COLD START CHARACTERISTICS OF AN ETHANOL ENGINE

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ABSTRACT

The present study aims to investigate the parameters affecting cold start characteristics of ethanol at low temperature, and suggest a solution to avoid cold starting problem without the installation of second fuel tank. The testing engine is a 125 CC. volume displacement, single cylinder four strokes SI engine with fuel injection and ignition timing system controlled by ECU (electronic control unit). The cold starting performance tests were extensively conducted with different percentage of ethanol blends, surrounding temperatures, heating inside combustion chamber, heater injector, pre-cranking without fuel injection, and amount of fuel injection. From the experimental results, when using ethanol fuel in conventional engine, the problem of cold starting was observed 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. Glow plug and pre-cranking heating methods can help the engine start at much lower temperature. The combination of many techniques can make the ethanol engine start at the temperature as low as 3.5 °C. These findings offer solutions to the cold start problem in engine fuelled with pure ethanol fuel in Thailand.

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Wittawat Imerb

Contents

Contents (Cont.)

Page

List of Table

List of Figure

List of Figure (Cont.)

CHAPTER 1

INTRODUCTION

1.1 Motivatives

For many decades, all kind of vehicle engines work with fuels produced from crude oil. However, crude oil is running out and many countries want to be independent from importing of crude oil. Limited of energy sources are the warning of a potential depletion of energy in the future, so we need renewable sources of energy such as bio-fuels as a substitution of crude oils. Although fuel economy of engines is greatly improved from the past and will probably continue to be improved, increase in number of automotive alone dictate that there will be a great demand for fuel in the near future. Gasoline and diesel will become scare and most costly. Alternative fuel technology, availability, and use must and will become more common in the coming decades. Because of the high cost of petroleum products, some developing countries are trying to use alternate fuel for their vehicle. Another reason motivating the development of alternate fuel is the fact that a large percentage of crude oil must be imported from other countries which control the larger oil fields. As of now many alternate fuels have been used in limited quantities in automobiles. Quite often, fleet vehicle have been used for testing (e.g. taxies, delivery vans, utility company trucks). This allows for comparison with similar gasoline-fueled vehicles, and simplifies fueling of these vehicles, The engines used for alternate fuels are modified engines which were originally designed for gasoline fueling. They are, therefore, not the optimum design for the other fuels. Only when extensive research and development is done over a period of years will maximum performance and efficiency be realized from these engines. However, alcohol fuels exhibit numerous differences in their fuel characteristics compared to petroleum-based fuels. One of the major differences between these two types of fuels is vapor pressure and heat of vaporization. The low volatility and high latent heat of vaporization of alcohol fuels results in a low vapor pressure at lower temperatures. This characteristic of alcohol fuels severely impacts the cold start performance of an alcohol-powered vehicle compared to a gasoline engine type. Normally, vapor pressure of fuel should be high enough to allow successfully ignite at low temperature condition. Simultaneously, it must be low enough to guarantee a minimal 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 temperature below 13 °C (ethanol flash point), the fuel vapor/air ratio of the ethanol is below the lean limit due to its low volatility. The reason of this characteristic can be explained from examination of the chemical properties of ethanol. The key properties of interest are boiling point, latent heat of vaporization and ignition temperature. Gasoline has constituents with a range of boiling points from ~25°C to ~200°C, while ethanol has a single boiling point of 78.4°C. The implication of this property is the percentage of fuel that vaporizes to an ignitable mixture will be less for ethanol than gasoline at low temperatures.

The further temperature drops below the lowest boiling point of the fuel, the more this issue becomes worse. Comparing the latent heat of vaporization of gasoline to ethanol, it is observed that the amount of energy consumed to convert gasoline from liquid state to gas per unit of mass is approximately three times lower than ethanol. This implies that almost three times amount of energy needed to be given to ethanol to vaporize fuel droplets to form an ignitable air-fuel mixture. The third significant factor which impacts cold starting is the ignition temperature. Ethanol has an ignition temperature at 13°C which is 50°C higher than gasoline. The consequence of this property is ethanol requires more energy to ignite an air-ethanol mixture as it requires for an air-gasoline mixture assuming all other variables were kept the same.

In conventional gasoline engine, the cold start problem is usually solved by over-fueling during start up to ensure enough fuel evaporation for ignition. However, this technique is not workable for the ethanol-fueled engine when the environment temperature is below 0°C. In Brazil, the flexible fuel vehicles are equipped with the secondary fuel tank to use for cold starting of this type of engine. However the exists of secondary fuel tank is considered to be inconvenient and unsafe for customers. In USA, Europe and many countries chose E85, mixtures of gasoline and ethanol, instead of pure ethanol to overcome an installation of additional fuel tank. The 15% of gasoline in E85 increases the vapor pressure enough for cold starting.

An agricultural country such as Thailand has a lot of agricultural products which can be used as raw materials for ethanol production. Ethanol is one of good choices for renewable energy in Thailand. In addition, using ethanol as an alternative energy is supported by Government of Thailand. However, there must be some modification on the Spark Ignition (SI) engine, because of the well known problem when using ethanol with SI engine in the winter or under low-temperature environment, the engine is hard to start. This is the main problem of using ethanol with automotive engine. The goal of this research is to study and propose an approach to improve the efficiency of ethanol-fueled automotive engine in Thailand. Because Thailand's ambient temperature which some places, in the winter, will be lower than 10°C and can be dropped to the lowest of -2°C in high ground. Ethanol Vehicles exhibit poor cold start performance in an environment such that its temperature is below 11° C, since ethanol will not be able to form a rich fuel vapor-air mixture enough to support combustion.

The objectives of this research are to study the parameters effect to the cold start characteristics and to solve a problem of cold starting of ethanol fuel without installation of secondary fuel tank. The parameters such as ratio of ethanol and gasoline blends, ambient temperature, and amount of fuel injection are key parameters which will be examined.

1.2 Objectives

The aim of this study is to improve efficiency of cold start in conventional spark-ignition engine with ethanol by addressing following items

1.2.1 To investigate starting characteristics of an ethanol engine at low temperature

1.2.2 To figure out the solution for cold starting of the ethanol engine in Thailand

1.3 Scope of starting in low temperature

The scope of this study will explore following areas:

1.3.1 The minimum temperature to start the ethanol automotive engine.

The first study is aimed to investigate and figure out the minimum temperature that engine can be started using pure ethanol as a substitution for conventional gasoline with and without assistance from cold start techniques.

