Starting Characteristics of an Engine using Neat Ethanol

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Abstract

The objectives of this study are to investigate starting characteristics of ethanol at low temperature, and find out a solution for cold starting problem, which is related to the cold-start operation of engines fueled with ethanol. The testing engine is a single cylinder, four strokes SI engine with fuel injection and ignition timing system being controlled by ECU (electronic control unit). The cold starting performance tests were conducted using ethanol fuel with different percentage of ethanol, surrounding temperature, heating method, and amount of fuel injection. From the experimental results, when using ethanol fuel with conventional engine, the problem of cold starting occurred at surrounding temperature lower than 15 °C and 20 °C for E85 and E100, respectively. Increasing of injection duration can lower the possible cold start temperature of neat ethanol to 10 °C; whereas, glow plug and pre-cranking heating methods can make the engine start at 10 °C and 12.5 °C respectively. These findings could be considered as solutions to the cold start problem in engine fuelled with pure ethanol fuel in Thailand.

1. Introduction

For many decades, all kind of vehicle engines work with fuels produced from crude oil. However, crude oils are running out and many countries want to be independent of crude oil import. Limited energy sources have warned a potential lack of energy in the future so we need renewable energy to substitute crude oils. Thailand is agricultural country with a lot of agricultural product as sources for ethanol production. The ethanol is a good choice for renewable energy in Thailand. However, alcohol fuels exhibit numerous differences in their motor fuel characteristics when compared with petroleum-based fuels. One of the major differences between the fuels is the vapor pressure and heat of vaporization. The low volatility and high latent heat of vaporization of alcohol fuels result in a low vapor pressure at lower temperatures. This severely reduces the cold start performance of an alcohol-fueled vehicle as compared to a gasoline vehicle. Normally, vapor pressure of fuel should be high enough to allow good start at cold condition. Simultaneously, it should be low enough to guarantee minimum evaporation loss. The

European standard EN 228, i.e. reid vapor pressure (RVP) of fuel must be in the range of 45-60 kPa in summer and 60-90 kPa in winter. [1]. The vapor pressure of ethanol blended fuel decreases with higher percentage of ethanol. The ignition occurs when the vapor phase mixture of fuel and air is within flammability range. For ethanol, the vapor flammability limit of fuel vapor/air ratio is 4.3-19% by volume. At temperatures below 13° C (ethanol flash point), the fuel vapor/air ratio of the ethanol is below the lean limit due to its low volatility. [3] In conventional gasoline engines, the cold start problem is usually solved by over- fueling during start up to ensure enough fuel evaporation for ignition. Nonetheless, this technique is not appropriate for the ethanol. In Brazil, the flexible fuel vehicles are equipped with the second fuel tank to be used for cold starting of neat ethanol. However, this existing secondary fuel tank is considered inconvenient and unsafe for customers. In USA and Europe, many countries choose E85 instead of neat ethanol to avoid the installation of second fuel tank. The 15% of gasoline in E85 increases the vapor pressure enough for cold starting.

The current study will explore other alternatives to second fuel tank installation by studying the parameters, which affect to the cold start characteristics. The parameters such as ratio of ethanol and gasoline blends, ambient temperature, and amount of fuel injection were examined.

2. Experimental apparatus and procedure

Experimental apparatus is composed of three major systems, e.g. the engine system, the cold soak chamber and microcontroller. The Suzuki Skydrive engine was used as a test engine with the specification shown in Table 1. The test fuels are gasoline, pure ethanol and E85 from Petroleum Authority of Thailand. The properties of gasoline and ethanol used in this experiment are shown in Table 2.

