JJMIE

Volume 3, Number 2, June. 2009
ISSN 1995-6665
Pages 125 - 130

Jordan Journal of Mechanical and Industrial Engineering

Performance and Emission of Acetylene-Aspirated Diesel Engine

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Abstract

Studies reveal that acetylene gas produced from lime stone ($CaCO_3$) is renewable in nature and exhibits similar properties to those of hydrogen. In the present work, experimental investigation has been carried out on a single cylinder, direct injection, and compression ignition engine run on dual fuel mode with diesel as an injected primary fuel and acetylene inducted as secondary gaseous fuel to obtain data on engine performance and exhaust emissions. Fixed quantity of acetylene was aspirated, and readings were taken at various loads. Dual fuel operation resulted in lesser thermal efficiency when compared to neat diesel operation. Acetylene aspiration reduces smoke, soot formation, and exhaust temperature; and increases NOx emission. The emission of carbon mono oxide and carbon dioxide was lower under all operating conditions when compared to diesel operation.

Keywords: Dual Fuel Engine; Aspiration; Ignition Delay

1. Introduuction

In the present context, the world is confronted with the twin crisis of fossil fuel depletion and environmental degradation. Conventional hydrocarbon fuels used by internal combustion engines, which continue to dominate many fields like transportation, agriculture, and power generation leads to pollutants like HC (hydrocarbons), SOx (sulphur oxides), and particulates which are highly harmful to human health [1-2]. CO_2 from Greenhouse gas increases global warming. This crisis has stimulated active research interest in non-petroleum, a renewable and non-polluting fuel, which has to promise a harmonious correlation with sustainable development, energy conservation, efficiency, and environmental preservation.

Promising alternate fuels for internal combustion engines are natural gas, liquefied petroleum gas (LPG), hydrogen, acetylene, producer gas, alcohols, and vegetable oils. Among these fuels, there has been a considerable effort in the world to develop and introduce alternative gaseous fuels to replace conventional fuel by partial replacement or by total replacement. Many of the gaseous fuels can be obtained from renewable sources. They have a high self-ignition temperature; and hence are excellent spark ignition engine fuels. They cannot be used directly in diesel engines.

However, Diesel engines 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 air intake, 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 gaseous fuel occurs by flame propagation similar to SI engine combustion. Thus dual fuel engine combines the features of both SI and CI engine in a complex manner. The dual fuel mode of operation leads to smoother operation; lower smoke emission and the thermal efficiency are almost comparable to the diesel version at medium and at high loads. However, major drawback with these engines are higher NO*x* emissions, poor part load performance, and higher ignition delay with certain gases like biogas and rough engine operation near full load due to high rate of combustion [3].

Karim [4] has done extensive research to understand the nature of the combustion process in the dual fuel. He has used variety of gases like methane, ethane, propane, butane, hydrogen, ethylene, and acetylene as primary fuel. It is generally accepted that performance of dual fuel engines, irrespective of the type of gaseous fuel employed, is better at medium and high loads. However, it has been reported that at low outputs efficiency is slightly inferior to the base line diesel engine. Researchers have stressed the need to control the quantity of both pilot and gaseous fuel depending on load conditions for better performance.

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Haragopala Rao et al. [5] investigated performance of diesel engine in dual fuel mode by inducting small quantity of hydrogen diesel. At higher loads, the efficiencies attained are close to diesel with notable reduction in smoke, soot formation, and exhaust temperature. NOx emissions are increased with increase in peak pressure.

Gunea, Razavi, and Karim [6] conducted experiments on a four-stroke, single cylinder, direct injection diesel engine fueled with natural gas. Tests were conducted with diesel as the pilot fuel having different cetane numbers in order to find the effects of pilot fuel quality on ignition delay. They concluded that 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 performance of engines using low cetane value gaseous fuel.