1.3.2 The minimum amount of fuel injection to start an ethanol engine.

The main cold start modification technique is increasing amount of fuel injection in order to increase a density of fuel vaporization and a better chance of successful ignition. However, the more ethanol fuel injected to an engine, the more hydro-carbon was emitted from exhaust pipe by unburned fuel.

1.3.3 The minimum starting time of the ethanol engine.

1.3.4 The engine can start in the minimum Thailand's temperature.

In this study, conditions of experiment are set up from minimum temperature of Thailand in last 5 years and there are 3 separated criteria which will be measured for minimum temperatures – Bangkok, rural Thailand, and lowest temperature of Thailand (High ground and mountain).

1.3.5 Modification techniques which will be applied to conventional engine for starting at minimum temperature in Thailand.

Many techniques were used for reduce the starting time of ethanol engine at low temperature. Each technique can effect starting time and provide different results.

1.4 Overview of the contents

The research is divided into five chapters. The first chapter begins with the introduction to the renewable energy of world and Thailand in the future and the big problem when using ethanol. The second chapter further reviewing literature another research.

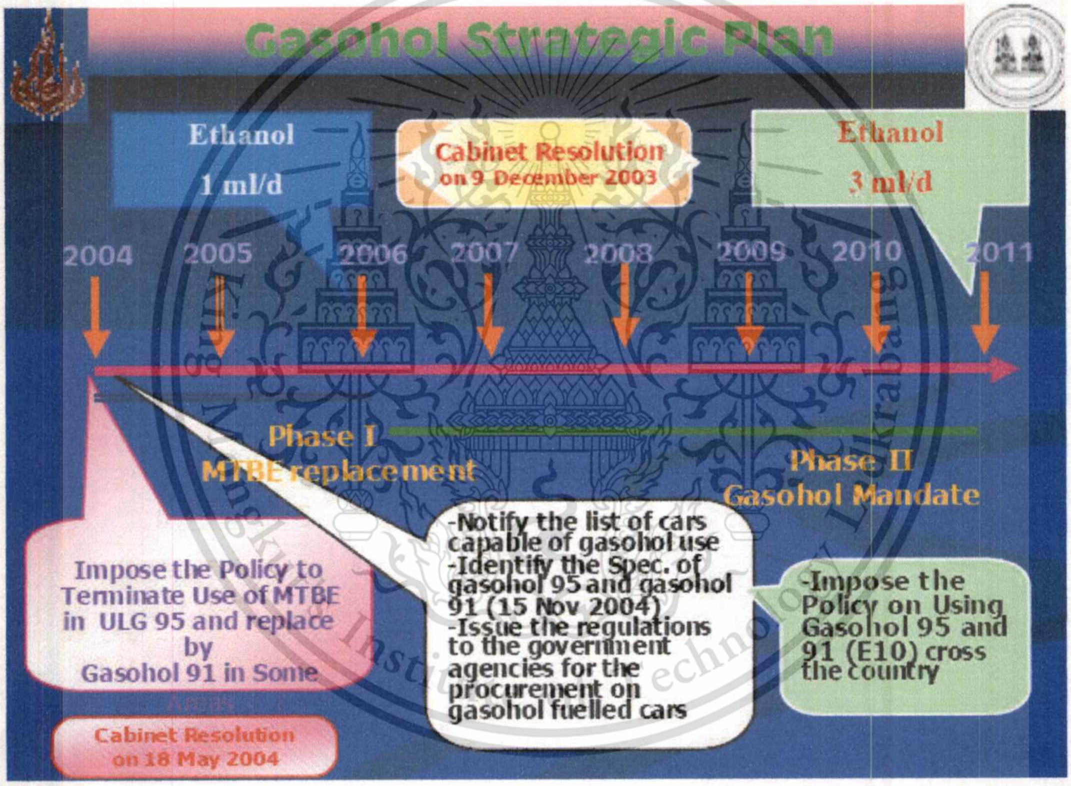
CHAPTER 2

RESEARCH BACKGROUND

2.1 Energy government policy

In those countries that are net oil importers, expectation about the net benefit of ethanol on reducing oil import is the primary driving force behind efforts to promote its production and use. Thailand imports a significant amount of oil to meet domestic demand. The ratio of the country's clued oil import to crude consumption stands at a high level (92% in 2001) Thu Lan T. Nguyen, Shabbir H. Gheewala, (2008)[20]. Not only does oil consumption cost the country amount of foreign currency via oil import bills but also contributes to environmental degradation. In that context, domestically produced ethanol has emerged as a potential substitute for conventional gasoline, most likely effective in both fossil oil savings and pollution mitigation. However, one of the concerns arising with an increased use of ethanol is its relatively high price over gasoline. This situation is not different for Thailand, a new market for fuel ethanol in Asia. To enhance ethanol's cost competitiveness against conventional gasoline, the government's measures include excise tax exemption and fuel subsidies. In Thailand, though the promotion for ethanol to enter the energy market had started in the past 20-30 years, its popularity was first recognized in 2001. With the government's bio-fuel policy, ethanol is being distributed to consumers in the form of gasohol, a mixture of ethanol and gasoline at ratio of 1:9. Quite confident about abundant sources of raw materials for ethanol production, the Thai government has launched a project to replace gasoline with gasohol nationwide on January 2007 (Pichalai, C, 2005).[21] Ministry of Energy had determined the energy strategies for a country competitiveness, which had been approved by the cabinet on 2 September 2003. One among these strategies is the sustainable alternative energy development that had set the target on increasing the proportion of commercial renewable energy or renewable power generation /industry from 0.5 percent in 2002 up to 8 percent by 2011. Bio-fuel development, as for ethanol and bio-diesel, is a goal under the Plan of Increasing Proportion of Renewable Energy Use. Ministry of Energy, by DEDE, had established a Gasohol Strategy to propose in the Joint Meeting between Ministers of Energy, of Agricultural and Cooperatives and of Industry and then proposed to the cabinet on 9 December 2003. In fact, market price is just only one aspect of bio-fuels' performance. It would not inform policy makers adequately about potential benefits of bio-fuels, e.g., fossil oil savings and environmental improvements upon substituting fossil based liquid fuels in transportation. (Thu Lan T. Nguyen, Shabbir H. Gheewala and Savitri G., 2006)[22]

According Thailand’s government energy policy aimed to promote alternative fuel that has the advantages following above. However, blending process between ethanol and gasoline is an extra cost from transportation of ethanol and gasoline to mix them together in same place. Thus, usage of neat ethanol has no extra cost for transportation before mix together with gasoline to be gasohol. Ministry of Energy had set the target on using an ethanol for MTBE substitution in gasoline 95 by 1 ml/d by 2006 and on using an ethanol for 3 ml/d for MTBE substitution in gasoline 95 and for oil substitution in gasoline 91 by 2011 shown in Figure 2.1.