Table. 1 Suzuki Skydrive specification

Engine type	SOHC 2-valve 4 strokes air-cooled
Displacement	124cm^{3}.
Bore x stroke	53.5 x 55.2 mm.
Compression ratio	9.6:1
Fuel system	DCP (Discharge Pump)-injector
Ignition system	Electronic transistor
Starter	Electric starter

Table. 2 Properties of ethanol compared with gasoline [2, 4]

Fuel properties	Gasoline	E85	Ethanol
Formula (for C=1)	$CH_{1.814}$	$CH_{2.8}O_{0.4}$	$CH_3O_{0.5}$
Molecular weight	100-105	n/a	46.07
Density kg/l 15 ^{o}C	0.69-0.79	0.76	0.79
Oxygen cont.(wt%)	0	30	35
Boiling point, ^{o}C	27-225	n/a	78
Vapor pressure, kPa	58.8	35-70	17
Heating value, MJ/l	32.2	23.9	21.3
LHV, kJ/kg	2830	n/a	2690
Heat of vapor (kJ/kg)	305	n/a	840
Flash point, ^{o}C	-43	n/a	13
Auto-ignition t, ^{o}C	257	n/a	423
Flammability limit, vol%			
Lower	1.4	n/a	4.3
Higher	7.6	n/a	19.0
Stoichiometric A/F ratio	14.7	9.47	9.0
Octane number			
Research	97	101	107
Motor	80-90	n/a	89.7

The temperature data and starting time were measured by sensors and microcontroller. All measured data were recorded by personal computer as shown in Fig. 1.

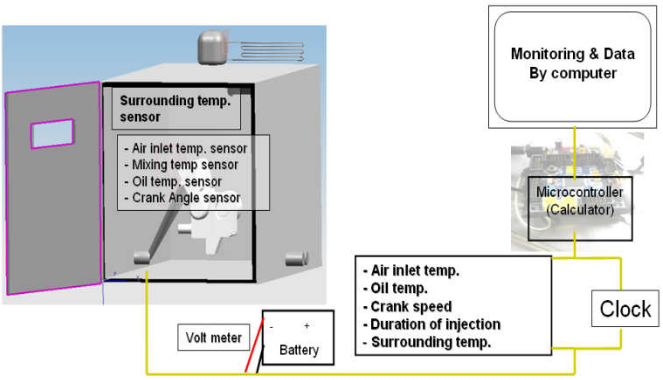

Fig.1 Schematic diagram of the experimental setup

A cold soak chamber was designed and manufactured in order to control ambient temperature. A conceptual drawing of this chamber is shown in Fig. 2. The walls, floor and ceiling of the chamber are made from three layers of standard building foam board insulation partially encapsulated in sheet stainless steel. The cold soak chamber can operate at the lowest temperature of -20 $^{\circ}$C while the lowest temperature of this experiment is -2 $^{\circ}$C, which is the lowest temperature in Thailand according to the temperature data of Thai Meteorological Department. [5]

In the test engine, air and fuel were mixed together in the intake port system prior to entry to the engine cylinder. The test engine was equipped with an original DCP (Discharge Pump)-injector as shown in Fig. 3. Then, the injection duration was adjusted to be able to run with ethanol fuel. A sub-module to adjust the injection duration was added to the original ECU (Electronic Control Unit).

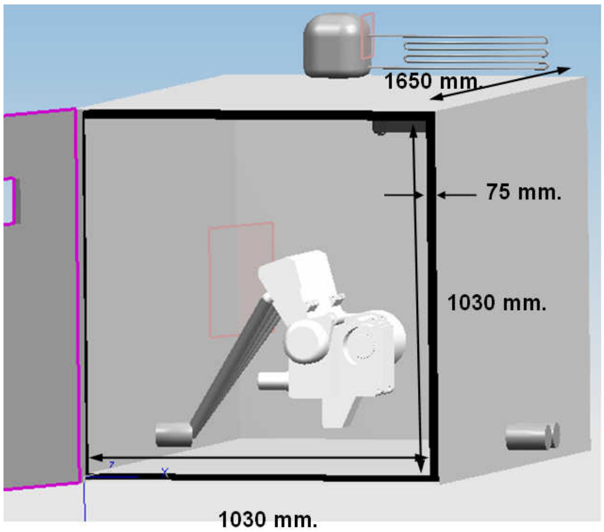

Fig. 2 Design of the cold-soak chamber

Fig. 3 Suzuki Skydrive engine in the cold soak chamber

During the test, data was acquired with the use of micro controller device that communicated and displayed values read by the computer. For consistency in analyses, additional parameters were measured and recorded. These additional parameters are listed and explained below.

