Dual Fuel Operation of Used Transformer Oil with Acetylene in a DI Diesel Engine

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***Abstract* – Used transformer oil (UTO) is 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 the engine exhibited lower nitric oxide (NO) and higher smoke emission, compared to that of diesel operation. In order to improve the performance and reduce the smoke emission, dual fuel mode was attempted in the presented investigation. Acetylene was inducted as secondary at three different flow rates along with the air, to study the performance and emission behavior of a four-stroke, 4.4 kW diesel engine, while UTO was injected as the pilot fuel with the optimized injection timing. The acetylene flow rates used in the study are 132 g/h, 198 g/h, 264 g/h and 330 g/h. The experimental results were compared with diesel with acetylene in the dual fuel operation in the same engine. Higher thermal efficiency and reduction in exhaust gas temperature by about 24 % was observed at full load. Smoke was reduced by about 13.7%, in comparison with the UTO operation at full load.**

Index Terms— Acetylene, Emissions, Performance, Used transformer oil

I. INTRODUCTION

The industrial revolution and increased population in the last two centuries have resulted in an increased consumption of fossil fuels. Particularly, internal combustion engines were operated with petroleum fuels that were derived from oil and gas industries. This resulted in increased greenhouse gases (GHG) in the environment significantly during the last three decades. The GHG emissions include carbon dioxide, carbon monoxide, oxides of nitrogen, water vapour and ozone. These gases are the main sources for global warming and ozone depletion. Between the years 1970 and 2004, the GHG emissions increased at an average of 1.6% per year, with carbon dioxide emissions from the use of fossil fuels growing at the rate of 1.9% per year. The total emissions at the end of 2009 were estimated to be 49.5 GT, and equivalent of carbon dioxide. These emissions included carbon dioxide from the burning of fossil fuels, land use, and other industrial sources. The combined effects of fossil fuel depletion, increased energy consumption and regulation on emissions have forced the world to search for alternative fuels that can replace the fossil fuels.

The landfills associated with municipal and industrial waste, 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, waste 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 substances into useful energy for internal combustion engine applications [1]-[5].

Among the waste oils, the UTO is the most appropriate, because annually significant amount of UTO is disposed off. The quantity of the UTO disposed off annually is quite difficult to estimate from the literature and statistics, but day by day more number of transformers are installed and the UTO has to be disposed off. From the data collected by, “Disposal of transformers oil-PISC 2146”, during the years 2006 - 2010, the annual income was 12000-60000 dollars.

Recently, experimental studies on exploring the possibility of utilizing the UTO as an alternative fuel in a CI engine, were carried out, UTO is used as fuel in the form of blend and sole fuel. The combustion, performance and emission behaviour of a single cylinder four stroke, direct injection diesel engine were studied with UTO diesel blends, and UTO as a sole fuel [6].

Engine experiments were also performed with different injection timings using UTO as the sole fuel. The different injection timings adopted for the experiments were 18.5°CA to 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 retarded injection timing of 18.5°CA, UTO gave a maximum reduction of NO emission by about 2% at full load, compared to that of the original 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°bTDC.

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Table I Physical and combustion properties of fuels

Properties	**Acetylene**	**Hydrogen**	LPG	Diesel
Formula	C_2H_2	H_2	C_3H_8 – 30% C_4H_{10}-70%	C_8-C_{20}
Density at 1.01325 bar & and 293 K kg/m_3)	1.092	0.08	0.72	840
Auto-ignition temperature (K)	578	572	485–545	527
Stoichiometric air fuel ratio (kg/kg)	13.2	34.3	15.5	14.5
Flammability limits (volume %)	2.5-81	4–74.5	2.15-9.6	0.6-5.5
Flame speed(m/s)	1.5	3.5	0.38	0.3
Adiabatic flame temperature (K)	2500	2400	2773	2200
Lower calorific value (kJ/kg)	48,225	1,20,000	46300	42,500
Ignition energy (mJ)	0.019	0.02	0.25	-

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Dual fuel operation in a diesel engine offers the potential of reduction in smoke emission with improved performance at full load for high viscous fuels. However, dual fuel operation normally encounters the problem of low efficiency at part loads. This is because of the incomplete combustion of the inducted fuel and air. The use of fuels with wide flammability limits and high flame velocity can reduce this effect. Numerous research works on dual fuel in compression ignition engines have been documented in the recent past [7]-[10]. 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 oxides of nitrogen and smoke in the entire load range, with higher brake thermal efficiency [11], whereas, hydrogen in the dual fuel mode, with jatropha as a primary fuel, showed higher NO emission and brake thermal efficiency, and lower smoke emissions [12].