Gasohol Strategic Plan

Ethanol
1 ml/d

Cabinet Resolution
on 9 December 2003

Ethanol
3 ml/d

2004 2005 2006 2007 2008 2009 2010 2011

Phase I
MTBE replacement

Phase II
Gasohol Mandate

Impose the Policy to Terminate Use of MTBE in ULG 95 and replace by Gasohol 91 in Some Areas

Cabinet Resolution
on 18 May 2004

-Notify the list of cars capable of gasohol use
-Identify the Spec. of gasohol 95 and gasohol 91 (15 Nov 2004)
-Issue the regulations to the government agencies for the procurement on gasohol fuelled cars

-Impose the Policy on Using Gasohol 95 and 91 (E10) cross the country

Figure 2.1 Thailand’s government energy policy planning[23]

2.2 Ethanol fuel

Alcohols are an attractive alternate fuel because they can be obtained from both natural and manufactured sources. This section deals with the chemical and physical properties of ethanol, especially those relevant to its use in automotive vehicles. More engine specific properties such as energy density, octane rating, and so on are discussed in later sections.[4]

2.2.1 Characteristics of ethanol

Ethanol has been used as automobile fuel for many years in various regions of the world. Brazil is probably the leading user, where in the early 1990s. About 5 million vehicles operated on fuels that were 93% ethanol. For a number of years gasohol (gasoline + alcohol) has been available at service stations in the United States. Gasohol is a mixture of 90% gasoline and 10% of ethanol. As with methanol, the development of system using mixtures of gasoline and ethanol continues. Two mixture combinations that are important are E85 (85% ethanol) and E10 (gasohol). E85 is basically an alcohol fuel with 15% gasoline added to eliminate some of the problems of pure alcohol (i.e., cold starting, tank flammability, etc.). E10 reduces the using of gasoline with no modification required to the automobile engine. Flexible-fuel engines are being tested which can operate on many ratio of ethanol-gasoline. Ethanol can be made from ethylene or from fermentation of grains and sugar. Much of it is made from corn, sugar beets, sugar cane and even cellulose (wood and paper). The present cost of ethanol is high due to the manufacturing and processing required. This would be reduced if larger amounts of this fuel were used. However, very high production would create a food-fuel competition, with resulting higher costs for both. Some studies show that at present in the United States, crops grown for the production of ethanol consume more energy in plowing, planting, harvesting, fermenting and delivery than what is in the final product. This is defeats one major reason for using an alternate fuel. Ethanol has less HC emissions than gasoline.

The chemical formula for ethanol is C_2H_5OH, sometimes written as EtOH or C_2H_6O. It is also known under many names such as ethyl alcohol or hydroxy ethane and is the type of alcohol found in alcoholic beverages. Ethanol is a rather simple organic molecule consisting of a group of carbon and hydrogen atoms with a hydroxyl group (an oxygen and a hydrogen atom) attached. Compared to most gasoline components, the ethanol molecule is small and light, having a molecular weight of just 46 g/mol (see Table 3.2 for relevant properties of ethanol and gasoline). Ethanol is somewhat special in its electrochemistry; the molecule is being polar at one end and non-polar at the other. The polarity of a molecule refers to the distribution of electric load in the molecule and it is a significant factor in physical and chemical behavior of substances. The presence of a hydroxyl group in the ethanol molecule allows it to participate in hydrogen bonding with other ethanol molecules or other polar substances. The bond is relatively weak but strong enough to make ethanol more viscous and less volatile than other similar but less polar substances. The fact that the ethanol molecule has both a polar and a non-polar end makes ethanol soluble in both polar and non-polar substances. The polar end makes ethanol miscible with water (and other polar substances), and the non-polar end allows it to miscible with many non-polar organic substances, such as gasoline and, to a lesser extent, diesel fuel. The hydrogen bonding in ethanol also causes the substance to have a rather low volatility for a molecule of such relatively small molecular weight. Under atmospheric conditions, ethanol is a liquid, although it will gradually evaporate if exposed to the atmosphere. It is colorless and has a distinct of taste and smell Ethanol is categorized as a mildly toxic substance.

2.2.2 Important qualities of SI engine fuels

Gasoline which is mostly used in the present day SI engines is usually a blend of several low boiling parafins, naphthenes and aromatics in varying proportions. Some of the important qualities of gasoline are discussed below especially effect with cold start problem.

2.2.2.1 Volatility

Volatility is one of the main characteristic properties of fuel which determines its suitability for use in an SI engine. Since gasoline is a mixture of different hydrocarbons, volatility depends on the fractional composition of the fuel. The usual practice of measuring the fuel volatility is the distillation of the fuel in a special device at atmospheric pressure and in the presence of its own vapor. The fraction that boils off at a definite temperature is measured. The characteristic points are temperature at which 10, 40, 50 and 90% of the volume evaporates as well as the temperature at which boiling of the fuel terminates. The method for measuring volatility has been standardized by the American Society for Testing Materials (ASTM) and the graphical representation of the result of the tests is generally referred to as the ASTM distillation curve. The more important aspects of volatility related to engine fuels are discussed in detail in conjunction with the distillation curve.

V. F. Andersen et al. (2009)[25] investigated volatility of alcohol-gasoline blends as result on distillation curves. This investigation observe on presented for single-alcohol blends in gasoline, containing 5-85% by volume of methanol, ethanol, 1-propanol, 2-propanal, 1-butanol, i-butanol (2-methyl-1-propanol), and t-butanol (2-

