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DEVELOPMENT, PERFORMANCE AND COMBUSTION OF DUAL FUEL ENGINES: A STUDY

Chandra Prakash Sigar*

ABSTRACT

Dual fuel engines utilize two fuels (one in gaseous form and the other in liquid form) for their working. In dual fuel engine, the primary fuel (in gaseous form) is mixed with air outside the cylinder before it is inducted into the cylinder. After induction in the cylinder, the mixture of gas and air is compressed during the compression stroke and before the end of the stroke, near TDC, a pilot quantity (about 20%) of liquid fuel (normally diesel) is injected to initiate combustion.

Keywords: *Dual Fuel Engines, Gaseous Form, Liquid Form, Compression Stroke, Combustion.*

Introduction

The combustion process of dual fuel engine lies between that of the Spark Ignition (SI) engine and the Compression Ignition (CI) engine.

Changing the amount of primary gaseous fuel added to inlet manifold normally controls the power output of the engine. Most of the advantages of the CI engines can be obtained when they work on dual fuel mode. The possibility of existing CI engines to run on dual fuel, without any major modifications, and the flexibility of duel fuel engines to switch back to pure diesel mode as and when required, are two important advantages.

The main problem associated with dual fuel engines is poor utilization of the inducted fuel at light loads and loss of combustion control at high loads that is commonly termed as the onset of knock. The longer burning rate of the gas allows more time for heat transfer to the end gas, resulting in tendency to knock. The use of gas (primary fuel) in CI engines involves an evolution of two stages of ignition and combustion processes resulting in three types of knock: diesel knock, spark knock, and erratic knock due to spontaneous ignition of the primary fuel. The dual fuel engine knock is seen to depend on engine speed and load, combustion temperature, pilot fuel/gas ratio and turbulence in the cylinder. The operating conditions improve by increasing pilot fuel and reducing the primary fuel.

Dual fuel operation normally poses problems of low efficiency when the concentration of the inducted pilot fuel is low. This is because the lean mixture of the inducted fuel with the air does not burn well. Use of gaseous fuels with wide flammability limits and high flame velocity can overcome such problems in the dual fuel engine. Since the vegetable oils produce high smoke emissions, dual fuel approach can be a viable option for improving their performance.

Development

Early in the development of diesel engine, the idea of operating on gaseous fuels with pilot ignition was recognized. Dr. Diesel in 1894 had projected that illuminating gas injected with atomized drops of kerosene through a nozzle stops misfiring. In 1898, a patent granted to him claims 'a combustion process in which the compression temperature of the working mixture does not reach its own ignition temperature, but the ignition temperature of a second easier ignited fuel was reached or exceeded, so

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* Associate Professor, B.B.D. Government College, Chimanpura, Jaipur, Rajasthan, India.

that an injection of this later starts the combustion of the mixture'. He stated that the quantity of the gaseous fuel supplied to the engine as the main fuel was limited to small proportions due to loss of combustion control. In the year 1932, Heidelberg of U.S.A. claimed a method of operating a diesel engine comprising compressing in the engine cylinder a mixture of air and fuel to a temperature less than its ignition point and its ignition through a liquid fuel. Until 1935 commercial units of dual fuel engines were not actually put into operation. National Gas and Oil Engines co. LTD. built the first vertical gas-diesel engine in England in 1940. In the United States, Worthing Pump and Machinery Co., Buffalo, N.Y., was the first to develop and research the naturally aspirated dual fuel engine to operate with low-pressure gas induction and pilot oil ignition in 1943. The same company had developed first turbo charged dual fuel engine in 1945.

Many researchers have reported utilization of natural gas and hydrogen. Germans contemplated the use of dual fuel system for aircraft engines during 1939-45 war, in so called ring process. They used petrol as the main fuel and a complex glycol alleged to have cetane number of 180 as the pilot fuel.

Boyer in 1943 made projections explaining the future of dual fuel engines.

Performance, Combustion and Emission Characteristics

Experimental investigations by Poonia revealed that a low injector needle lift pressure (150 bar) results in severe knocking at high loads, whereas at loads less than 80%, an improvement in the brake thermal efficiency up to 3% can be obtained by reducing the injector pressure from 170 bar to 150 bar. Injection advance had lesser effect as compared to injector opening pressure on performance. Use of low intake temperature and smaller pilot quantities were needed to reduce the knock.

