Effect of injection timing on the Ignition delay of Ethanol blended diesel engine

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Abstract:

It is awareness and concern for environmental protection that has been provided the greater stimulation for most of the recent research in use of non fossil or other so called clean fuels for internal combustion engines. Compared with petroleum fuels, alcohol fuels have the undesirable features of low calorific value and a high enthalpy of vaporization. In this regard the experiments are conducted to analyse the effect of variation of injection timing on ethanol blended diesel engine.

The experiments were conducted to analyse the effect on ignition delay period of ethanol blended fuel by retarding and advancing up to 2^0 of base line injection timing of diesel engine.

It was observed that the ignition delay decreases up to 7.6 % as advancing the engine by 2^0 in the ethanol blended fuel. The ignition delay increases up to 23% as retarding the engine by 2^0. The cylinder temperature and pressure at the time of fuel injection plays important role. The change in the proportion of the ethanol blended fuels strongly influences the ignition delay and the premixed combustion duration.

Keywords: *Ignition delay, Injection timing, Blended fuel, Ethanol.*

Introduction:

In 1973, diesels comprised 2.5% of the European market. The increase of the diesel share in the European market due to the oil crisis in the year 1983 was rapid in the following years. New cars in Europe were mostly powered by diesel and the sales rose by more than 31% by the year 2000. The diesel share was steadily increasing and touched 51.78% by the year 2007 [1]. More than 60% of vehicles were diesel powered in Luxembourg and Belgium by the year 2009 [2]. In 2011, first time in the UK, diesel cars surpassed the petrol car sales [3].

The robustness, reliability and capability of the diesel engine and higher torque production at lower speeds have lead to its growth in the automobile sector. Subsequently, emissions of diesel cars led to the beginning of legislated emission standards. State of California in the year 1966, introduced the first emissions norms, and consequently the entire USA adopted the same abiding by the United States Environmental Protection Agency (EPA) [4]. The emission standards since then have been tightened progressively with passing years. With respect to the rising emission concerns, Europe introduced in the year 1993 its Euro 1 mission standard limiting the NO_x and particulate matters [5].

Depletion of crude oil reserves, lead to the sharp increase in prices which resulted in the early 1973. Increase in emissions and introduction of the emission norms due to climatic changes, has lead to the conservation of energy and diversification of sources of energy [6]. Researchers escalated their interest on possible aspects for reduction in emissions and also to search for alternative fuels for internal combustion engines. The readily available fuel which was a head turner was alcohols. The cost of production of alcohol was very cheap, especially ethanol and methanol. Ethanol and methanol can be readily produced from sources like biomass, coal and natural gas. Alcohol has been cited by many researchers to offer solutions to a number of varied problems. Possible solutions to offer in meeting the stringent environmental polluting agents and control laws were met by these alcohols [7].

It is the awareness and concern for environmental protection that has provided the greater stimulation for most of the recent research in use of non fossil or other so called clean fuels for internal combustion engines. Compared with petroleum fuels, alcohol fuels have the undesirable features of low calorific value and a high enthalpy of vaporization [8]. Their high auto-ignition temperatures and, therefore, high octane ratings render them as more suited for replacement of gasoline in spark-ignition engines. Brazil has been a world leader in its programme initiated in 1975 to substitute ethanol for gasoline in small cars.

In CI engines it gives rise to long ignition delay periods, quantified by very low cetane numbers. If alcohols are to be seriously considered as a substitute for petroleum fuels on a large scale, however, they must at the same time be deployed as a substitute for gasoil. Without gasoil substitution crude oil importation levels in non-oil producing countries will have to be maintained in order to sustain the demand for gasoil.

The colourless transparent liquid Ethanol (C_2H_5 - OH,) is similar to methanol in terms of engine characteristics with its latent evaporation temperature being 1.3 times lower than that of methanol. Its higher energy density than methanol provides opportunity to use smaller fuel tanks in vehicles.