Das [7] suggested that hydrogen could be used in both SI engine and 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), low pressure direct injection (LPDI), and high pressure direct injection (HPDI); and suggested to use manifold injection method for induction of gases to avoid undesirable combustion phenomenon (back fire) and rapid rate of pressure rise.

Wulff et al. [8] used 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 better than that of fossil fuels. The combustion was under lower temperature, and this prolonged the life expectancy of the engine.

Ashok Kumar et al. [9] studied suitability of acetylene in SI engine along with EGR, and reported that emission got drastically reduced on par with hydrogen engine with marginal increase in thermal efficiency.

Swami Nathan et al. [10] had conducted experiment in CI engine by using acetylene as a fuel in HCCI mode along with preheated take charge heating. The efficiencies achieved were very near to diesel. NO*x* and smoke level were reduced drastically. However, HC level was increased.

2. Acetylene Production and Properties

Acetylene is chosen as an alternative fuel in the present study. Since it is renewable in nature, it seems to posses similar properties of hydrogen (table 1) and can be used as an alternative fuel in internal combustion engines in competition with hydrogen fuel. Acetylene was discovered in 1836 in England by E.Davy. It is a colorless gas with a garlic smell produced from calcium carbonate (lime stone), which is abundant and renewable in nature in a lime kiln at 825°C which yields calcium oxide (lime) by liberating CO_2. Calcium oxide is heated along with coke in electric furnace to produce calcium carbide. Finally calcium carbide is hydrolyzed to liberate acetylene.

Acetylene has a very wide flammability range, and minimum ignition energy is required for ignition since the engine can run in lean mode with higher specific heat ratios leading to increased thermal efficiency. It has higher flame speed and hence faster energy release. And at stoichiometeric mixtures, acetylene engines could closely approach thermodynamically ideal engine cycle. High self-ignition temperature of acetylene allows larger compression ratios than diesel engines do. Due to lower quenching distance similar to hydrogen, flame cannot be quenched easily in the combustion chamber. Due to lower ignition energy, high flame speed, wide flammability limits, and short quenching distance lead to premature ignition and also lead to undesirable combustion phenomenon called knock, the primary problems that have to be encountered in operation of acetylene engines.

Table 1. Physical and Combustion Properties of fuels.

Properties	Acetylene	Hydrogen	Diesel
Formula	C_2H_2	H_2	$C_8 – C_{20}$
Density kg/m^3 (At 1 atm & 20 °C)	1.092	0.08	840
Auto ignition temperature (°C)	305	572	257
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 (Equivalent ratio)	0.3 – 9.6	0.1 – 6.9	------
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 Stoichiometeric mixture (kJ/kg)	3396	3399	2930

In the present work, a single cylinder, direct injection air, and cooled diesel engine were modified to work in the dual fuel mode with acetylene as the secondary inducted fuel and diesel as the primary injected fuel. The performance and emission at different output with fixed quantity of aspirating acetylene are presented in this work.

3. Experimental Setup and Methodology

A single cylinder four stroke air cooled naturally aspirated direct injection diesel engine developing 4.4 kW at 1500 rpm, fueled with diesel fuel was utilized for acetylene dual fuel operation. The specifications of the engine are given in table 2. A Schematic of the experimental arrangement is shown in Figure 1.

Acetylene was introduced into intake manifold at a point closer to the intake valve by a non-return valve arrangement through a flame trap. The flow of acetylene was controlled by needle valve and was measured by a calibrated gas flow meter. Air flow was determined by measuring the pressure drop accurately across a sharp edge orifice of the air surge chamber with the help of a manometer. The diesel flow was 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 cathode –ray oscilloscope along with crank angle encoder. Chromel-alumel K-type thermocouple was used for exhaust gas temperature measurement. The exhaust gas constituents CO, CO_2, HC, NO*x*, and smoke were measured by a Qurotech QRO-401 gas analyzer, and Bosch smoke meter was used for the measurement of smoke.

Table 2. Engine Specification.