Elliot and Davis have studied the effect of gas air mixture strength on the performance of dual fuel engine. They observed that when the gaseous fuel quantity in the intake air was below a certain limit, the amount of gas reacting with pilot fuel was increased. If the concentration of the gas is below the lower flammability limits, the gas does not react completely with air unless the source of ignition is very intense.

Nwafor examined the effect of advanced injection timing on the performance of natural gas used as primary fuel in dual fuel combustion. By advancing the injection timing (the standard being 30º BTDC) by 3.5º (i.e., 33.5º BTDC), he found that it compensated the longer ignition delay and slower burning rate of natural gas. The engine ran smoothly on this timing but seemed to incur penalty on fuel consumption especially at high loads.

Simonson concluded that the intake air restriction, higher injection rates, advanced injection timing, pre-heating of intake air charge and increase in pilot diesel gave higher thermal efficiency.

Karim suggested that pilot fuel quantity is one of the important variables controlling the performance of dual fuel engines at light loads. Any measure that can lower the effective lean flammability limit of the cylinder charge and promote flame propagation will improve part load performance. One of the measures used to improve the low load performance is intake air throttling.

Jajoo found that the instant at which the fuel starts to burn in combustion chamber considerably depends upon the timing of injection of fuel. The first appearance of the actual flame has a big effect upon gas pressure and temperature for rest of the cycle. In diesel engine the proportion of diffusion burning is also increased because of retarded injection timing.

Retarding the injection timing from the specified one causes considerable deterioration in the engine performance. In dual fuel engines, advancing the injection timing of the pilot fuel leads to an increase in its ignition delay resulting in greater dispersion and vaporization of the pilot fuel. This adversely affects the lower limit of flammability of gaseous fuel. Retarding the pilot fuel timing at full loads reduces the engine knock.

Schumacher investigating a diesel biogas dual fuel engine found that the effect of fuel cooling at the injection nozzle is also considerably reduced leading to an appreciable increase in thermal stress at the nozzle. The self-cleaning effect of the spray hole is furthermore diminished. Both effects lead to an increase in nozzle choking. This is because of the low rates of pilot diesel flow as compared to the normal diesel flow in a diesel engine.

Prasad used biogas and diesel and found that at 50% biogas substitution, the thermal efficiency is comparable to that of pure diesel cycle operation.

Prabhukumar concluded that knock limited power output in a dual fuel engine and percentage diesel substitution by LPG is higher as compared to hydrogen diesel dual fuel engine due to its faster burning rate.

Use of LPG as an Alternative Fuel

A mixture of gaseous petroleum compounds, principally butane and propane, together with smaller quantities of similar gases, is known as Liquefied Petroleum Gas (LPG). It is chemically similar to gasoline, since it consists of a mixture of compounds of hydrogen and carbon, but it is highly volatile. LPG exists in the form of vapors at normal temperatures and atmospheric pressure, but when stored in containers under high pressure it assumes liquefied state. When stored in containers it is under tremendous pressure (approximately 13.8 bars at 38 °C) and needs extremely strong tanks for storage.

LPG is already used as an alternative fuel for internal combustion engines in the automotive sector. It is becoming more widely used as an increasing number of automotive vehicles are being fitted with the equipment required to make use of it. Besides being low in cost, LPG has the advantage of having a high-octane value (93 for pure butane; 100 for propane). Since it is a dry gas, LPG does not create carbon in an engine, and does not cause dilution of engine oil. As a result, maintenance and internal parts replacement is reduced. Oil changes are also less frequent because it is a cleaner burning fuel than gasoline. Other advantages are, easy cold weather starting, lack of exhaust order, and elimination of evaporation.

LPG can be used in IC engines at relatively high compression ratios without knock, lesser volumetric efficiency loss as compared to other gaseous fuels, and relatively low emissions of hydrocarbons and carbon monoxide as compared to gasoline are other benefits. LPG is free of lead and has very low sulfur content. It is felt that, use of LPG can enhance the combustion rate of vegetable oils and reduce emissions because of its high flame velocity.

Use of Vegetable Oils as Alternative Fuel

Vegetable oils are being considered world over as one of the most promising candidates for alternative to diesel fuel. The reasons are their renewable nature, ease of production and their suitability to diesel engines. Vegetable oils are also referred to as bio-fuels. Several vegetable oils are being examined as fuels in different regions of the world. In India, edible oils have been excluded from being used as fuel due to their shortage even now. Inedible (non edible) vegetable oils can be a valuable supplemental source of energy for India. The country is blessed with a largely tropical climate, with a wide variety of vegetation, including oil-seed bearing trees.