- Crank Start: The first time the engine starts to rotate, the engine speed (RPM) recorded by micro controller is greater than zero.

- Engine Start: The ignition occurs, the engine speed (RPM) reaches 900 rpm and remains above that value.
- The temperature of engine oil , air intake, and mixture
- Injection duration
- Battery voltage

These data were displayed by cold start timer program developed by the authors. Fig. 4 shows example of software interface. In order to eliminate the detrimental effects of changes in battery voltage at cold temperatures, the battery was continuously charged to maintain the same voltage during each test.

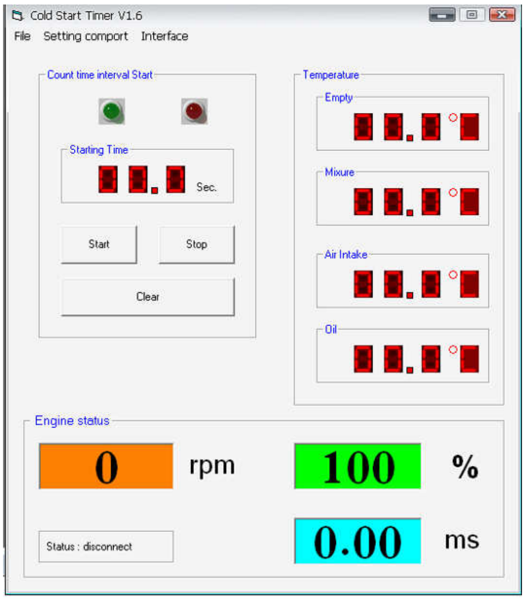

Fig. 4 Program interface

The variable parameters were ambient temperature, type of fuels, amount of fuel injection, and cod start solutions. The ambient temperature was changed from -2 to 25 °C according to the temperature data from Thai's Meteorological Department [5]. The test fuels were gasoline RON91, E85, and anhydrous ethanol. Injection duration was increased from 10%, 20%, 30%, 40%, 50% to 100% in order to compensate the lower energy content of anhydrous ethanol. For the cold start, solutions were explored an electric heater (glow plug), heated injector, and pre-cranking.

3. Result and discussion

The conventional gasoline engine was run with test fuels at different temperatures. The starting time of each fuel are shown in Fig. 5.

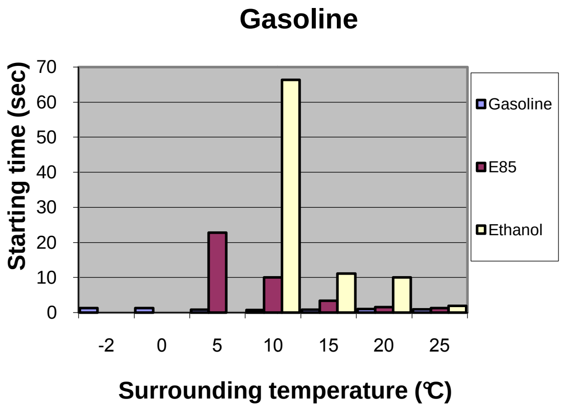

Fig. 5 The starting time of conventional engine with different fuels

In case of gasoline, the engine can start even at low temperature of -2 °C. In case of E85, the engine can start one time at 15 °C. The engine can also start at 10°C and 5°C under the condition of two consecutive starts. For example, the time for 1st trial start at 10°C is 10 seconds and the 2nd start is 1.3-1.7 seconds so Fig. 5 shows 11.3-11.7 seconds for 10°C. The conventional engine can start with anhydrous ethanol normally at 20 °C but the second start is required at 15 °C. It is not possible to start the conventional engine with E85 and E100 at temperature lower than 15 °C and 20°C respectively.