Make and model	Kirloskar, TAF 1
Type	4 stroke , air cooled
General details	Four stroke, compression ignition, 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 °C btdc and 200 bar

The engine was started using diesel fuel; and was allowed to warm up. Acetylene fuel was then supplied into intake manifold at fixed flow rate of 3lpm through a gas flow meter, which is at equivalence of 0.13 ratio. The load on the engine was increased. The quantity of injected diesel fuel was automatically varied by the governor attached to it, which maintains the engine speed at 1500 rpm throughout the experiment.

4. Error Analysis

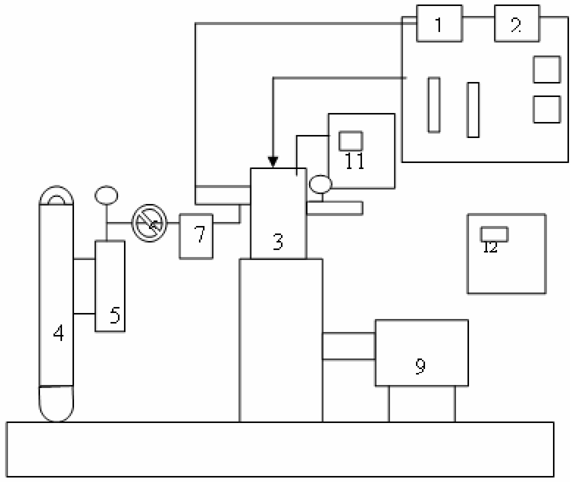
Errors and uncertainties in the experiments may result from instrument selection, condition, calibration, environment, observation, reading, and test planning. Uncertainty analysis is needed to prove the accuracy of the experiments. An uncertainty analysis was performed using the method described by J.P. Holman [11].

Percentage uncertainties of various parameters like total fuel consumption, brake power; specific fuel consumption, and brake thermal efficiency were calculated using the percentage uncertainties of various instruments given in Table 3.

Total percentage uncertainty of this experiment == Square root of{(uncertainty of TFC)^2 +(uncertainty of brake power)^2 +(uncertainty of specific fuel consumption)^2 +(uncertainty of brake thermal efficiency)^2 +(uncertainty of CO)^2 +(uncertainty of CO_2)^2 +(uncertainty of unburned hydrocarbon)^2 +(uncertainty of NO*x*)^2 +(uncertainty of smoke number)^2 +(uncertainty of Exhaust gas temperature)^2 +(uncertainty of pressure pickup)^2}

Total percentage uncertainty of this experiment = square root of $\{(1)^2 + (0.2)^2 + (1)^2 + (1)^2 + (0.2)^2 + (0.15)^2 + (0.2)^2 + (0.2)^2 + (1)^2 + (0.15)^2 + (1)^2\} = \pm 3$ %

Using the calculation procedure, the total uncertainty for the whole experiment is obtained to be ± 3 %.



LEGENDS.
1. Air flow meter , 2. Diesel fuel tank ,3. Diesel engine
4. Acetylene generator, 5. Flame trap , 6. Flow control valve
7. Gas flow meter , 8. Intake manifold , 9. Dynamometer.
10. Control panel , 11.Oscilloscope, 12.Gas analyser.

Figure 1 Schematic of the experimental setup.

5. Result and Discussion

In the present work, acetylene gas was aspirated in the intake manifold in CI engine with diesel being the ignition source. The performance and emission characteristics are compared with baseline diesel operation.

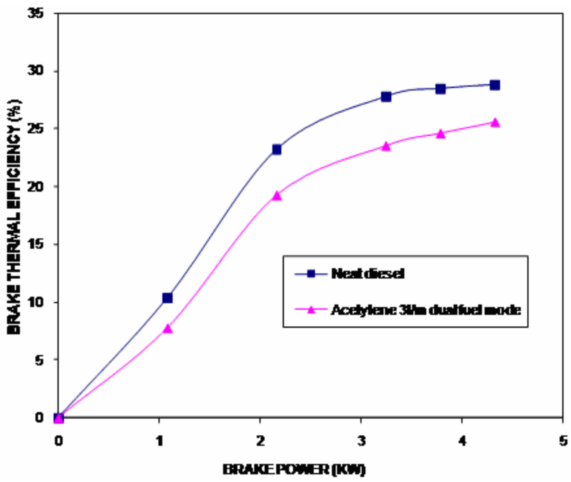


Figure 2. Variation of brake thermal efficiency with brake power.