Studies have revealed that some of these oils can directly substitute diesel in electricity generating sets and irrigation pump sets (which need no modifications). Such oils when used are commonly known as 'Straight Vegetable Oils' (SVO). After being extracted in expellers they are only filtered to remove suspended solid particulates.

The alternative diesel fuels must be technically and environmentally acceptable and economically competitive. From the viewpoint of these requirements, triglycerides (vegetable oils) and their derivatives are considered as viable alternatives for diesel fuels. They are biodegradable and renewable fuels. They have reasonably high cetane number. The flashpoint of vegetable oils is high and hence it is safe to use them. Vegetable oils typically have large molecules, with carbon, hydrogen and oxygen being present.

Vegetable oils have higher molecular mass and viscosity. And contrary to fossil fuels, these are free from sulfur and heavy metals. The problems with substituting triglycerides for diesel fuels are mostly associated with their high viscosity, low volatility and polyunsaturated character. Developing vegetable oil derivatives that approximate the properties and performance of hydrocarbon based diesel fuels can mitigate these problems. Some of the methods to make them compatible with CI engines are; pyrolysis, micro-emulsification, blending and transesterification. Amongst these methods, blending and transesterification are the most viable and commonly used techniques.

Vegetable Oil in Diesel Engines

In 1900, Dr. Rudolf Diesel showed at the World Exhibition in Paris that his diesel engine was capable of running on a variety of fuels, including peanut oil. Later in 1911, Dr. Diesel also said that the diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries that use it. From the very beginning the diesel engine concept has been associated with vegetable oils as well as the original liquid coal tar and later the petroleum derivatives. Initially, diesel engines were designed and developed to be of a dual fuel nature. It is believed KHD Deutz Engine Manufacturers, Germany, warranted their original engines for operation with vegetable oils.

A research project, Advanced Combustion Research for Energy from Vegetable Oils (ACREVO) was conducted by a consortium of eight European research institutes and universities. The final report of the project states, "the flames have been studied with particular regard to stable gases (CO, CO_2, NO_x, O_2 and hydrocarbons), temperature, soot formation and burn out at different rape seed oil preheating temperature. All the data have been compared to those obtained from a classic diesel oil under the same burning.... The overall combustion performances of the rapeseed oil are very satisfactory in comparison with the diesel fuel, while the rapeseed produces almost 40% less soot than diesel fuel.... It has been established that an addition of 9% ethyl alcohol causes reduction in the inlet oil temperature from 150° C to 80° C. Moreover, the combustion of the emulsion produces less soot at the exhaust; the amount is almost one half less than that produced by the rapeseed oil". Many researchers have concluded that coking is a potential serious problem with unmodified vegetable oil fuels.

In a summary of 22 short term engine tests conducted at 12 locations worldwide in which vegetable oil was compared to diesel as a fuel, peak engine power on the vegetable oil fuels ranged from 91 to 109% of that produced when the same engine was operated with diesel fuel. In these tests, 16 of the 22 reported peak power equal to or exceeding that when the engines were operated on diesel. Fuel consumption was generally slightly higher reflecting the reduced energy content of the vegetable oil. Thermal efficiencies are also generally reported to be slightly higher than for diesel fuel.

Goering studied the characteristic properties of eleven vegetable oils to determine which oils would be best suited for use as an alternative fuel source. Of the eleven oils tested, corn, rapeseed, sesame, cottonseed, and soybean oils had the most favorable fuel properties.

Bruwer studied the use of sunflower seed oil as a renewable energy source. When operating tractors with 100% sunflower oil instead of diesel fuel, an eight percent power loss occurred after 1000 hours of operation. The power loss was corrected by replacing the fuel injectors and injector pump. After 1300 hours of operation, the carbon deposits in the engine were reported to be equivalent to an engine fueled with 100% diesel except for the injector tips, which exhibited excessive carbon build-up.

Conclusion

The present work was mainly directed towards experimental and theoretical investigations on a single cylinder, constant speed water cooled CI engine operating in both single fuel and dual fuel mode, to have a comparative understanding of performance, combustion and exhaust emission characteristics under different load conditions.

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