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 closer to that of diesel at full load. The oxides of nitrogen, hydrocarbon, and carbon monoxide 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 [13].

Table I, gives the comparison of physical and combustion properties of acetylene, hydrogen and LPG gas and the properties of diesel. Acetylene gas is having low density, high auto ignition temperature and very little ignition energy which are close to that of hydrogen. The calorific value of acetylene gas is more than that of diesel fuel and sufficient flammability limits. So acetylene gas can be used as an alternative fuel for diesel engine.

To improve the efficiency and reduce the smoke emission from the UTO fuelled engine, an attempt has been made to run the engine on dual fuel mode where acetylene was inducted at different flow rates as secondary fuel. The mass flow rate of acetylene was varied as 132 g/h, 198 g/h, 264 g/h and 330 g/h. The performance and emission characteristics between diesel, UTO, diesel with acetylene and UTO with acetylene on dual fuel mode operations have been compared and presented in this paper.

II. 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 [14]. The physico chemical properties of the UTO and diesel are compared with those of pure diesel, and are given in Table II. The chemical composition of UTO is given in Table III.

Table II Comparison of UTO and diesel

Property	UTO	Diesel
Density @ 30 °C (g/cc)	0.89	0.84
Gross calorific Value (kJ/kg)	39120	46500
Cetane number	43.6	55
Flash point (°C)	150	50
Fire point (°C)	172	56
Carbon residue (%)	0.02	26
Sulphur content (%)	-	0.045

Table III Chemical composition of UTO and diesel

Description	UTO	Diesel
C (%)	89.95	86.5
H (%)	9.19	13.2
N (%)	0.03	0.18
S (%)	0.35	0.3
O by difference (%)	0.44	0
Water content (%)	Nil	Nil
Ash content (%)	Nil	Nil
Carbon residue (%)	0.02	0.02

Table IV Engine specifications

Parameter	specification
Engine type	DI, Naturally aspirated, air cooled
Number of cylinders	1
Speed (rpm)	1500
Bore (mm)	87.5
Stroke (mm)	110
Rated power (kW) @1500 rpm	4.4
Piston type	Bowl-in-piston
Capacity	661 cm^3
Compression ratio	17.5
Injection timing (°CA bTDC)	20
Type of fuel injection	Pump-line-nozzle injection system
Nozzle type	Multi hole
No. of holes	3

The technical specifications of the test engine are given in Table IV. The engine was coupled to an electrical dynamometer with resistance loading. A schematic diagram of the experimental arrangement is shown in Fig. 2. 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. The acetylene flow rates were varied as 132, 198, 264 and 330 g/h.

The air flow was measured by finding out the pressure drop across a sharp edge orifice of the air surge chamber and by the sensors. 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 element flush mounted in the cylinder head into the combustion chamber. The transducer with sensor voltage is proportional to the cylinder pressure. The crank position sensor was determined by using a crank angle encoder and a sensor mounted on the flywheel.

The NO emission was measured by the AVL gas analyzer (AVL, DiGas444). The smoke density was measured by an AVL smoke meter (AVL437). The NO emission was measured electrochemical analyzer respectively. Table 5 shows the range, accuracy and uncertainty of instruments used for the investigation.

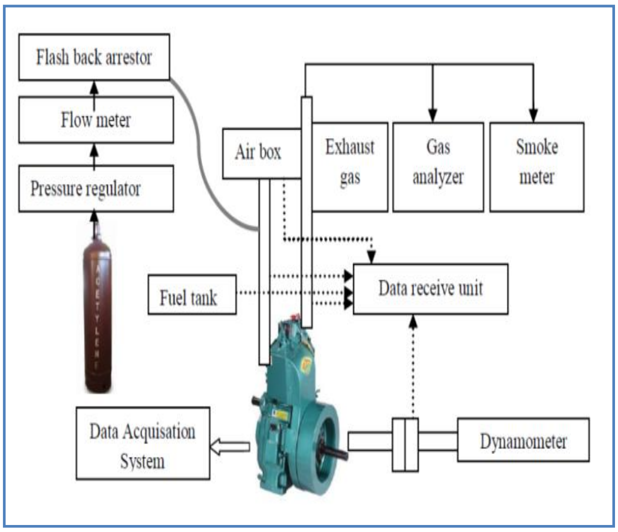

Fig.1. Experimental setup

Table V Range, accuracy and uncertainty of instruments.

