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Dual fuel operation of used transformer oil with acetylene in a DI diesel engine

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ABSTRACT

Used transformer oil (UTO) is a waste oil obtained from power transformers and welding transformers. It possesses considerable heating value and properties similar to diesel fuel. A preliminary investigation on the utilization of the UTO in a single cylinder, four stroke small powered direct injection (DI) diesel engine revealed that at an optimum injection timing of 20°CA the engine exhibited lower nitric oxide (NO) and higher smoke emissions, compared to that of diesel operation. In order to improve the performance and reduce the smoke emission, a dual fuel operation was attempted in the present investigation. Acetylene was inducted as a primary fuel at four different flow rates viz 132 g/h, 198 g/h, 264 g/h and 330 g/h along with the air, to study the combustion, performance and emission behavior of a four-stroke, 4.4 kW diesel engine, while the UTO was injected as pilot fuel with the optimized injection timing. The experimental results were compared with diesel-acetylene dual fuel operation in the same engine. Acetylene aspiration reduced the ignition delay and maximum cylinder pressure by about 3°CA, and 25% respectively at full load in comparison with the sole UTO operation. Higher thermal efficiency and lower exhaust gas were also observed at full load. Smoke was reduced by about 13.7%, in comparison with the UTO operation at full load.

1. Introduction

The industrial revolution and increased population in the last two centuries have resulted in an increased consumption of fossil fuels. Particularly, internal combustion (IC) engines were operated with the petroleum based fuels. This resulted in increased level of carbon dioxide (CO_2) in the environment significantly during the last three decades. CO_2 is one of the greenhouse gases (GHG) that causes global warming.

The other GHG emissions include CO, NO_x, water vapor and methane. Between the years 1970 and 2004, the GHG emissions increased at an average of 1.6% per year, with CO_2 emissions from the use of fossil fuels growing at the rate of 1.9% per year. The total emissions at the end of year 2009 were estimated to be 49.5 GT, and equivalent of carbon dioxide.

The landfills associated with the municipal and industrial wastes, also contribute to the GHG emissions. If the landfills are minimized by converting them into useful energy, then the source of GHG emissions can be reduced to a great extent. Among the industrial wastes, disposed tyres, plastics and oils, and refrigerants are the main contributors of GHG emissions. The used oil, a contributor to industrial waste includes brake fluids, and hydraulic, transmission, motor, crank case, gear box, synthetic and transformer oils. Such oils can be recycled and used in various ways. The first way is to change the original properties of the oil. The second way is to recover the heat energy available in it. Some of the researchers have converted such waste organic substances into useful energy for IC engine applications [1–5].

Among the waste oils, the UTO is the most appropriate, because annually significant amount of UTO is disposed off. Day by day, more numbers of transformers are installed and hence it is expected that the disposal of the UTO will be significant in the current years.

Recently, experimental studies on exploring the possibility of utilizing the UTO as an alternative fuel in a CI engine, were carried out. UTO was used as a fuel in the form of blend and sole fuel. The combustion, performance and emission behavior of a single cylinder, four stroke, DI diesel engine were studied with the UTO diesel blends, and UTO as a sole fuel [6]. The engine experiments were also performed with the different injection timings using UTO as the sole fuel. The different injection timings adopted for the experiments were 18.5–27.5°CA at a regular interval of 1.5°CA. The brake thermal efficiency increased by about 1% compared to the standard injection timing. At the retarded injection timing of 18.5°CA, UTO gave a maximum reduction of NO emission by about 2% at full load,

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Nomenclature

BP	brake power (kW)	NO	nitric oxide
BSEC	brake specific energy consumption (kJ/kW h)	NO_x	oxides of nitrogen
BSFC	brake specific fuel consumption (kg/kW h)	TFC	total fuel consumption
CD	combustion duration	UBHC	unburnt hydrocarbon
CO	carbon monoxide	UTO	used transformer oil
CO_2	carbon dioxide	WPO	waste plastic oil
EGT	exhaust gas temperature	°CA	degrees crank angle

compared to that of theoriginal injection timing. In comparison with original injection timing, an increased level of smoke by about 10.4% was noticed with 18.5°CA. Based on the performance and emissions, the optimum injection timing was found to be 20°CA.

Dual fuel operation in a diesel engine offers a potential reduction of smoke emission with an improved performance at full load for high viscous fuels. Numerous research works on dual fuel in compression ignition (CI) engines have been documented in the recent past [7–10,11]. The research works are pertained to the use of different fuels, methods of induction or injection, varying engine geometry etc.