methyl-2-propanol). Most alcohols are shown to form mixtures with gasoline exhibiting near-azeotropic behavior that significantly affects the shape of the distillation curves. The results are compared to literature data available for some alcohols. In addition, distillation curves for a variety of dual-alcohol blends are presented, containing 10% of each of two alcohols. We show that such dual-alcohol blends have distillation curves closer to that of the base gasoline than single-alcohol blends with20%of either alcohol individually. At present, ethanol is the only bio-fuel alcohol available in scale. Haltermann EEE gasoline was tested. EEE gasoline is similar to "Indolene" from Amoco/BP, both of which are standard gasoline without additives. EEE gasoline has a Reid vapor pressure of 60-63 kPa. And the ethanol used was ethanol (99.5+%, 200 proof, <0.005% water). Distillation curves for ethanol blends are shown in Figure 2.2 and are provided in tabular form in the Supporting Information. The trends for ethanol-gasoline blends are similar to those observed for methanol-gasoline blends. A similar type of effect has been observed with vapor pressures of blends where adding small percentages of alcohol to gasoline increases the vapor pressure more than adding larger percentages. The observations above are consistent with the well known phenomenon of azeotropic behavior of mixtures of methanol and the hydrocarbons of the base gasoline. For a true azeotrope, the liquid molar composition is identical to the composition of the vapors formed. During distillation of an azeotrope, both compositions remain constant until the fluid is completely evaporated. Thus, the distillation curve for a true azeotrope should become flat and remain flat until the distillation is complete. With the methanol-gasoline blends, the distillation curve never becomes truly flat and exhibits a steady rise in the late region. Given these considerations, it may be more appropriate to describe this as a "near-azeotropic mixture" of the alcohol and the gasoline hydrocarbons. While the addition of 5-25% ethanol leads to little, or no, discernible change in IBP (initial boiling point), there is a substantial decrease in distillation temperature (i.e., increase in volatility) over the middle portion of the distillation curve. As observed with methanol blends, the addition of small amounts of ethanol (E5 and E10) gives the largest increase in volatility for the first approximately 30% of the distillation curve. As the fraction of ethanol increases (from E10 to E25), each distillation curve moves progressively closer to that of gasoline over the first approximately 30% of the volume distilled. The IBPs for E50 and E85 blends are substantially greater than those of the base gasoline and trend toward that for pure ethanol (78 °C). As similarly observed for methanol blends, the extent of the deviation in the initial portion of the distillation is substantially larger than would be expected simply from the amount of ethanol in the blend. For example, the distillation temperature for E5 increases more slowly than the base gasoline from

T10 to T30, but then increases sharply at T50 and thereafter, approaching that of gasoline. These observations indicate that ethanol forms a near-azeotropic mixture with the gasoline hydrocarbons and consequently the impact of ethanol on fuel volatility is substantially greater than expected for ideal mixtures.

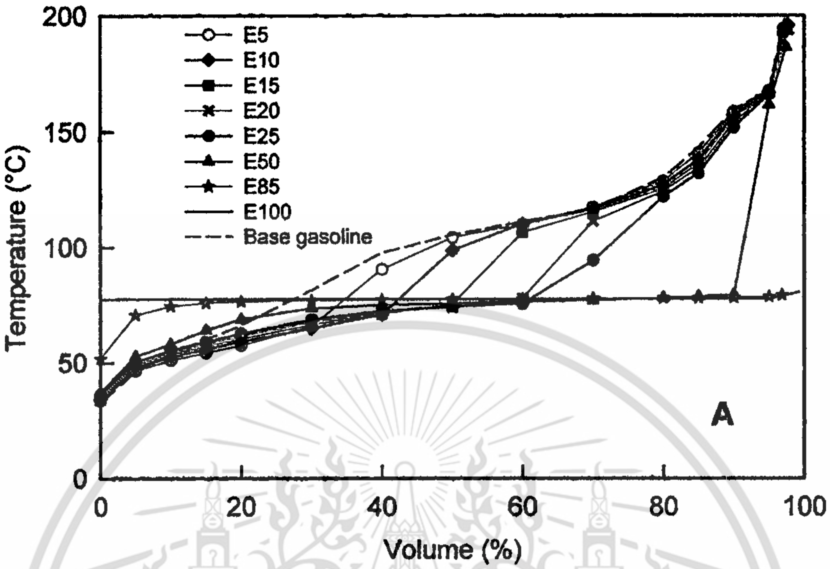


Figure 2.2 Distillation curves for blends of ethanol and gasoline[25]

As Lange's handbook of Chemistry 10th edition[31] – The formula is estimated vapor pressure of ethanol with temperature is illustrated in Figure 2.3. The trend line of vapor pressure is likely very low in low temperature. By standardize of Reid Vapor Pressure (RVP) at 37.7°C has value of vapor pressure more than at 10°C about 10 times. According calculation can define cold start problem at low temperature by limitation of lean flammability limit of ethanol. The too low ethanol vapor pressure or too low of ethanol in gas phase is not ignite and start of combustion.

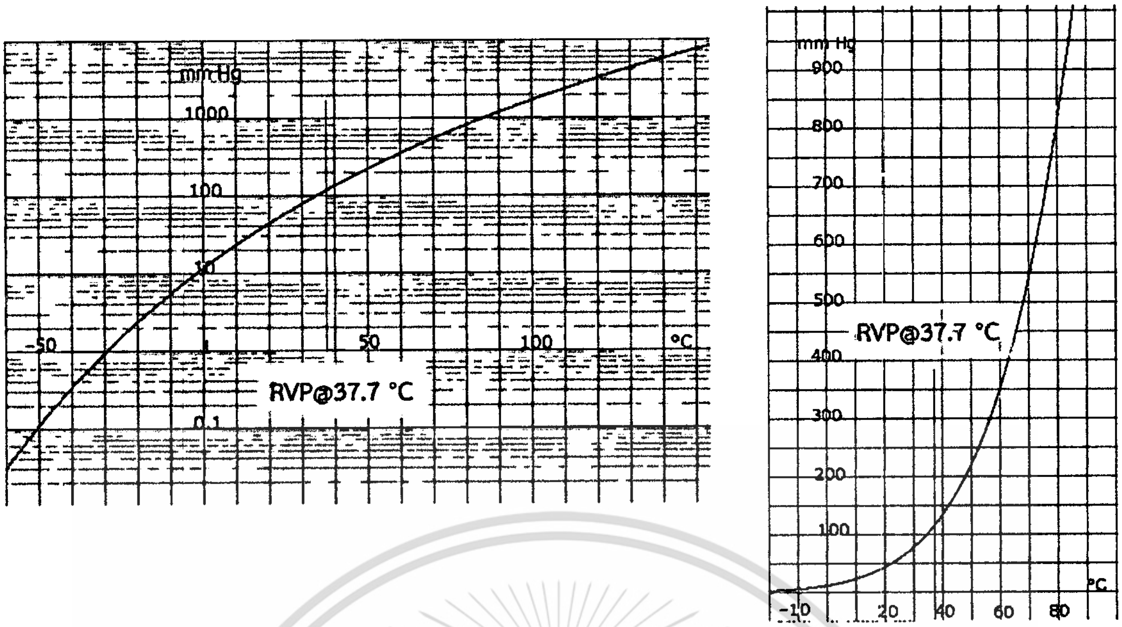


Figure 2.3 Ethanol vapor pressure with Temperature by Calculation [31]

Ethanol vapor pressure vs. temperature. Uses formula:

$$P_{mmHg} = 10^{8.04494 - \frac{1554.3}{222.65+T}} \qquad (2.1)$$

2.2.2.2 Starting and warm up

A certain part of the gasoline should vaporize at the room temperature for easy starting of the engine. Hence, the portion of the distillation curve between about 0 and 10% boiled off have relatively low boiling temperatures. As the engine warms up, the temperature will gradually increase to the operating temperature. Low distillation temperatures are desirable throughout the range of the distillation curve for best warm-up.

