

# Suitable Ignition Timing and Fuel Injection Duration for Ethanol-Gasoline Blended Fuels in a Spark Ignition Internal Combustion Engine

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**Abstract**— This study was aimed to identify the suitable timing and duration of spark ignition for ethanol and gasoline blended fuel in an internal combustion engine. The four cylinders with 1,600 cc Toyota 3ZZ-FE engine was used as the tested engine. The gasoline with octane number of 87.5 was mixed with 99.5% purified ethanol to produce E-10, E-20, E-30, E-40, E-50, E-60, E-70, E-85 and E-100 blended fuels. The test conditions were set at stoichiometric combustion, and the engine speed between 2,000 – 5,000 rpm with the throttle position at 6, 9, 13, 16, 19, 22 and 26, respectively. The ignition timing and fuel injection duration were tuned for maximum brake torque conditions. The experimental results illustrate that as the composition of ethanol in the blended fuels increases, the required ignition timing for maximum brake torque conditions becomes more advanced while the required injection duration increases as well.

**Keywords:** *Alternative fuel; Ethanol-gasoline blends; Ignition timing; and Fuel Injection;*

## I. Introduction

Ethanol has become significant fuels for replacement of gasoline in transportation section. With higher octane number, ethanol requires earlier ignition timing than gasoline fuel. Ethanol also has higher enthalpy of vaporization than gasoline. Therefore the effective volumetric efficiency of air intake may be changed. The heating value of ethanol is lower than those of gasoline, thus increasing the fuel consumption rate. [1]

Hsieh et. al. [2] studied the engine performance and emission of ethanol-gasoline blended fuels with the ethanol composition of 0%, 5%, 10%, 15%, 20% and 30%, respectively. Their study confirmed the increase of fuel consumption due to low heating value of ethanol. The unburned hydrocarbon and carbon monoxide in exhaust gas reduces as the ethanol composition increases. Al-Hasan [3] investigated the effects of blended ethanol in gasoline with the ethanol composition range of 0% to 25% on the Toyota TERCEL-3A engine. The engine was tuned for maximum brake torque conditions. His study showed the increase in brake torque and fuel consumption.

Wu et. al. [4] studied effects of ethanol composition on the required air-fuel equivalent ratio of ethanol-gasoline blended fuels. Their study showed that the lean composition is suitable for high ethanol composition at fixed throttle position and fuel injection conditions. Celik [5] studied the suitable ethanol composition in ethanol-gasoline blended fuels for engines at the compression ratio of 6:1 and 10:1. He recommended the most suitable ethanol composition of 50%. Most previous researches [1] – [7] mentioned the low vapor pressure of ethanol at low temperature, which may cause the start-up problems for cold start condition. This problem could be overcome by development of advance electronic controlled unit. The suitable air/fuel equivalent ratio for ethanol fuel, gasoline fuel and ethanol-gasoline blended fuel seems to be at  $\lambda = 1$ , which is the recommended equivalent ratio for the design operating conditions of three-way catalytic converters. In this work, the gasoline with octane number of 87.5 was mixed with 99.5% purified ethanol to produce E-10, E-20, E-30, E-40, E-50, E-60, E-70, E-85 and E-100 ethanol-gasoline blended fuels. These blended fuels were tested in the four cylinders with 1,600 cc Toyota 3ZZ-FE engine. The engine operating conditions were fine tuned for maximum supplied brake torque. The suitable spark ignition timing and injection duration were identified with respect to the ethanol composition in ethanol-gasoline blended fuels.

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TABLE I. PROPERTIES OF GASOLINE AND ETHANOL

Property	Gasoline	Ethanol
Chemical Formula	C <sub>4</sub> to C <sub>12</sub>	C <sub>2</sub> H <sub>5</sub> OH
Stoichiometric Air-Fuel Ratio	14.7	9.0
Specific Gravity	~0.7328	~0.7894
Boiling Point (°F)	80 - 437	172
RVP (kPa)	61.4	19.3
Net Heat of Combustion (MJ/kg)	45.5	26.9
Latent Heat of Vaporization (kJ/kg)	350	920
Octane Number		
- Research (RON)	~92	111
- Motor (MON)	~82	92

