



Experimental studies on simultaneous injection of ethanol–gasoline and n-butanol–gasoline in the intake port of a four stroke SI engine



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ABSTRACT

Two separate injectors were used to simultaneously inject ethanol and gasoline in the intake port of a single cylinder SI engine. The relative amounts of the two fuels on mass basis and the spark timing were changed using a real time controller. Neat gasoline could be used till 35% throttle beyond which higher thermal efficiency and torque could be obtained by switching to 30% ethanol. This system can be used to provide sufficient margin for knock free operation. Efficiency and torque were better at a mass ratio of 1:1 (50% of ethanol and 50% of gasoline) due to faster combustion as a result of better mixture preparation as compared to conventional pre-blended injection of gasoline and ethanol. However, NO and HC were slightly elevated. This dual injection system can allow the use of ethanol only when needed while permitting stoichiometric operation even under high torque conditions by adjusting the proportion of ethanol. Ethanol–gasoline and n-butanol–gasoline were compared in terms of performance and emission with dual injection strategy. The amount of n-butanol has to be increased with increase in torque conditions for better performance and low emission. The benefit of using ethanol with gasoline is significant at high torque conditions.

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1. Introduction

Ethanol apart from being a renewable fuel has properties that can enhance the performance of spark ignition (SI) engines. The use of neat ethanol (100%) is reported to improve the torque and efficiency at wide open throttle (WOT) as compared to gasoline. The important properties of ethanol are compared with those of gasoline in Table 1 [1–4]. Ethanol has high octane number, flame velocity and latent heat of evaporation. Ethanol also increases the ratio of specific heats of combustion products and results in an increase in the number of moles of products of combustion as compared to gasoline operation. These factors also lead to increase in efficiency and torque [5–8].

Addition of ethanol to gasoline reduced the cycle by cycle variations due to wider flammability limits and high flame velocity of ethanol [9]. The charge cooling effect was predominant with the

use of 50% or more of ethanol by volume along with gasoline to mitigate the engine knock [10]. The chemical antiknock benefit of ethanol was significant when adding up-to 50% ethanol and further addition was not very effective [10,11].

The high latent heat of vaporization of ethanol affects the cold starting characteristics of blends and this can be solved by one of the following: starting the engine with gasoline alone, heating the fuel and heating the intake air [12–17]. The volume of ethanol in gasoline affects the performance and emissions of the engine and it needs to be varied based on the operating conditions [18–23]. Phase separation in ethanol gasoline blends occurs in the presence of moisture. Phase separation mainly depends on temperature, water content and the amount of ethanol mixed with gasoline [24,25]. Adding co-solvents like methanol and/or n-butanol by a small amount in ethanol–gasoline blend can avoid phase separation [5,24,25].

Continuously mixing the blends in the fuel tank by a mixing pump is also one of the solutions [6]. Online blending in a carburetor [9,26] can solve the issue of phase separation and the ratio of alcohol to gasoline (fuel ratio) can be varied based on the operating conditions. However, controlling the fuel flow rate of two different

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Table 1
Properties of gasoline and ethanol [1–4].

Property	Gasoline	Ethanol	n-butanol
Chemical Formula	C ₄ –C ₁₂	C ₂ H ₅ OH	C ₄ H ₉ OH
Composition (C, H, O) (mass %)	86, 14, 0	52, 13, 35	65, 13.5, 21.5
Lower heating value (MJ/kg)	42.7	26.8	33.1
Density (kg/m ³)	745	790	810
Octane number ((R + M)/2)	90	100	87
Boiling temperature (°C)	25–215	78	118
Latent heat of vaporization (25 °C) (kJ/kg)	380–500	904	716
Self-ignition temperature (°C)	≈ 300	420	343
Stoichiometric air/fuel ratio	14.7	9.0	11.2
Laminar flame speed @ 1 bar, 390K, Ø = 1.1 (cm/s)	≈ 52	63	57
Mixture calorific value (MJ/m ³ @ Ø = 1)	3.75	3.85	3.82
Ignition limits in air (vol %)			
Lower limit	0.6	3.5	1.4
Upper limit	8	15	11.2
Solubility in water at 20 °C (ml/100 ml H ₂ O)	<0.1	fully miscible	7.7

fuels at different flow rates is complex in carburetor based systems as compared to port injected systems. Response to the transient conditions is poor with carburetor. In the port injection systems the pulse width (on time) of the injectors can be changed for varying the fuel flow rate easily. Such a system which has two separate injectors in the intake port, one for alcohol and another one for gasoline were used in this research work.