2.2.2.3 Operating Range Performance

In order to obtain good vaporization of the gasoline, low distillation temperatures are preferable in the engine operation range. Better vaporization tends to produce both more uniform distribution of fuel to the cylinders as well as better acceleration characteristics by reducing the quantity of liquid droplets in the intake manifold.

2.2.3 Fuel evaporation

In addition to the break-up of the spray and the mixing processes of air and fuel droplets, the evaporation of liquid droplets also has a significant influence on ignition, combustion, and formation of pollutants. The formation of fuel vapor due to evaporation is a prerequisite for the subsequent chemical reactions. The evaporation process determines the spatial distribution of the equivalence ratio, and thus strongly affects the timing and location of ignition. The energy for evaporation is transferred from the combustion chamber gas to the colder droplet due to conductive, convective, and radiative heat transfer, resulting in diffusive and convective mass transfer of fuel vapor from the boundary layer at the drop surface into the gas, Figure 2.4. This again affects temperature, velocity, and vapor concentration in the gas phase. Hence, there is a strong linking of evaporation rate and gas conditions, and, for this reason, there must always be a combined calculation of heat and mass transfer processes. In order to describe the evaporation process mathematically, the following assumptions are usually made: the radiative heat transfer is neglected because it is small compared to the convective one. Because it is not feasible to resolve the flow field around all the droplets of a spray, the evaporation modeling is based on averaged flow conditions and average transfer coefficients around the droplets. The droplets are usually assumed to be of spherical shape. Deformation, break-up, collisions, and other interactions of droplets are neglected during the calculation of evaporation. Further on, the droplet's interior is usually assumed to be well mixed. For this reason, there are no spatial gradients of the relevant quantities like liquid temperature, concentration of fuel components, boiling temperatures, and critical temperatures, heat of evaporation etc. inside the droplet, and only a dependence on time is possible. Furthermore, the solubility of the surrounding gas in the liquid and the effect of surface tension on the vapor pressure are neglected. In order to determine the transport processes at the gas/liquid interface (mass and energy fluxes), phase equilibrium is assumed. It is presumed that the phase transition (liquid to vapor) is much faster than the vapor transport from the surface into the surrounding gas. Further on it is assumed that even if the conditions in the gas phase or inside the droplet change (e.g. temperature rise), phase equilibrium is always immediately reached. The concentration of fuel vapor and thus also the properties of the gas mixture in the boundary layer are strongly dependent on radius, Figure 2.4 In order to get representative values for the calculation of the diffusive mass transport, simplified vapor concentration curves are customarily used.

In order to determine the transport processes at the gas/liquid interface (mass and energy fluxes), phase equilibrium is assumed. It is presumed that the phase transition (liquid to vapor) is much faster than the vapor transport from the surface into the surrounding gas. Further on it is assumed that even if the conditions in the gas phase or inside the droplet change (e.g. temperature rise), phase equilibrium is always immediately reached. The concentration of fuel vapor and thus also the properties of the gas mixture in the boundary layer are strongly dependent on radius, Figure 2.4. In order to get representative values for the calculation of the diffusive mass transport, simplified vapor concentration curves are customarily used.

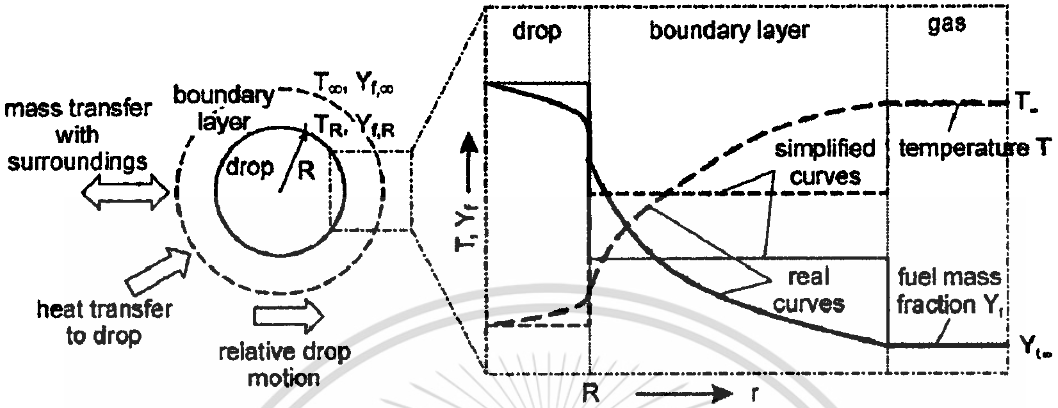


Figure 2.4 Schematic view of drop vaporization[24]

Although real fuels consist of a multitude of different components that influence the evaporation process (more volatile but less ignitable components evaporate first, components with higher molecular weight evaporate later), the standard approach today is to use a single-component model fuel. Usually tetradecane (n-$C_{14}H_{30}$) is used in order to represent the relevant properties of diesel, and octane is used for gasoline. The temperature change of the liquid droplet can be obtained from an energy balance. The total heat flux transferred from the hot gas to the liquid droplet results in an increase of droplet temperature (heating) and in evaporation. In equation 2.2-2.4, m_{drop} and T_{drop} are the droplet mass and temperature, $C_{p,l}$ is the specific heat capacity of the liquid fuel, Δh_{evap} is the enthalpy of evaporation, and m_{evap} is the mass that evaporates in the time interval dt. Using equation 2.3 and 2.4 in equation 2.2 and solving for the temperature change yields.