5.1. Brake Thermal Efficiency

The variation of brake thermal efficiency with brake power is shown in figure 2.The brake thermal efficiency in induction technique is found to be 11.23% lower, when compared with neat diesel fuel of 28.84% efficiency at full load. In general, it may be noted that in the dual-fuel engines, the thermal efficiency decreases at low loads and

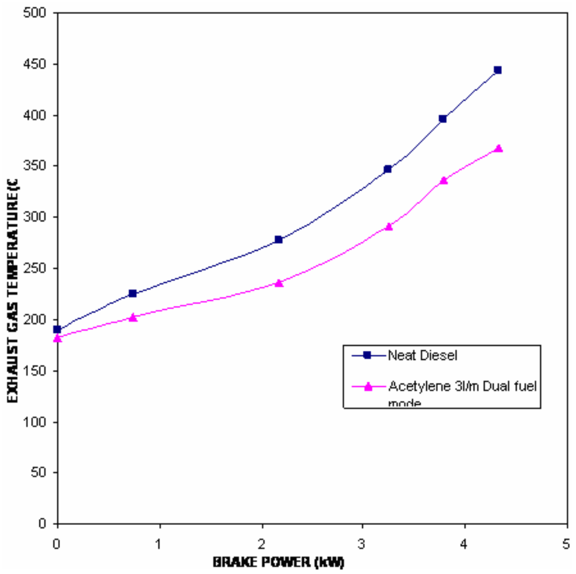


Figure 3. Variation of exhaust gas temperature with brake power.

increases above the base line at full load operation with addition of inducted fuels like LPG, CNG etc., [3]. However, acetylene, because of its wide flammability limit and high combustion rate, is an exception where efficiency is lower throughout the load spectrum. With high loads, the brake thermal efficiency falls because of high diffusion rate and faster energy release .This confirms that faster energy release occurs with acetylene introduction; and is also supported by the observed increase in maximum cycle pressure.

At partial loads with a small quantity of injected fuel, the flame fronts propagating from ignition centers do not extend to all the regions of the combustion chamber and leaves some of the homogeneously dispersed acetylene unburnt, causing low thermal efficiency at low loads.

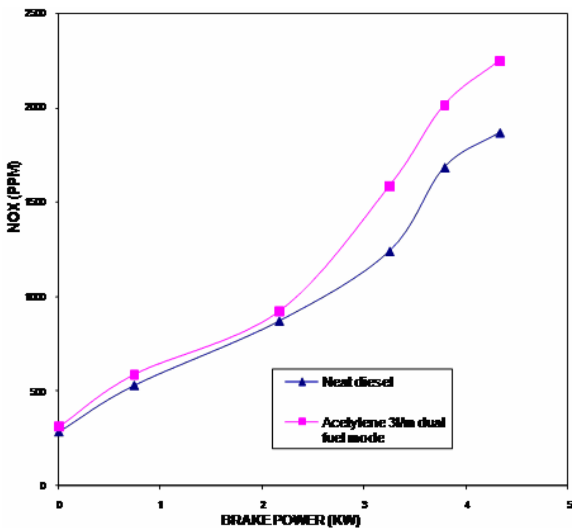


Figure 4. Variation of NO*x* with brake power.

5.2. Exhaust Gas Temperature

The exhaust gas temperature at full load, depicted in figure 3, reaches 368°C in acetylene induction technique and 444°C in the case of base line diesel operation. Acetylene induction decreased the exhaust gas temperature at all loads, indicating the advancement of energy release in the cycle and higher flame speed. Cylinder pressure diagram confirmed this, in which maximum pressure was observed to occur earlier in the cycle when acetylene was introduced along with the intake air.