Instrument	Range	Accuracy	Uncertainty (%)
Load indicator	250–1000W	±0.1kg	0.2
Temperature indicator	0–900	±1 °C	0.15
Burette	1–30cc	±0.2 cc	1.5
Speed sensor	0–10,000 rpm	±10rpm	±1
Exhaust gas analyzer			
NO	0–5000 ppm	±50ppm	1
Smoke meter	0–100%	±1 %	1
Pressure transducer	0–110bar	±1bar	0.15
Crank angle encoder		±1	1

III. ENERGY SHARE OF ACETYLENE

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

Table VI Energy share of acetylene

Acetylene inducted at different flow rates (g/h)	Load (%)	Energy share of acetylene when diesel as primary fuel	Energy share of acetylene when UTO as primary fuel
132	0	27	29
	25	21	24
	50	17	18
	75	13	13
	100	11	12
198	0	41	38
	25	36	33
	50	29	28
	75	23	23
	100	18	19
264	0	54	62
	25	46	52
	50	39	44
	75	24	39
	100	24	29
330	0	60	80
	25	57	62
	50	50	50
	75	37	44
	100	30	36

From the table, it can be observed that the acetylene required at no load is higher than that required at full load. The increase in the energy share of acetylene at no load may be due to the lower combustion chamber temperatures, and also due to the mixing of primary fuel, with residual gases present inside the engine cylinder from the previous cycle.

IV. RESULTS AND DISCUSSION

A. *PERFORMANCE PARAMETERS*

1. *Brake Thermal Efficiency*

Fig.2. shows the brake thermal efficiency for diesel and the UTO with acetylene, at different flow rates. The brake thermal efficiency for diesel and the UTO is 28.6 and 30.4% respectively at full load. The efficiency in the dual fuel mode at maximum brake power of diesel is found to be 28.5% at 132 g/h, 28.4% at 198 g/h, 28.2% at 264 g/h and 27.8% at 330 g/h of gas flow rates

respectively. For the UTO at different acetylene flow rates of 132 g/h, 198 g/h, 264 g/h and 330 g/h the thermal efficiency is 30.1, 29.9, 29.2 and 28.8% respectively at maximum brake power. By the induction of acetylene, the thermal efficiency increases compared to that of diesel and the UTO operation. This may be due to the high heat release rate, which leads to high cylinder pressure and better utilization of the heat input [15].

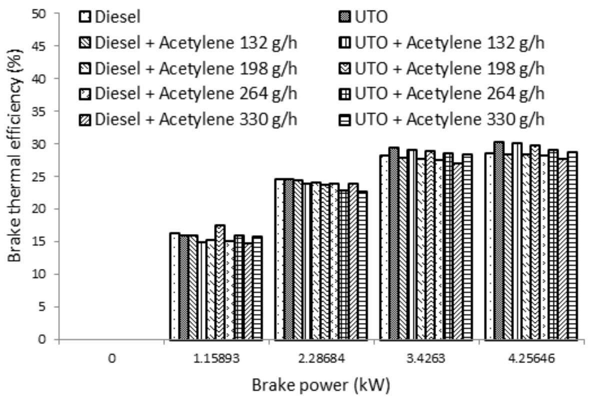

Fig.2. Variation of brake thermal efficiency with brake power.

2) Exhaust Gas Temperature

Fig.3. illustrates the variation of the exhaust gas temperature with brake power for diesel and the UTO at different acetylene flow rates. Diesel exhaust gas temperature is 270^{o}C, whereas for UTO, it is 354^{o}C at the maximum brake power.

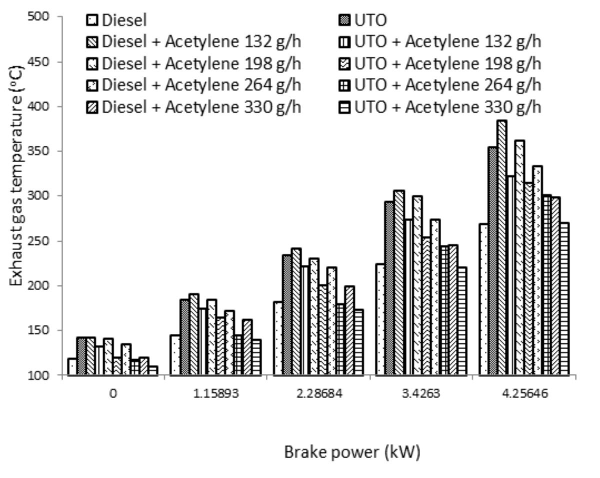

Fig.3. Variation of the exhaust gas temperature with brake power.