$$\dot{Q}_{drop} = \dot{Q}_{heating} + \dot{Q}_{evap}\,, \tag{2.2}$$

$$\dot{Q}_{heating} = m_{drop} c_{p,l} \frac{dT_{drop}}{dt}\,, \tag{2.3}$$

$$\dot{Q}_{evap} = \Delta h_{evap} \frac{dm_{evap}}{dt}\,, \tag{2.4}$$

The Microscopic View - When a solid or a liquid evaporates to a gas in a closed container, the molecules cannot escape. Some of the gas molecules will eventually strike the condensed phase and condense back into it. When the rate of condensation of the gas becomes equal to the rate of evaporation of the liquid or solid, the amount of gas, liquid and/or solid no longer changes. The gas in the container is in equilibrium with the liquid or solid. The pressure exerted by the gas in equilibrium with a solid or liquid in a closed container at a given temperature is called the vapor pressure. at a higher temperature, more molecules have enough energy to escape from the liquid or solid. At a lower temperature, fewer molecules have sufficient energy to escape from the liquid or solid. Figure 2.5 show microscopic equilibrium between gas and liquid at low temperature on right figure. Note the small number of particles in the gas. On left figure is representing microscopic equilibrium between gas and liquid at high temperature. Note the large number of particles in the gas.

Figure 2.5 Equilibrium Vapor Pressure [32]

2.2.4 Flash-boiling

When a liquid, initially in a sub-cooled state, is rapidly depressurized to a pressure sufficiently below the saturated vapor pressure, it can no longer exist in the liquid state, and a rapid boiling process called flash-boiling is initiated. A portion of the fuel then evaporates instantaneously and cools the rest of the liquid down. This sudden evaporation results in a significant increase of spray volume and a faster spray break-up. In the case of high-pressure diesel injection, the phenomenon of flash-boiling can only be achieved if the fuel is sufficiently preheated before injection. In the case of gasoline injection, flash-boiling is much easier to obtain due to the lower boiling curve. Especially if gasoline is injected in the intake manifold where the static pressure can fall below the saturated vapor pressure of some hydrocarbon fuel components. Such a condition will result in unintended flash-boiling. This causes significant changes in the fuel spray distribution and the fuel-air mixing. figure 2.7 shows the conventional and the flash-boiling fuel injection in a pressure- enthalpy diagram. Sub-cooled liquid exists to the left of the liquid saturation line, and superheated vapor exists to the right of the vapor saturation line.

Superheated liquid can exist for a significant period of time without phase transition in a metastable condition between the liquid saturation line and the liquid spinodal, while to the right of the liquid spinodal there is no metastable state and liquid and vapor must coexist. During injection, the highly pressurized fuel leaves the nozzle through the injection hole, in which the liquid is strongly accelerated and the pressure decreases. In the case of conventional injection (line 1'- 2'), the fuel temperature, and thus the enthalpy, is too low to cross the liquid saturation line during pressure decrease. In the case of flash-boiling injection, the increased fuel temperature results in a higher fuel enthalpy, and the fuel undergoes a pressure reduction from point 1 to point 4 while passing through the nozzle hole. Between point 2 and point 3, vapor bubbles are formed and begin to grow. If there were be enough time, an equilibrium vapor fraction would be achieved. As point 3 is approached, the nucleation rates become large, and beyond point 3 the transition from vapor to liquid becomes explosively rapid.

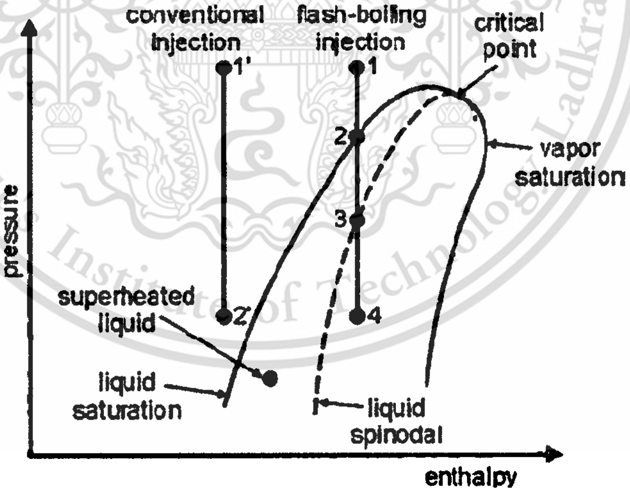


Figure 2.6 Comparison of conventional injection and flash-boiling injection[24]

2.2.5 Ethanol for SI engine

Ethanol has higher antiknock characteristic compared to gasoline. As such with an ethanol fuel, engine compression ratios of between 11:1 and 13:1 are usual.

Today's gasoline engines use a compression ratio of around 7:1 or 9:1, much too low for pure alcohol.

In a properly designed engine and fuel system, alcohol produces fewer harmful exhaust emissions. Ethanol contains about half the heat energy of gasoline per liter. The stoichiometric air fuel ratio is lesser for ethanol than for gasoline. To provide a proper fuel air mixture, a carburetor or fuel injector fuel passages should be doubled in area to allow extra fuel flow.

Ethanol does not vaporize as easily as gasoline. Its latent heat of vaporization is much greater. This affects cold weather starting. Ethanol liquefies in the engine and will not burn properly. Thus, the engine may be difficult or even impossible to start in extremely cold climate. To overcome this, gasoline is introduced in the engine until the engine starts and warms up. Once the engine warms, alcohol when introduced will vaporize quickly and completely and burn normally. Even during normal operation, additional heat may have to be supplied to completely vaporize ethanol. Ethanol burns at about half the speed of gasoline. As such, ignition timing must be changed, so that more spark advance is provided. This will give the slow burning ethanol more time to develop the pressure and power in the cylinder. Moreover, corrosion resistant materials are required for fuel system since ethanol is corrosive in nature.

2.3 Historical temperature in Thailand

Thailand is a tropical country. Average ambient temperature is higher than 25°C. The engine is workable without cold start problem. But according to historical minimum temperature data in Thailand can be consider cold start problem of ethanol engine will be occur in winter.

