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Experimental investigation of port injection of acetylene in DI diesel engine in dual fuel mode

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ABSTRACT

As the world finds itself in the midst of universal energy shortage, compounded by a parallel need to reduce pollutants of all kinds; we must take serious look at novel sources of abundant energy and methodology of its use. Acetylene with its remarkable combustion properties appear to be proving itself as the best fuel for future internal engines if it is utilised properly. Because of inherent difficulties in handling acetylene, technology has emphasized the utilization of acetylene by injection techniques to combat back fire in internal combustion engines. An experimental investigation was carried out on a single cylinder, air cooled, DI diesel engine designed to develop 4.4 kW at 1500 rpm. Acetylene was injected into the intake port as a secondary fuel and diesel was injected directly into the cylinder. The optimized injection time of 5° aTDC and injection duration of 90 °CA (9.9 ms) was arrived. The gas flow rate was fixed at 110 g/h, 180 g/h and 240 g/h. The combustion, performance and emission parameters were studied for the above flow rates by varying the load from low load to full load. Results show that NO_x, HC and CO emissions reduced when compared to diesel operation due to leaner operation. A marginal increase in smoke emission was observed and brake thermal efficiency was nearer to diesel operation. On the whole it is concluded that without loss in thermal efficiency, safe operation of acetylene is possible in timed port injection technique. Reduced NO_x, HC and CO emission levels, with marginal increase in smoke emission level were achieved.

1. Introduction

There is a rapid growth rate in global motor vehicle population like passenger cars, trucks, buses, motor cycles and three wheelers. These vehicles have brought many advantages in increasing the mobility of millions of people, creating more jobs and enhancing the standard of living. These benefits have been offset by excess of air pollution, by emission of large quantities of CO, HC, NO_x, CO_2 and toxic substances like fine particles which adversely affect the human health and environment [1]. The increase in vehicle population has also led to fossil fuel depletion. The above twin crisis problem has led researchers to find an alternative to the presently used fuels, which should be pollution free, energy efficient and compatible with today's automobiles. The suggested alternative fuels are alcohol, biodiesel, and gaseous fuels like CNG, LPG, hydrogen, and acetylene. Among the suggested fuels, gaseous fuels have shown excellent performance and lower emission than other fuels. The work of Karim [2,3] on utilization of gaseous fuel such as methane, propane, acetylene, ethylene, and hydrogen in diesel engine reveals that the maximum amount of gas consumption is limited due to the onset of knock. He also reported that in dual fuel engines at low load, when gaseous fuel concentration is low, 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 and Moore [4] has done extensive research to establish the nature of the combustion process in the dual fuel engine. He has used various 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 employed, is better at medium and at high loads. Rao et al. [5] 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 fuel operation with a notable reduction in smoke, soot formation, and exhaust temperature. NO_x emissions increased with increase in peak pressure. Tomita et al. [6] showed that by inducting hydrogen in the intake port of the diesel engine, NO_x emission decreased because of lean premixed combustion. Hydrocarbon (HC), carbon monoxide (CO), and carbon dioxide (CO_2) decreased without exhausting smoke with a marginal decrease in thermal efficiency.

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Das [7] 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 (CMI), timed manifold injection (TMI), continuous port injection (CPI), timed port injection (TPI), low-pressure direct injection (LPDI), and high-pressure direct injection (HPDI) and suggested timed manifold injection method for the induction of gases to avoid undesirable combustion phenomenon and rapid rate of pressure rise. Nagarajan et al. [8] have carried out an experimental study adopting the timed port injection technique in compression ignition engine with diesel being the ignition source for hydrogen–air mixture. It was reported that the emissions such as CO, CO_2, and HC decreases drastically to negligible concentration. This is due to efficient combustion of hydrogen fuel. It was also stated that the brake thermal efficiency increases from 20% to 25%. SwamiNathan et al. [9] conducted experiments in CI engine by using acetylene as a fuel in HCCI mode along with preheated intake charge. The efficiency achieved was very near to diesel fuel operation. NO_x, and smoke level decreased drastically. However, HC level increased.