## II. Experimental Setup

In this experiment, the 3ZZ-FE Toyota engine with specification as in Table 2 was used as the test engine. The fuel injector was enlarged to increase the fuel feeding rate from 185 cc/min to 365 cc/mm. The Haltech E11-V2 electronic control unit was used to control the ignition timing and injection duration. The engine performance was tested at the engine speed of 2000, 2500, 3000, 3500, 4000, 4500 and 5000 rpm with the throttle position at 6, 9, 13, 16, 19, 22 and 26, respectively

TABLE II. TEST ENGINE SPECIFICATION

Engine		3ZZ-FE	
Number of cylinder		4 cylinder inline	
Valve arrangement		16 valves DOHC	
Fuel system		Electronic Fuel Injection	
Ignition system		Spark Ignition System	
Displacement		1598cc	
Cylinder bore x stroke		79.0 x 81.5 mm	
Compression ratio		10.5 : 1	
Maximum Power		81 kw at 6,000 rpm	
Maximum Torque		150 Nm at 6,000 rpm	
Timing range	Intake	open	2° ~ 42° BTDC
		close	50° ~ 10° BTDC
	Exhaust	open	42° BTDC
		close	2° BBDC

The air/fuel ratio is fixed at stoichiometric conditions. The ignition timing is tuned for supplied maximum brake torque (MBT). The ethanol-gasoline blended fuels with ethanol composition of E-10, E-20, E-30, E-40, E-50, E-60, E-70, E-85, and E-100 were tested and their physical properties are reported in Table 3.

A 3-phase 50 kW generator was connected to the tested engine for measurement of electrical power production. The saline salt was used as electrical circuit load. The produced electrical power was measured by Primus KM-06 multifunction meter. The schematic view of experimental setup was shown in Fig. 1.

## III. Results and Discussion

The experimental results show that the corresponding supplied torque at the maximum brake torque at  $\lambda \sim 1$  varied with the ethanol composition in ethanol-gasoline blended fuels as shown in Fig. 2. The results at 5,000 rpm as in Fig.2 show that E-85 provides the maximum brake torque (MBT) of 23.46 Nm at the throttle position (TPS) of 26% and ignition timing of 38 °CA, BTDC. With higher octane number of ethanol, the proper ignition timing becomes more advance without problems of detonation knock in engine cylinders; thus increasing the engine performance.

When determining the brake specific fuel consumption (bsfc) as in Fig. 3, the fuel consumption seems to increase with the ethanol composition. The brake specific fuel consumption of E-100 is about 661.94 g/kW-h, which is 25.65% higher than E-10 due to the low heating value of ethanol.

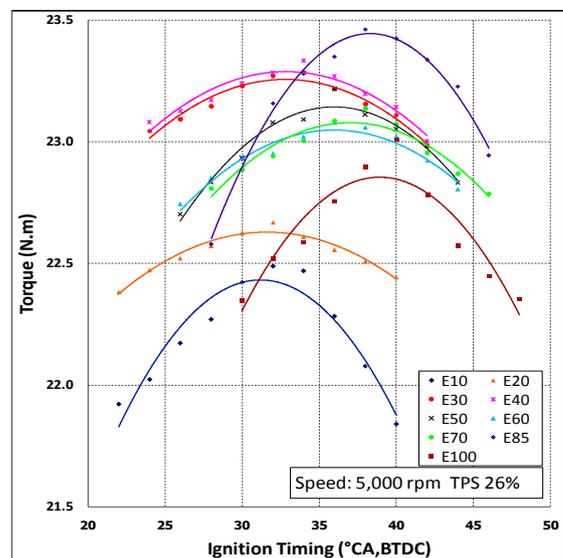


Figure 2. Variation of break torque with ignition timing at stoichiometric air-fuel ratio