Table 2.1 Minimum temperature in last 5 years of Bangkok[Appendix C]

Year	Temperature(°C)	Month
2006	13.9	February
2007	18.1	February
2008	17.9	January
2009	15.5	January
2010	20.0	January

Table 2.2 Minimum temperature in last 5 years of Thailand[Appendix C]

Year	Temperature(°C)	Location	Month
2006	3.5	Northern	February
2007	5.6	Northern	February
2008	6.0	Northern	January
2009	4.2	North-eastern	January
2010	9.8	Northern	January

Table 2.3 Minimum temperature in last 4 years of High ground[Appendix C]

Year	Temperature(°C)	Location	Month
2003	1.5	Northern	February
2004	-2	Northern	January
2005	2.5	Northern	January
2006	2.5	North-eastern	January

2.4 Cold start issues

There are two major problems related to cold engine starting when using ethanol with conventional SI engine. The first problem is reliable engine startup without excessive cranking and amounts of CO_2. The other is relatively slow heating (light off) of the way catalyst. In general, starting up of FFV vehicle engine will not be problem if certain measures are taken. For example, cold start is generally not a problem when low-level of ethanol is blended such as E5 or E10 (other than those problems normally experienced with gasoline fuel). An investigation of E10 by the European Oil Company Organization for Environment, Health and Safety (CONCAWE) and GFC shows that ethanol itself does not cause cold start problems, as much as the low volatility caused by ethanol blending. In other words, it is possible to adjust and maintain a volatility level that complies with the existing gasoline standards.

Even in a tropical climate, such as the Brazil, measures do have to be taken to accommodate some impractical properties of ethanol related to engine start-up. In general, when ethanol constitutes as the major part of mixtures, cold start problems are more likely to arise.[2]

Ethanol-fueled engine is different from gasoline engine. In SI-engine, cold start problems occur because of the air-fuel mixture produced in combustion space of an engine at low ambient temperatures, depending on the type of ethanol fuel, is too low for a successful initiation and sustain combustion. Pure ethanol needs a higher gaseous concentration in air to be flammable, at 4.3 percent by volume, compared to about 1.4 percent for gasoline; see table 3.2 of fuels properties for completed detail. Being a pure substance, ethanol does not like gasoline which contains many high volatile components such as pentane and hexane that allow gasoline fueled engine to start at very low temperatures.[3] Due to the combination of these two factors, pure ethanol requires a higher gaseous concentration than gasoline to be combustible at a given ambient temperature. The main focus of the solution to overcome these natural properties of ethanol is therefore boosting the vaporization of ethanol. Flammability limit property is important and cannot be omitted, however, this research only focuses on start ability of ethanol and a solution of cold start with ethanol. There are a lot of techniques to improve cold start problem with ethanol-fueled engine, according to a review of previous works.[4]

There are some consideration points to be concerned to overcome cold start problems, such as efficiency, cost of technology, ease of use, and start up emissions have to be evaluated for the particular geographical location and market situation.

2.5 Literature review

In this section, author carefully reviewed literatures from many researchers who are researching in the area of startup SI engine using ethanol as fuel at low temperature and results of their works can be summarize as follow;

In many cold climate countries have researched and solved cold start problem for many years and below lists some examples of research which author has reviewed in this section

S. Y. Liao *et al.* (2005) [5] investigated the cold-start combustion characteristics of ethanol-gasoline blends in a constant-volume chamber. It can be concluded that a reliable and rapid cold start of spark ignition engines is related to unburned hydrocarbon emissions, as well as energy efficiency. As combustion characteristics are relevant parameters for a stable combustion initialization. The effect of the equivalence ratio on the combustion pressure, ignition delay time, mass burning rate, and the flame propagation speed are studied in detailed. It is shown that moderate ethanol addition can slightly improve the reliability of a cold start, compared to gasoline, but with the increase of ethane content, this improvement of ethanol on a cold start does not become obvious. Ethanol addition into gasoline results in a significant increase of HC emissions for rich fuel-air mixtures with the same equivalence ratio, however, in view of a cold start, it is also indicated that HC and CO emissions can be reduced because the engine can never be over fueled like a gasoline engine.

Campbell S. (1996) [6] has studied flame and liquid fuel in an SI engine cylinder during cold start. An optical SI engine equipped with a conventional port injection fuel system was investigated during the cold start period as operated by unleaded regular gasoline. The high-speed multiple spectral infrared images were obtained in the results. From this study can be concluded that in the first ignition cycle, the flame fronts are observed over the entire imaging view of the chamber, which suggests that the fuel vapor was accumulated in the zone during the previous (no-ignition) cycle and the flame propagations in the second, third and fourth cycles are more intense and exhibit a remarkable difference in strength. It is extremely intense in second and comparably weak in third and fourth cycles. The reaction centers produce radiation after about 15 ATDC, indicating the need of a tie period for liquid fuel to be heated to support the local diffusion reaction. The liquid layers causing the local reaction did not appear in every cycle, and likewise the opposite was found after the engine was well warmed. Some cyclic variations in liquid layer formation are pronounced to exist in the engine cylinder.

Scott W. Jorgensen (1988)[7] has proposed compression gas temperature during compression in a cold cranking engine. As part of the investigation, the author surmises the reasons for a success of cold starting observed in Robert M. Siewert and Edward G Groff (1987)'s research.[8] The primary outcome of the paper was that the compression temperature has less of an effect on producing a combustible mixture at low temperatures compared to the total delivered ignition energy. The author explains that the increase in compression gas pressure negates the effects of increased compression gas temperature and it is in fact the ignition energy delivered to the fuel droplets caused them to vaporize and ultimately form a combustible mixture with air. The processes led to the success of the cold starting in last paper was the use of an AC ignition system that provides a series of spark discharges, the first of these discharges transfers their energy to the fuel droplets and causes them to vaporize, then the later discharges act to ignite the previously vaporized fuel droplets.

Dual-fuel systems incorporate two separated fuel systems, including a small auxiliary fuel tank that contains a volatile fuel blend for cold starts. The concept has been used for many years in Brazil in dedicated ethanol vehicles, using gasohol as the auxiliary fuel, and is still the cold start solution used in modern Brazilian FFVs.(Vicentini, 2005)[9] The dual-fuel concept is very effective in facilitating cold starts but requires car owners to monitor and refill two fuel tanks. This type of system might be unacceptable to consumers in more affluent countries, where the demand for user passive systems is stronger.

In cold climates, the blending of large amounts of gasoline into ethanol is generally used as the cold start solution. According to the season and local climate, E85 contains between 70 and 85 percent ethanol, gasoline constituting the remainder. Even though this strategy is effective in starting the engine, it invariably leads to very high emissions of unburned and partly burned fuel components during the cold-start and warm-up phases of driving,(Kane. E.L., et al., 2001)[3] mainly because a major part of the injected fuel condenses on the cold cylinder walls and later exits the engine unburned.(Stanglmaier et al., 1997)[10] This tendency can be partly mitigated by the use of a block heater currently implemented by Ford and Saab in their northern hemisphere FFVs. The block heater is a heating element in the engine coolant that powered by an external cord connected to the power grid, heats the coolant to the optimal temperature of about 90°C.