After the first trial start, the temperature in the combustion chamber increases due to the compression. Then during the second start, the additional fuel is supplied, which results in richer mixtures enough for ignition. Basically, when a re-start is done during a test, the engine has more fuel available to evaporate and combust; thus shortening the total starting time. This re-start, however, is unpleasant to the customer and results in poor hydrocarbon emissions. The battery voltage was kept fully charged throughout all the experiments so there was no significant variation of spark plug power. The comparison results of all test fuels in conventional engine are shown in Fig. 5.

Four methods were proposed to solve the cold start problem. The first method proposed for this experiment was increasing the amount of fuel injection. The injection duration was increased from 10, 20, 30, 50 to 100 % compared to the conventional one. By increasing amount of fuel injection, the engine can start at the surrounding temperature low as 10 °C. The result of fuel injection increasing is shown in Fig. 6. The reason that the engine hardly starts at the temperature lower than 12.5 °C is the limitation due to flash point of the ethanol (13 °C). The second method was increasing combustion chamber temperature by installing the electrical heater (glow plug) at the cylinder head. The heater was heat up at same time with engine switch on, 30 seconds before start, and 60 seconds before start. By increasing the combustion chamber temperature, the engine can start at 10 °C, as shown in Fig. 7.

The third method was heating the injector by holding the electric supply to heat up fuel inside before being injected into the intake port. The holding times were 10, 20, 30 second and wait for the time in some case. The result of heated injector technique is shown in Fig. 8.

According to this application, the heated injector could not reduce the starting time.

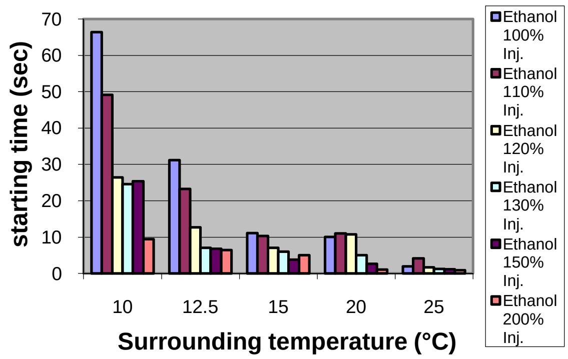

Fig. 6 The starting time of E100 with increasing amount of fuel

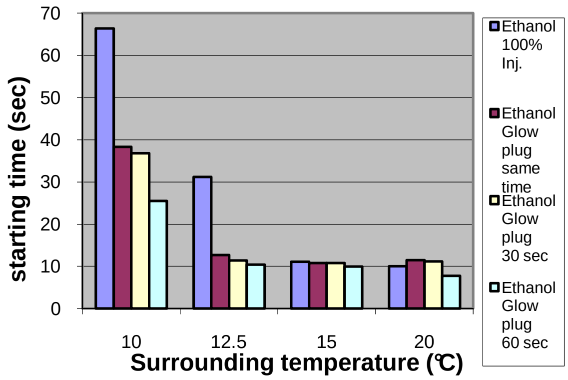

Fig. 7 The starting time of E100 with glow plug technique

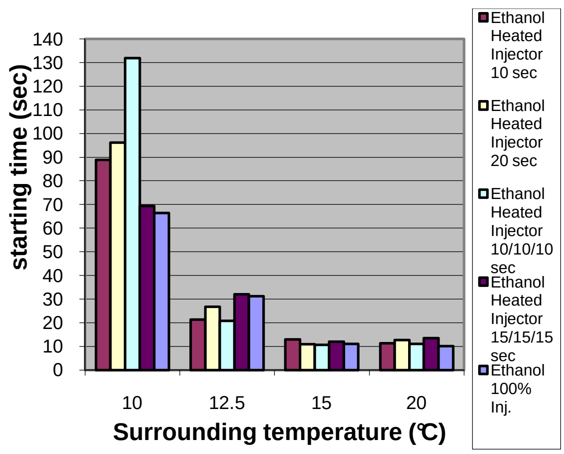

Fig. 8 The starting time of E100 with heated injector technique

The last method was the pre-cranking technique by starting the engine without injection. For the testing condition at surrounding temperature 10 °C, the starting time can be reduced by this method. With combination of glow plug method, the engine start was improved, as shown in Fig. 9