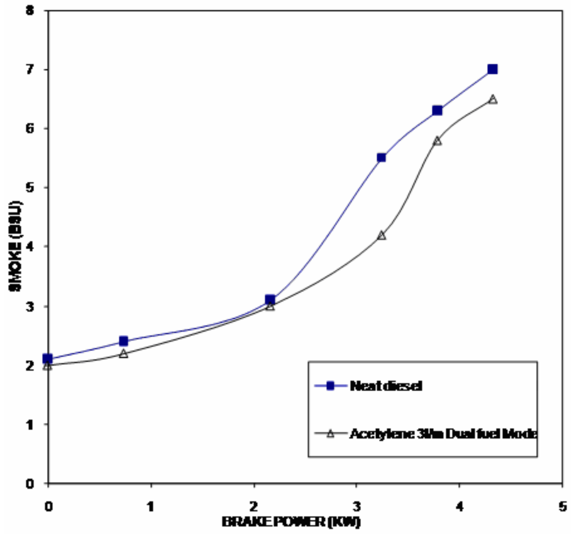


Figure 5. Variation of smoke with brake power.

5.3. Oxides of Nitrogen (NO_x)

It can be observed from figure 4 that NO*x* emission is 1866 ppm at maximum output with neat diesel fuel operation. In dual fuel operation with acetylene induction, NO*x* emission is increased by 17% when compared to baseline diesel operation. According to zeldovich mechanism model, the formation of NO*x* is attributed to the reaction temperature, reaction duration, and the availability of oxygen [1]. When acetylene is inducted, increase in NO*x* may be attributed to the increased peak cycle temperature level because of faster energy release, which is confirmed by increased peak cycle pressure.

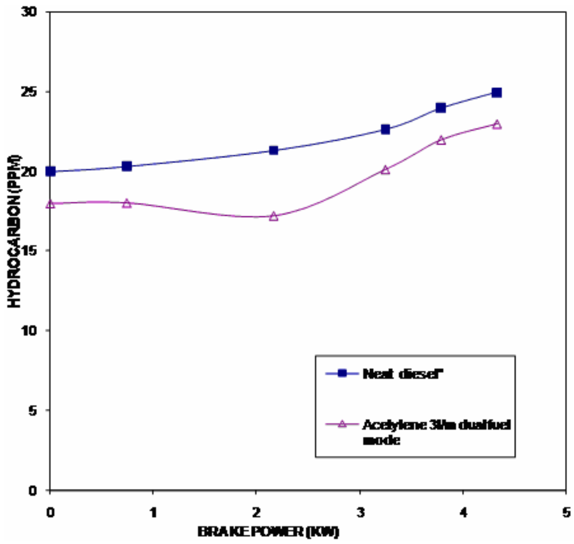


Figure 6. Variation of hydrocarbon with brake power.

5.4. Smoke

The variation of smoke level with brake power is shown in figure 5. The exact mechanism of smoke formation is still unknown. Generally speaking, smoke is formed by the pyrolysis of HC in the fuel rich zone, mainly under load conditions. In diesel engines operated with heterogeneous mixtures, most of the smoke is formed in the diffusion flame. The amount of smoke present in the exhaust gas depends on the mode of mixture formation. The combustion processes and quantity of fuel injected occur before ignition [2]. The smoke level increases with increase in diesel flow rate, and at full load it is 7 BSU in case of diesel fuel operation. Dual-fuel operation with any gaseous fuel proved to be a potential way of reducing the smoke density as compared to diesel operation. A reduction in smoke level is noticed. The smoke level is reduced by 14% in induction technique at full load when compared to baseline diesel operation. This may be attributed to the fact that combustion of acetylene-diesel fuel is faster, contributing to complete combustion, and is also due to triple bond in acetylene which is unstable.