The exhaust gas temperature is 384^{o}C at 132 g/h, 362^{o}C at 198 g/h, 333^{o}C at 264 g/h and 299^{o}C at 330 g/h of acetylene flow rates, for diesel operation with acetylene, and for the UTO at different acetylene flow rates of 132 g/h, 198 g/h, 264 g/h and 330 g/h it is 322, 315, 301 and 270^{o}C respectively The decrease in the exhaust gas temperature with increase of acetylene flow rate may be due to the earlier of energy release in the cycle [12].

B. EMISSION PARAMETERS

1. Nitrous Oxide (NO)

The variation of the NO emission with brake power is shown in Fig.4.The NO emission formed in the diesel engine is due to high combustion temperature and the availability of oxygen [16].

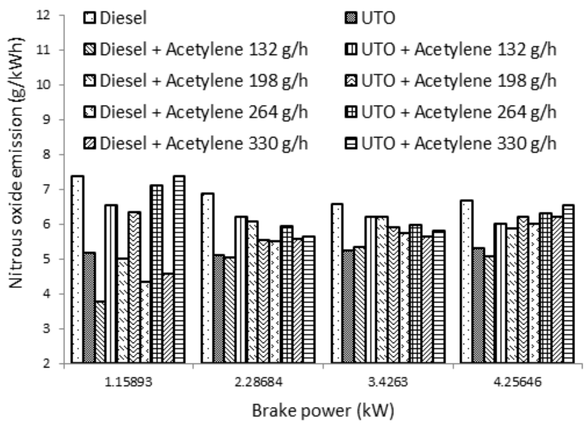

Fig.4. Variation of nitric oxide with brake power.

It can be observed that the UTO emits lower NO emission levels as compared to that of diesel. As the brake power increases the combustion gas temperature increases, which in turn, increase the formation of NO per kWh. In dual fuel operation, with the acetylene induction, the NO emission increases maximum brake power for both diesel and the UTO. This is due to the enhancement of combustion rate, which increases the temperature, and thus increases the NO emission.

2). Smoke Opacity

Fig.5. depicts the variation of smoke emission with diesel and UTO for different acetylene flow rates. It can be observed that the smoke emission for the UTO is significantly higher than that of diesel at maximum power.

The UTO with acetylene at different flow rates produces higher smoke, than diesel with acetylene at different flow rates. But, as the acetylene gas flow rate increases, the smoke opacity decreases, for both the primary fuels at maximum brake power. In the dual fuel mode, mixing of acetylene with the primary fuels leads to better combustion, resulting in lower smoke emission [17].

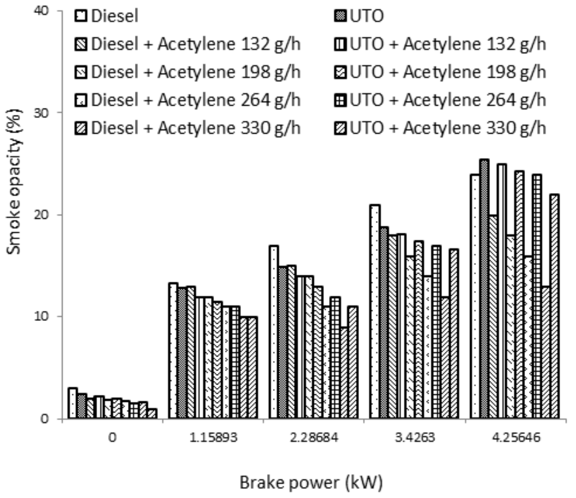

Fig.5. Variation of smoke with brake power.

V. CONCLUSION

A single cylinder, four stroke, air cooled, direct injection diesel engine developing a power of 4.4 kW at the rated speed of 1500 rpm, was operated successfully on diesel and the UTO with acetylene at different flow rates. The following conclusions are drawn based on the experimental results:

1) The UTO results in a higher exhaust temperature compared to that of diesel at maximum brake power. It is reduced in the dual fuel mode by about 23.7% for the UTO at maximum brake power.
2) NO emissions are found to increase by about 9 % and 23 % with sole diesel and the UTO operation with acetylene at different flow rates.
3) The smoke density is higher with the UTO as compared to diesel at maximum brake power. Smoke density decreases by 20.8 and 13.7% for diesel and UTO respectively at maximum brake power.

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