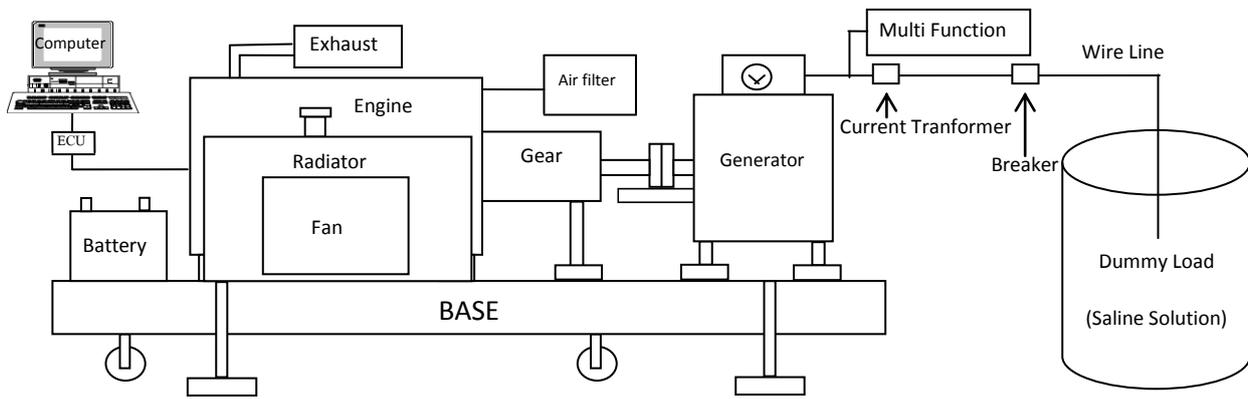


Figure 1. Schematic view of the experimental setup.

TABLE III. PROPERTIES OF ETHANOL GASOLINE BLEND FUELS

Property	Method	ULG91	E10	E20	E30	E40	E50	E60	E70	E85	E100
Dry Vapor Pressure @ 37.8 °C, kPa	ASTM D 6378	61.9	50.5	46.4	45.1	45	43.1	38.9	34.4	28.3	15.7
Specific gravity API @ 60 F, g/cm <sup>3</sup>	ASTM D 1298-99	0.7377	0.7568	0.7649	0.7683	0.7721	0.776	0.7803	0.7842	0.7898	0.7942
Density @ 15 °C, g/cm <sup>3</sup>		0.7375	0.7565	0.7642	0.7680	0.7718	0.7757	0.7799	0.7839	0.7895	0.7939
Distillation											
: 10 % vol. Evaporated, °C	ASTM D 189	54.5	53.7	56.7	57.2	57.2	57.8	60.2	65.6	70.5	-
: 50 % vol. Evaporated, °C		85.4	69.9	70.7	71.0	73.1	74.7	75.4	76.5	77.2	-
: 90 % vol. Evaporated, °C		132.9	126.0	124.5	115.9	78.4	78.3	78.2	78.1	78.0	-
: End point,		165.7	162.9	162.4	162.7	159.6	157.4	154.6	151.1	138.5	-
Water Content, % wt	ASTM D 6304-00	0.027	0.125	0.140	0.184	0.201	0.215	0.233	0.240	0.270	0.297
Ethanol Content, % vol	ASTM D4815	-	10.04	20.09	30.15	40.27	50.28	60.29	70.37	85.34	99.5

When determining the brake specific fuel consumption (bsfc) as in Fig. 3, the fuel consumption seems to increase with the ethanol composition. The brake specific fuel consumption of E-100 is about 661.94 g/kW-h, which is 25.65% higher than E-10 due to the low heating value of ethanol.

Figure 4 shows the effects of relative air-fuel ratio on the supplied torque at 5,000 rpm and throttling position (TPS) of 26%. The E-85 provide the corresponding maximum brake torque of 23.87 N.m at  $\lambda \sim 0.9$ . The supplied torque is reduced in the lean mixture regime.

Figure 5 shows the brake specific fuel consumption corresponding to the relative air-fuel ratio at the engine speed of 5,000 rpm and TPS of 26%. The minimum brake specific fuel consumption is found at  $\lambda \sim 1.05$  for most of ethanol composition.

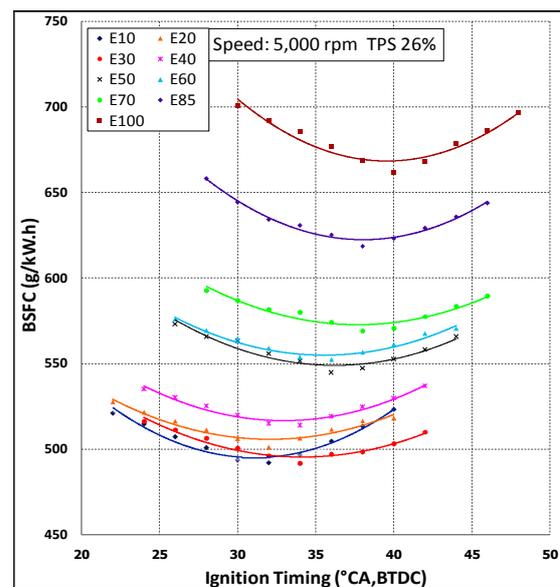


Figure 3. Variation of BSFC with ignition timing at stoichiometric air-fuel ratio