Thus, the dual fuel mode of operation leads to smoother operation, lower smoke emission and thermal efficiency is almost comparable to the diesel version at medium and at high outputs. 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 investigation to study the performance and emission characteristics in a compression ignited diesel engine. Acetylene seems to possess similar properties as that of hydrogen (Table 1). Acetylene is a colorless gas with garlic smell, with very wide flammability range and minimum ignition energy required for ignition [10]. It has higher flame speed, hence faster energy release, and at stoichiometeric mixtures, acetylene engines could more closely approach thermodynamically ideal engine cycle efficiency. 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 which are encountered in the operation of acetylene engines. One such step to preclude backfire is timed injection of fuel in the intake after the beginning of the suction stroke to ensure air being inducted prior to fuel delivery. This provides a pre-cooling effect and thus renders the preignition source ineffective. Based on the location of the injector three techniques are available; manifold injection, port injection, and direct injection. A timed port injection technique is adopted in the present investigation.

Table 1
Physical and combustion properties of fuels (14).

Properties	Acetylene	Hydrogen	Diesel
Formula	C_2H_2	H_2	C_8–C_{20}
Density (kg/m^3) (at 1.01325 bar and 293 °K)	1.092	0.08	840
Auto ignition temperature (°K)	578	845	527
Stoichiometeric 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	1,20,000	42,500
Lower calorific value (kJ/m^3)	50,636	9600	–
Max deflagration speed (m/sec)	1.5	3.5	0.3
Ignition energy (mJ)	0.019	0.02	–
Lower heating value of stoichiometric mixture (kJ/kg)	3396	3399	2930

Table 2
Engine specifications.

Make and model	Kirloskar, TAF 1
General details	4 stroke, air cooled, CI direct injection
Bore/stroke	87.5 mm/110 mm
Compression ratio	17.5:1
Type of combustion chamber	Hemispherical open combustion chamber
Rated output	4.4 kW at 1500 rpm
Injection timing and injection pressure	23 °CA bTDC and 200 bar

2. Experimental setup and methodology

The engine used for the experiment is a single cylinder, four-stroke, air-cooled, naturally aspirated, DI diesel engine, developing a rated power of 4.4 kW at 1500 rpm with a compression ratio of 17.5:1. The diesel is injected at 23° bTDC at a maximum injector opening pressure of 200 bar. The specifications of the engine are given in Table 2. A schematic depiction of the experimental arrangement is shown in Fig. 1. The engine is modified to operate with acetylene by positioning the solenoid operated gas injector on the cylinder head above the inlet valve seating position. The photographic view of injector is shown in Fig. 2. The voltage signal from the infrared sensor is processed by the electronic control unit (ECU) to vary the start of injection and duration of the injector opening. Acetylene is introduced into the engine intake port from the high-pressure cylinder through a double stage gas regulator, where the pressure is reduced to 2 bar. The flow of acetylene is controlled by needle valve and measured by a calibrated gas flow meter. Acetylene enters the injector through a non return valve and flame trap arrangement; the safety devices used to quench the back fire from the engine. Air flow is determined by accurately measuring the pressure drop across a sharp edge orifice of the air surge chamber with the help of a manometer. The diesel flow is measured by noting the time of fixed volume of diesel consumed by the engine. A water-cooled piezoelectric pressure transducer was fixed on the cylinder head to record the pressure variation on the screen of a digital cathode-ray oscilloscope along with the crank angle. Exhaust gas temperature was measured by a chromel–alumel K-type thermocouple. A Qurotech, QRO-401 gas analyzer, measures the exhaust gas constituents (CO, CO_2, HC, and NO_x) and smoke emission was measured by a Bosch smoke meter.

The engine was started using diesel fuel and allowed to warm up. Acetylene fuel was then supplied into intake port through the electronic gas injector. The start of injection and injection duration were varied by adjusting the knob in the electronic control unit (ECU). The start of injection timing is fixed at 5° aTDC, 10° aTDC, and 15° aTDC. Injector opening duration is fixed at 30° (3.3 ms), 60° (6.6 ms), and 90 °CA (9.9 ms) duration. Initially the injector opening time and duration were optimized at a fixed flow rate of the gas. From the experimental results, the optimized timing for injector opening was found to be 5° aTDC and injector duration was 90 °CA (9.9 ms) duration. Experiments were conducted at the optimised fixed injection duration of 90 °CA and injector opening time of 5° aTDC, the gas flow rate was fixed at 110 g/h, 180 g/h, and 240 g/h. For each flow, the load was varied from low load to full load; the quantity of injected diesel fuel was automatically varied by the governor attached to it, which maintained the engine speed at 1500 rpm throughout the experiment. The equivalence ratio varied from 0.71 to 0.63 for corresponding gas flow rate at full load. The energy share ratio at various load for the maximum flow rate of 240 g/h is given in Table 3.