An alcohol (methanol and ethanol) along with biodiesel is a very common and popular alternative fuel. Several studies were performed with not only adding only ethanol, methanol and biodiesel to diesel fuel but also with their mixtures to diesel fuel. Yao et al. [1] performed experiments using methanol diesel fuel. A compound combustion system for diesel methanol (DMCC) used on a naturally aspirated engine with and without the oxidation catalytic converter. As a result of these experiments using DMCC method with oxidation catalyst helps reduce all emissions emitted from engine like soot, NO_x, CO, and THC.

Ünlüönen & Şahin, [2] cited the production of ethanol from sugar beet and use ethanol as a fuel in Turkey. It was stated that using ethanol would reduce the consumption of fossil fuels and eventually, emissions of greenhouse gases. Turkey imports approximately 60% of its total energy demand. Turkish rural economy has witnessed a growth of 10-15% in agriculture sector after starting the practice of blending 5% ethanol with fuel. This also helps reduce foreign dependency for fossil fuels and emitted hazardous gases.

Cheung et al. [3] studied with biodiesel as an alternative fuel and used biodiesel with fumigation method instead of blending to investigate the effects of emissions and performance. Constant speed variable load tests were performed with 4 cylinder naturally aspirated engine. Test results showed that no significant change were observed in carbon dioxide (CO_2) emission and brake thermal efficiency, while carbon monoxide (CO) and hydrocarbon (HC) emissions were increased NOx and particulate matter (PM) emissions were decreased. Also an increase in emitted nitrogen dioxide (NO_2) from the exhaust was recorded. They reported their comparative test results with using fumigation technique and direct blending. Test results showed that using fumigation method all emission levels reduced much more than direct blending.

Ajav et al. [5] studied with 5%, 10%, 15% and 20% ethanol levels with diesel fuel and investigate the effect on engine performance and emissions parameters. There was not any significant difference between the power developed on the blends and the diesel alone. As a result up to 20% ethanol can be used safely with diesel without any power reduction. The ethanol percentage increases, the bsfc also get increases. It was observed that ethanol causes a reduction in CO and NO_x emissions.

Song et al. [6] examined ethanol-diesel blended fuel as an alternative fuel for diesel engine up to 20% level of ethanol. It was investigated emissions as HC, CO, NO_x, and PM and the PM extracts. The test was carried on the engine according to ECE R49 13-Mode tests cycle and they observed that CO and HC emissions increased with the increase of the ethanol volume percent and NOx emissions slightly increased. PM consists of dry soot and SOF. By using ethanol dry soot was reduced and SOF was increased because of more incomplete combustion and unburned hydrocarbon.

Rakopoulos et al. [7] experimentally investigated with ethanol as an alternative fuel to understand its effects on performance and emissions. A six cylinder turbocharged and inter-cooled Mercedes Benz mini bus engine was operated with 5% and 10% ethanol by volume and at three loads (20%, 40% and 60%) for 1200 rpm and 1500 rpm..

Lapuerta et al. [8] studied the effects of ethanol up to 10% on an automotive diesel engine with no engine modifications and no additives. They also used partial flow dilution tunnel to collect PM and they observed the change of particulate size distribution using ethanol. Torque, bsfc, and thermal efficiency were increased and smoke opacity and particulate matter emissions were reduced by adding ethanol to diesel. They measured a reduction in the mean particle diameter and a balance in NOx emissions. They suggested in their study that using additives obtains more homogeny blends and increases solubility of ethanol. Also, with some modifications in fuel pump the performance of the engine can be better.

Kim & Choi, [9] used ethanol due to its oxygenated contains with common rail DI diesel engine. Three different fuels: reference diesel fuel, ethanol-diesel blend and blend with cetane improver investigated the engine performance and emissions. The unburnt HC and CO emissions were slightly increased and smoke and particulate matter was decreased.

As per the reviewed articles, there are some gaps to deal with ethanol blended with diesel at different load and mixture conditions. This paper presents results of investigation on ignition delay by the effect of various injection timing and at different load conditions with diesel fuel blended with ethanol. The novelty of this work deals with relatively high percentage of ethanol at advance and retard injection timing.