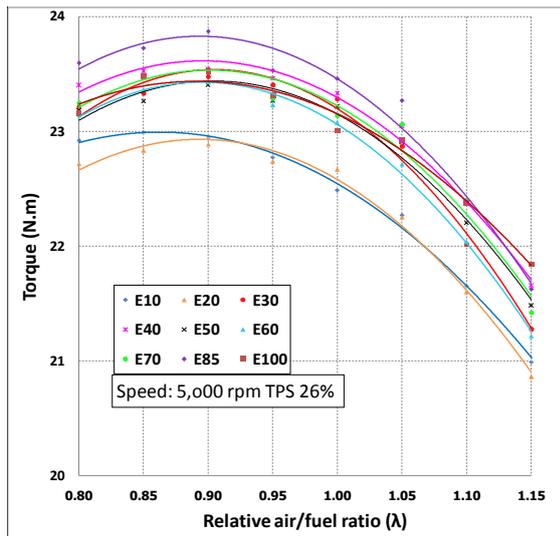


Figure 4. Variation of break torque with air-fuel ratio

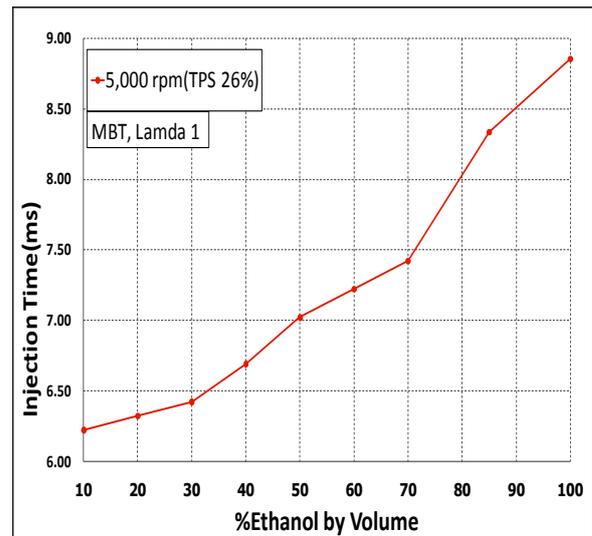


Figure 6. Duration time of injectors at MBT and stoichiometric air-fuel ratio

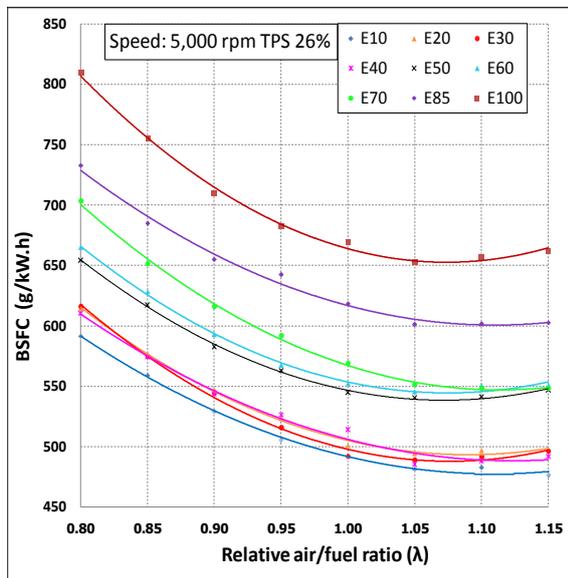


Figure 5. Variation of BSFC with air-fuel ratio

Figure 6 shows the required fuel injection duration corresponding to the ethanol composition in the ethanol-gasoline blended fuels. The injection duration needs to increase with the ethanol composition in order to compensate for the low heating value of ethanol in blended fuels.

#### IV. Conclusion

Since ethanol has lower heating value and higher octane number than gasoline, the high supplied torque is able to obtain by advancing the ignition timing. However, the brake specific fuel consumption seems to increase with the ethanol composition in ethanol-gasoline blended fuels. The relative air/fuel ratio for maximum brake torque is

obtained in the rich burn combustion regime, which the relative air/fuel ratio for minimum brake specific fuel consumption is obtained in the lean burn combustion regime.

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