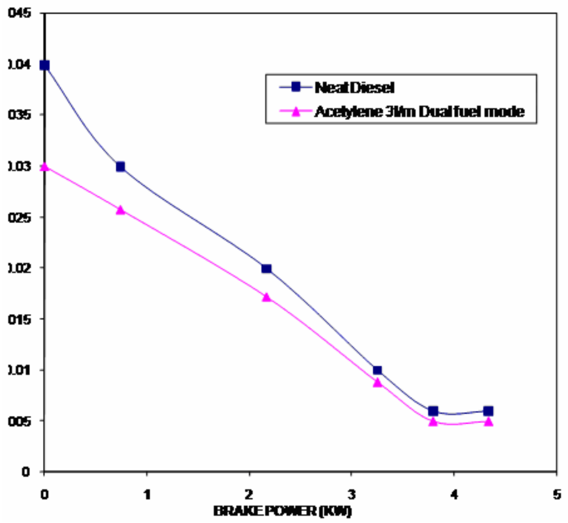


Figure 7.Variation of carbon monoxide with brake power.

5.5. Hydrocarbon Emissions

Figure 6 depicts the variation of hydrocarbon emissions with load. The HC emissions are 25 ppm in baseline diesel operation and 23 ppm when acetylene is aspirated at full load in induction technique. The reduction in HC emission in the case of dual fuel mode is due to the higher burning velocity of acetylene which enhances the burning rate.

5.6. Carbon Monoxide Emissions

The variation of carbon monoxide emissions with load exhibits similar trend of HC. This is shown in figure 7. The CO emissions are lower compared to the base line diesel operation. The maximum is 0.01% by volume in induction technique followed by base line diesel of 0.02% at full load. The CO emissions are lower due to the complete burning of the fuel, and is also due to the reduction in the overall C/H ratio of total fuel inducted into the engine.

5.7. Carbon Dioxide Emissions

The CO_2 emissions are lower compared to the base line diesel, the minimum being 8.7% by volume at full load in acetylene induction technique followed by 9.0% by volume in baseline diesel operation, as shown in figure 8. The CO_2 emission of acetylene is lowered because of lower hydrogen to carbon ratio.

5.8. Pressure Crank Angle Diagram

Figure 9 portrays the variation of cylinder pressure with crank angle. The peak pressure is about 72.1 bar at maximum power with base line diesel operation. Peak pressure is further increased in dual fuel operation with acetylene induction at maximum load. In dual fuel engine, the trend of increase in peak pressure is due to increased ignition delay and rapidity of combustion. There is an increase to about 3. bar when acetylene is inducted. The peak pressure for acetylene inducted dual fuel engine is advanced by 5°CA compared to peak pressure of diesel at full load. The advance in peak pressure for acetylene combustion is perhaps due to instantaneous combustion of acetylene as compared to diesel. The rate of pressure rise is also high for acetylene operated dual fuel engine, compared to diesel operated engine due to instantaneous combustion of acetylene fuel.

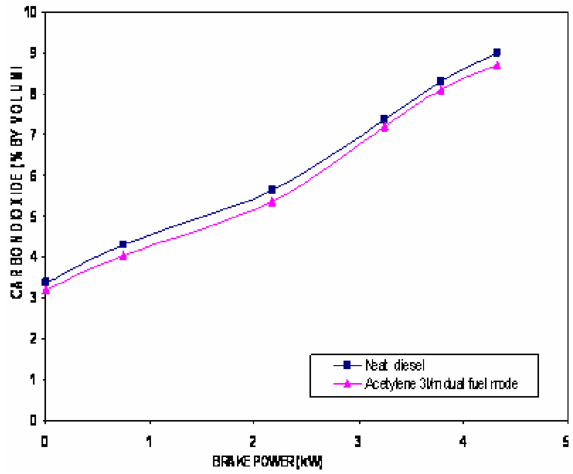


Figure 8. Variation of carbon dioxide with brake power.

