuel for ignition. The performance and emissions at different outputs with varied flow rate at 0.20 kg/h, 0.26 kg/h and 0.39 kg/h of acetylene quantity are presented in this work.

2. Experimental setup and methodology

A single cylinder, four-stroke, air-cooled, and naturally aspirated, DI diesel engine designed to develop a power of 4.4 kW at 1500 rpm

Table 1
Physical and combustion properties of fuels [17].

Properties	Acetylene	Hydrogen	Diesel
Formula	C_2H_2	H_2	C_8–C_{20}
Density kg/m^3 (At 1.01325 bar and 20 °C)	1.092	0.08	840
Auto ignition temperature (K)	578	845	527
Stoichiometric air fuel ratio, (kg/kg)	13.2	34.3	14.5
Flammability Limits (Volume %)	2.5–81	4–74.5	0.6–5.5
Flammability Limits (Equivalence ratio)	0.3–9.6	0.1–6.9	–
Adiabatic flame temperature (K)	2500	2400	2200
Lower Calorific Value (kJ/kg)	48,225	120,000	42,500
Lower Calorific Value (kJ/m^3)	50,636	9600	–
Max deflagration speed (m/s)	1.5	3.5	0.3
Ignition energy (MJ)	0.019	0.02	–
Lower Heating value of Stoichiometeric mixture (kJ/kg)	3396	3399	2930