Experiments were conducted, using LPG in dual fuel mode in a Jatropha fueled diesel engine. The engine showed a reduction in the NO_x and smoke in the entire load range, with higher brake thermal efficiency [12], whereas, hydrogen in the dual fuel mode, with Jatropha as a primary fuel, showed a higher NO emission and brake thermal efficiency, and lower smoke emissions [10]. An experimental study was performed to investigate the effect of pilot injection pressure on the engine performance and exhaust emissions characteristics with biodiesel–CNG dual fuel mode in a diesel engine. The result showed the reduction of some emission and increase of oxides of nitrogen [13]. Sarjovaara et al., used ethanol as a CI engine fuel utilizing dual-fuel combustion technology [14]. Research has also been carried out using methanol as dual fuel with diesel. Experimental results show that at low and medium loads, there is a significant decrease in the dry-soot emission in diesel/methanol dual fuel mode before the diesel, but a little increase at high load [15].

A study was carried out using a timed manifold injection technique, and inducting acetylene in a four-stroke, 4.4 kW diesel engine, with diesel as the primary fuel. Experiments were conducted for various gas flow rates of 110 g/s, 180 g/s and 240 g/s. The performance was found to be closer to that of diesel at full load. The NO_x, HC, and CO emissions decreased due to lean operation, with a marginal increase in smoke emission. It was concluded that acetylene replacement of up to 24% was possible, with a reduction in emission parameters [16]. Table 1 gives the comparison of physical and combustion properties of acetylene, hydrogen, LPG and CNG gas and the properties of diesel.

The main objective of this investigation is to improve the performance, emission and combustion characteristics of UTO fueled diesel engine using acetylene. Acetylene was inducted at different mass flow rates of 132 g/h, 198 g/h, 264 g/h and 330 g/h in suction while the UTO was injected as the pilot fuel. Experiments were conducted on a single cylinder, air cooled, DI, naturally aspirated, diesel engine at a constant speed and variable load conditions. Experiments were also conducted with diesel, UTO and diesel with acetylene at 132 g/h, 198 g/h, 264 g/h and 330 g/h mass flow rate for comparison.

2. Experimentation

The property of the UTO depends upon the service life of the transformer oil. Although the actual service life varies widely depending on the manufacturer, design, quality of assembly, materials used, maintenance, and operating conditions, the expected life of a transformer is about 40 years [17]. The physico chemical properties of the UTO and diesel are compared with those of diesel, and are given in Table 2. The chemical compositions of UTO and diesel have been measured at ITA Lab Pvt. Ltd. Kolkata, India shown in Table 3.

The technical specifications of the test engine are given in Table 4. The engine was coupled to an electrical dynamometer with resistance loading. A schematic diagram of the experimental arrangement is shown in Fig. 1. The engine was modified to work on dual fuel mode, by inducting acetylene in the intake pipe at a proper distance to avoid overheating, in the intake port. The acetylene stored in a high-pressure cylinder at a pressure of 15 bar was reduced to a pressure of 1 bar by a pressure regulator. The flow of acetylene was controlled by a needle valve, and measured by a calibrated gas flow meter. Acetylene enters the injector through a non-return valve, a flash back arrestor and flame trap. Four acetylene flow rates viz 132, 198, 264, 330 g/h, were used in the study. The flow rate was regulated with the help of a regulator. Fig. 2 shows the arrangement of duel fuel operation.

The air flow was measured by finding out the pressure drop across a sharp edge orifice of the air surge chamber and by a sensor. The fuel consumption was determined, by using calibrated burettes with an accuracy of 0.1 CC. A thermocouple in conjunction with a temperature indicator was connected at the exhaust pipe that indicated the exhaust gas temperature. A data acquisition system was used to collect the data from all the sensors and stored for offline calculations. The cylinder pressure was measured using a Kistler pressure transducer (6613A). The transducer was flush mounted in the cylinder head into the combustion chamber. The transducer with sensor voltage is proportional to the pressure. The crank position in degree crank angle was determined by using a crank angle encoder and a sensor mounted on the flywheel. With the help of pressure at every crank angle, ignition delay, heat release rate and combustion duration were determined using empirical relations given that in appropriate section.

The exhaust gas constituents; CO, HC and NO were measured by the AVL gas analyzer (AVL, DiGas444). The smoke density was measured by an AVL smoke meter (AVL437). The HC, CO and NO emissions were measured by flame ionization detector, non-dispersive infra-red analyzer and electrochemical analyzer respectively. Table 5 shows the range, accuracy and uncertainty of instruments used for the investigation.

3. Energy share of acetylene

Table 6 shows the energy share of acetylene required for stable combustion of diesel and the UTO at different loads.

$$\text{Energy share of acetylene} = \frac{m_{C_2}H_2}{m_{C_2H_2} + m_f} \quad (1)$$