Experimental set-up and procedure

The present study was carried out on a four stroke, compression ignition engine, model Ashok Leyland ALU WO 4CT diesel engine coupled with 62.5 kVA generator. The engine is equipped with in-line 4 vertical cylinders featuring direct injection, water cooled and turbocharged with intercooler. The rated power output is of 75.5 HP at 1500 RPM.

The experiments were performed under the following conditions:

(i) Case I: engine runs on diesel only with injection timing at 18, 17, 15 and 14° BTDC.

(ii) Case II: engine runs on mixture of 20% ethanol and 80% diesel with injection timing at 18, 17, 15 and 14° BTDC.

(iii) Case III: engine runs on mixture of 40% ethanol and 60% diesel with injection timing at 18, 17, 15 and 14° BTDC and

(iv) Case IV: engine runs on mixture of 60% ethanol and 40% diesel with injection timing at 18, 17, 15 and 14° BTDC.

The test matrix (Table 1) is divided into two parts on the basis of experiments made over the diesel test rig. The different fuel injection pump timing settings were used for this study: 1 and 2° CA retarded and 1 and 2°CA advanced from the baseline setting of 16°CA, BTDC. The degrees of timing change refer to crankshaft degrees.

Table 1. Test Matrix for Injection Timing

(a)			
Case No.	Primary Fuel	Secondary Fuel	Load Percentage (%)
I	Diesel	-	0, 10, 20, 40
II	Diesel	Ethanol	0, 10, 20, 40
(b)			

Case No.	Load (%)	Substitution (%)	Injection Timing (°BTDC)				
			18	17	16	15	14
I	0, 10, 20, 40		Diesel	Diesel	Diesel	Diesel	Diesel
II	0, 10, 20, 40	20	Ethanol + Diesel	Ethanol + Diesel	Ethanol + Diesel	Ethanol + Diesel	Ethanol + Diesel
III	0, 10, 20, 40	40	Ethanol + Diesel	Ethanol + Diesel	Ethanol + Diesel	Ethanol + Diesel	Ethanol + Diesel
IV	0, 10, 20, 40	60	Ethanol + Diesel	Ethanol + Diesel	Ethanol + Diesel	Ethanol + Diesel	Ethanol + Diesel

Results and Discussion:

Ignition Delay

With the injection timing of 16^{o} BTDC and injection pressure of 260 bar, the change in ignition delay of pilot diesel with different load conditions was investigated at 10, 40 and 80% load conditions.

The ignition delay period may be defined as the time lag between the commencement of diesel injection into the cylinder and the point of first detectable rise in cylinder pressure due to exothermic energy release within the mixture [10]. During the ignition delay period a unified physicochemical process takes place in which all transformations, both physical and chemical, occur simultaneously [11].

The compression and expansion process inside the internal combustion engine considering the non-reactive portion is considered to be the polytropic process, where PV^{n} = constant. The value of the polytropic index for the experimental engine is found to be 1.344 for diesel operation only [11]. The crank angle corresponding to fuel injection and the crank angle at which positive heat release occurred was used to calculate the ignition delay from the heat release curve. Fig. 1 (a, b, c & d) shows the ignition delay of ethanol blends for advanced, standard and retarded injection timing (at no load, 10%, 20% and 40% of full load condition). The ignition delay for 20% load condition and 20% blends was observed to be 15, 14, 12 and 12°CA for injection timing of 18, 17, 15 and 14° BTDC respectively compared to 13°CA for the baseline injection timing of

16°BTDC. The actual start of fuel injection is affected by the pump setting, but it can also be influenced by changes in fuel properties such as the viscosity, the bulk modulus, and the speed of sound [10]. The start of fuel injection is important because the time taken from the actual time of injection to the actual fuel injected early produces higher flame temperatures and may contribute to higher emissions. The effect of changes in fuel injection timing on the start of combustion is complicated by the effect of the different fuel cetane numbers. The cetane number is an indicator of the time delay between when the fuel is injected and when it starts to burn.