Blending of ethanol and gasoline online before the mixture is supplied to a single fuel injector [5] can also avoid phase separation. In one such attempt, a mixing chamber was used before the injector to blend ethanol and gasoline. The relative amounts of these fuels were varied using a stepper motor based valve. However, real time variation of fuel ratio has not been reported with this system and transient response lag may occur due to time taken for mixing the two fuels [5]. Some other studies reported the benefits of using an additional port fuel injector in a direct injection engine for mitigating knock using high amounts of ethanol [22,27]. These systems are expensive and controlling the two different systems (one port injection and one direct injection) operating at different injection pressures and timings. Thus it needs sophisticated controls and high power requirement. Use of two port injectors for injecting two fuels simultaneously which is very cost effective and easiest to control. This is the main focus of this research work.

n-Butanol is an emerging alcohol and limited studies only reported with n-butanol in SI engines. The differences in properties of n-butanol and ethanol have led to a comparative performance and emission analysis between n-butanol–gasoline and ethanol–gasoline operation with the dual injection strategy. The results of using ethanol–gasoline and n-butanol gasoline are also discussed.

2. Present work

This work is aimed at developing and evaluating the potential of a system that can vary the relative amounts of ethanol and gasoline in a SI engine based on the operating condition and availability of ethanol. Both these fuels were injected into the intake manifold through two separate injectors. The amounts of ethanol and gasoline could be varied from 0 to 100% using a real time engine controller, which is difficult in the case of pre-blended ethanol–gasoline. The two fuel sprays were targeted at two different portions of the intake valve to improve evaporation. The experiments were conducted to study the performance, emission and combustion characteristics of the engine with this dual injection system.

The efficiency and emission characteristics have been reported

with simultaneous injection of ethanol and gasoline using dual injection system at different torque conditions. Apart from this, a comparison was also presented with conventional pre-blended operation (two fuels mixed well outside) of ethanol and gasoline using a single injector. In addition, the effect of ratio of n-butanol and gasoline on performance and emissions was compared with those of ethanol–gasoline injection using new dual injection system. The present dual injection system has more benefits in terms of operation, control and at the same time retains the benefits of using alcohols at suitable proportion based on the operating conditions and availability of the fuel. The following are the summary of advantages of the dual injection system.

- The proportion of alcohol and gasoline can be varied based on the operating condition for good performance.
- Use of alcohols in limited quantities at suitable operating conditions where the performance and emission benefits are significant can be possible with this system in countries where the availability of the alcohol is less.
- Methanol and ethanol will separate from gasoline without additives after they are blended with gasoline due to their hygroscopic nature.
- Cold starting and warming up can be done by using gasoline alone and thereby reducing the emissions at starting with this system.
- High amount of alcohols can be used only during knock period to boost the engine power and it could avoid knocking with change in ambient temperatures.
- Hydrous ethanol with very high water content can be used along with gasoline since no phase separation issue with simultaneous injection system.
- Part load efficiency can be improved by increasing the compression ratio of the engine with this dual injection system; further, more alcohol can be injected at full torque conditions to mitigate knock.

3. Experimental set up

A photograph view of the experimental set up is shown in Fig. 1a. A naturally aspirated, four stroke, single cylinder, air cooled three wheeler automotive engine of 200 cc capacity, compression ratio 9.4 and rated power of 6.5 kW@5000 rpm was used. This engine was coupled to an eddy current dynamometer (Dynalec, India) with closed loop control of speed which was used to apply and measure the torque. Two fuel injectors were oriented on a

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