5.9. Heat Release Rate

Figure 10 indicates the rate of heat release for acetylene operated dual fuel engine at 3 lpm flow rate, and diesel engine at full load as well. The burning rate diagram can be divided into three distinct phase, namely ignition delay, premixed combustion phase, mixing controlled combustion phase, and late combustion phase [1]. The heat release rate for acetylene aspiration shows distinct characteristics of explosive, premixed type combustion followed by a brief second phase dip in burning rate and then a rapid increase during the third phase of combustion of the gas mostly diffusion type of combustion.

6. Conclusions

Experiments were conducted to study the performance and emission characteristics of DI diesel engine in dual fuel mode of operation by aspirating acetylene gas in the inlet manifold for various loads, with diesel as an ignition source. The following conclusions have been arrived at, based on the experimental results:

- Brake thermal efficiency in dual fuel mode is lower than diesel operation at full load, as a result of continuous induction of acetylene in the intake.

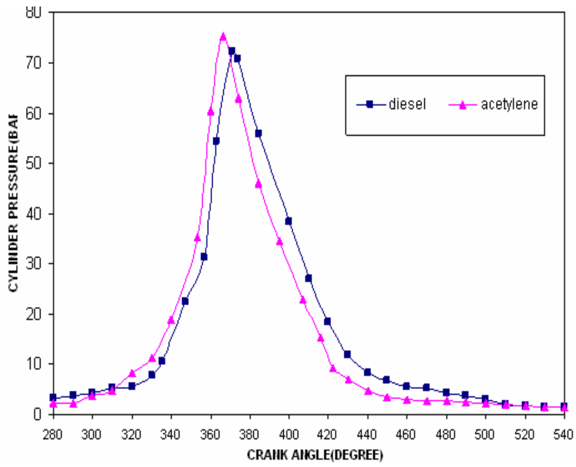


Figure 9.Variation of cylinder pressure with crank angle.

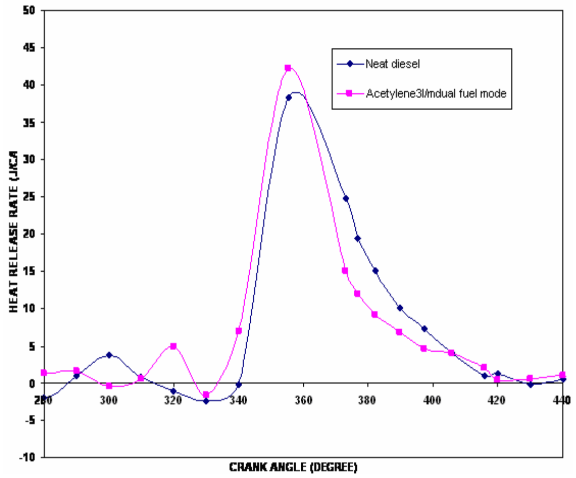


Figure 10. Variation of heat release rate with crank angle .

- Dual fuel operation of acetylene exhibits lower exhaust gas temperature of about 76°C as compared to diesel operation.
- There is an appreciable reduction in smoke level. It dropped from 7 to 6.50 BSU when compared to neat diesel operation.
- A perceivable reduction in HC, CO and CO2 emissions was observed with acetylene operated dual fuel mode. The reduction in HC and CO2 emissions at maximum load is of 8 % and 3% respectively when compared to diesel operation.
- There is an increase in the peak cylinder pressure and rate of pressure rise, when gas is inducted.

On the whole, it is concluded that acetylene induction resulted in a slight decrease in thermal efficiency, when compared to baseline diesel operation. Exhaust temperature, HC, CO, CO_2 and smoke emissions were less than baseline diesel operation. However, a significant increase in the NO_x emission is observed in the exhaust. To conclude, we state that acetylene would compete with hydrogen in near future for use of alternative fuel in internal combustion engine. By applying certain techniques like TMI, TPI of gas to get increased efficiency and reduced NOx emissions level.

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