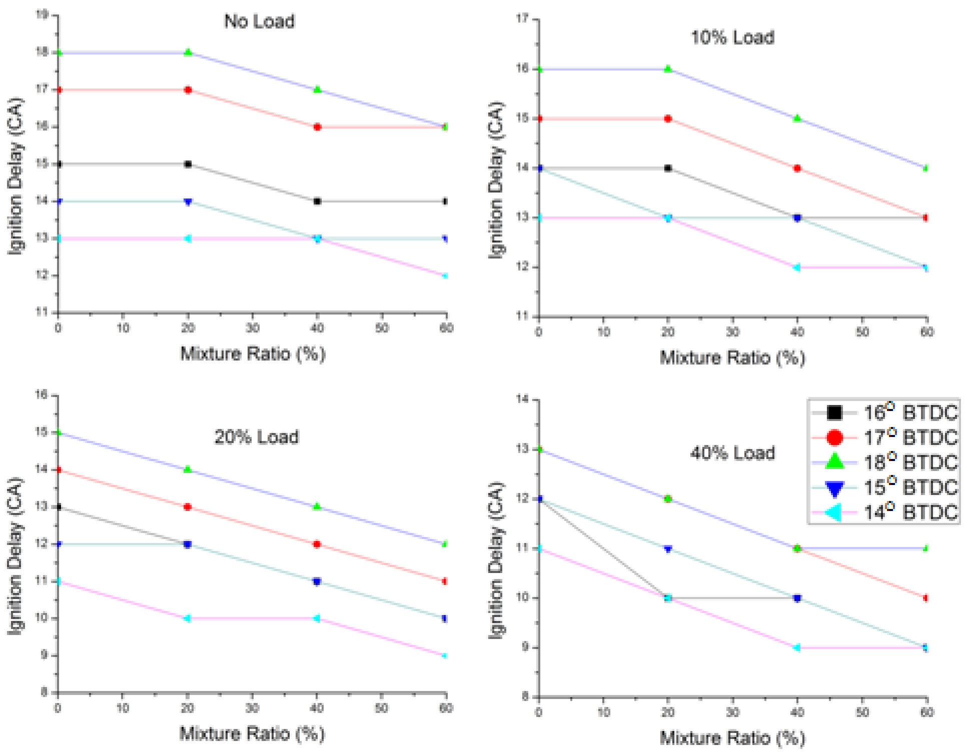

Fig. 1. Effect of varying injection timings on ignition delay for varying ethanol blends at (a) no load condition, (b) 10% load condition, (c) 20% load condition and (d) 40% load condition

At the light load engine condition, the start of combustion was more retarded than at the higher load engine condition. These differences in the start of combustion are the result of shorter ignition delay and different physical properties, such as higher bulk modulus, viscosity can also cause an earlier injection event [11-13]. As the substitution of fuel increases, the ignition delay of the diesel fuel initially increases due to the change in partial pressure of the substituted fuel and decreases as the quantity of the diesel fuel reduces and the amount of oxygenated fuel increases at top dead centre position. This is also due to the reduction in the temperature of the charge at the top dead centre position. The contribution and characteristic of the fuel depend on the amount of substitution being taken place as well as the operational load condition and the amount of each fuel present in the combustion chamber. The increase in the oxygenated fraction in the blend increases the amount of heat released during the premixed zone of combustion. The delay in the ignition of this combustible mixture in the presence of ethanol gets enriched, and thus, the premixed combustible mixture in the presence of the ignition delay and oxygenated compound increases the amount of heat release. The change in the proportion of the blended fuels strongly influences the ignition delay and the premixed combustion duration for ethanol blends.

Conclusions:

The experiments were performed on varying injection timing up to 2^0 advance and retard conditions. The following observations were concluded:

1) The ignition delay decreases by 7-8 % in advancing the engine by 2^0.
2) The ignition delay increases by 23% in retarding the engine by 2^0.
3) The cylinder temperature and pressure at the time of fuel injection plays important role.
4) The change in the proportion of the ethanol blended fuels strongly influences the ignition delay and the premixed combustion duration.

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