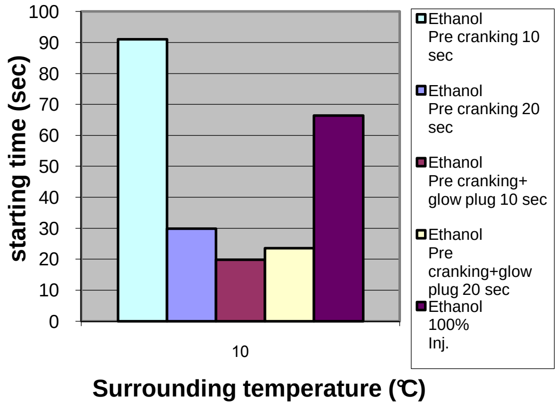

Fig. 9 The starting time of E100 with pre-cranking technique

Overall, the shortest starting time was achieved by increasing amount of fuel to twice of the original but the effect of increasing the fuel was a high hydrocarbon and emission. Hence, 50% increased amount of fuel injection was selected to combine with glow plug technique at the same time with engine switch on, which exhibited similar staring time to twice fuel injection, as shown in Fig. 10.

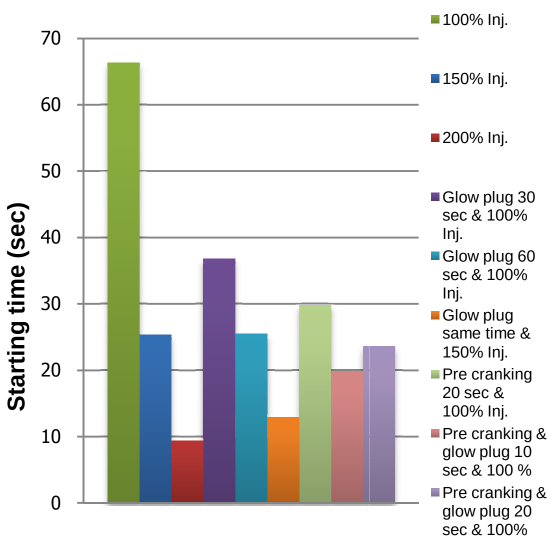

Fig. 10 The starting time of E100 with combination techniques

4. Conclusion

The conventional engine was run with ethanol fuel in the cold soak chamber at low temperature. The engine was also modified to overcome the cold start problem when using the ethanol fuel. The experimental results can be summarized as follows

1. In case of E85, conventional engine can start in one time at 15 °C, and two consecutive times at 5 °C of surrounding temperatures.

2. In case of E100, conventional engine can start in one time at 20 °C, and two consecutive times at 15 °C of surrounding temperatures.

3. Double of fuel injection can start the engine with shorter starting time when surrounding temperature is over than 10 °C.

4. Increasing the combustion chamber temperature method by glow plug and pre-cranking can solve cold start problem at 10 °C of surrounding temperature.

5. For heated injector technique, the starting time cannot be reduced for all of surrounding temperatures.

6. Combination method of increasing amount of fuel and increasing combustion chamber temperature yields similar staring time improvement to doubling of fuel alone and can start the engine can start in twice consecutive times at 10 °C of surrounding temperature.

Even though the result of this experiment may not be enough to solve the cold start problem in all of Thailand's condition, according to temperature history data of capital town in Thailand, ethanol engine can be used without cold start problem by combination method. Other parameters such as strength of spark, enhancing the fuel evaporation, starting motor or combination of all techniques should be studied in the further stage.

5. Acknowledge

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