The block heater solution has several serious shortcomings, however, chief among them is the need to plug the vehicle into the power grid and the poor choice between either wasting energy in keeping the coolant always warm when not driving, or alternatively, having to wait a very long time for the engine to heat up sufficiently before starting the engine. Although the block heater solution avoids the need to monitor two fuel tanks, the system can arguably be less user passive than the dual-fuel technology. At the same time, the need for an external power source necessitates national infrastructures of electrical power connections in the public space.

However, the block heater also has advantages. First, the devices needed are inexpensive and efficient in facilitating cold starts. Second, they reduce cold-start emissions considerably, both by vaporizing a greater fraction of the fuel and by heating the cylinder walls enough to prevent the (highly emission-producing) condensation of fuel species on cold cylinder walls.

In essence, OBDS (Onboard distillation system) provides the cold-start capability of the dual fuel system, by a user-passive and relatively inexpensive technology, which can be retrofitted for existing vehicles. Overall, the patent seems to be superior to other SI cold-start systems, when comparing price, convenience of use, start-up time, emissions and potential for retrofitting. The distillate is more volatile than gasoline, giving better cold start performance and lower cold start and warm-up emissions than gasoline or bi-fuel vehicles. At the same time, the price of the system is fairly low, both when used as a conversion kit but especially if used in mass production vehicles.[4]

Robert M. Siewert and Edward G Groff (1987)[11] have summarized the outcomes of the paper specific to alcohol fuel were that start time of 1-3 seconds could be achieved at -29°C. The start time were achieved through the use of a mechanical high pressure, direct fuel injection system and AC ignition system, key points to achieving successful cold starting were injection of fuel across the spark plug gap while firing the ignition system, long dwell times corresponding to high ignition energy and to a lesser extent increased compression ratio corresponding to increased cylinder air temperature on compression. The authors observed that the ignition energy for initiating and sustaining combustion at low temperatures for alcohol was of high importance.

Gregory W. Davis *et al.* (2000) [12] have studied using hydrogen to improve cold start problem of ethanol vehicle with E85. It can be summarized that cold start is a definite problem in alcohol fuels making it is almost impossible to start below 10 °C without additional technology. Operating with E85 at low temperature, despite of additional 15% gasoline, does not solve the cold starting problem. This problem can be minimized by using hydrogen supplemented E85 during cold starts. Not only does the cranking time decrease, but the emissions are also likely to decrease since over-fueling can be minimized. Increasing the amount of hydrogen injection decreases crank time up to about 12% hydrogen by volume. Additional hydrogen after that doesn't provide any noticeable improvement. The minimum level of hydrogen required appears to be around 8% at cold start conditions of -4 °C. This level of injection ensures that the hydrogen will not fall below the minimum flammability limit of 4 % for a substantial amount of time during engine startup. This information can then be used in order to size a reformer to meet cold start conditions.

Gregory W. Davis *et al.* (1999) [13] have studied the effect of multiple spark discharge on the cold-start ability of an E85 fueled vehicle. The results of the cold start testing show that the multiple spark capacitive discharge ignition does provide quicker cold starting and better idle characteristics than a standard OEM ignition. On the other hand, results of the cold start testing using the circular electrode spark plugs are inconclusive. They caused a significant increase in cold start time yet helped the engine to warm up quicker. It can be proposed that ethanol fuel wetting of the spark plug caused misfires which hurt cold starting, but once combustion temperatures were high enough that fuel wetting was no longer a problem, better combustion was realized. There is no hard data to confirm this theory, so further testing would be required. If a similar design spark plug which has a much larger shunt path was used, it might be possible to achieve even better cold starting than with the multiple spark ignition and OEM plugs.

Daniel Kabasin *et al.* (2009) [14] have investigated heated injector for ethanol cold start. In order to determine heated injector requirements, CFD (Computational Fluid Dynamics) was utilized in first to predict phenomena. As shown in figure 2.7 during a cold start without pre-crank heating, the PCM firstly applies 100% duty cycle to the heater when cranking commences in order to heat the ethanol. As the engine fires and begins to run, PCM reduces the fuel rate as well as the heater's duty cycle corresponding to its fueling command. As the engine settles into its cold idle, a minimal duty cycle maintains an elevated stream temperature to improve warm up drive-ability. In this case the PCM applies 100% duty cycle to the heater before cranking commences when a pre-set is triggered, such as the opening of the driver's door or insertion of the ignition key, is detected. As in the no pre-heating case, the PCM reduces the fuel rate as well as the heater's duty cycle when the engine fires and begins to run. Similarly, as the engine settles into its cold idle, a minimal duty cycle maintains an elevated stream temperature to improve warm up drivability. The result is shown in figure 2.8. Heating the fuel also improves low temperature warm-up drive-ability. Many sub tank systems require sustained gasoline injection. Heating the fuel reduces the liquid fuel requirement by increasing the vaporized fuel fraction.

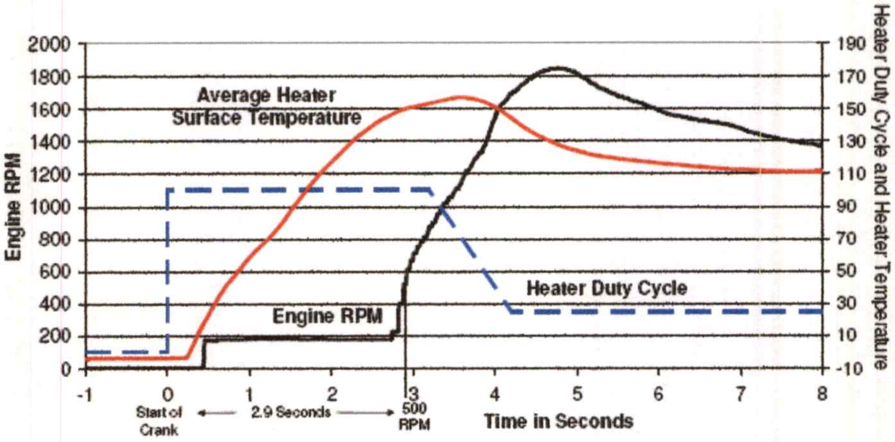


Figure 2.7 Ethanol engine at -5 °C without pre crank heating prototype injectors

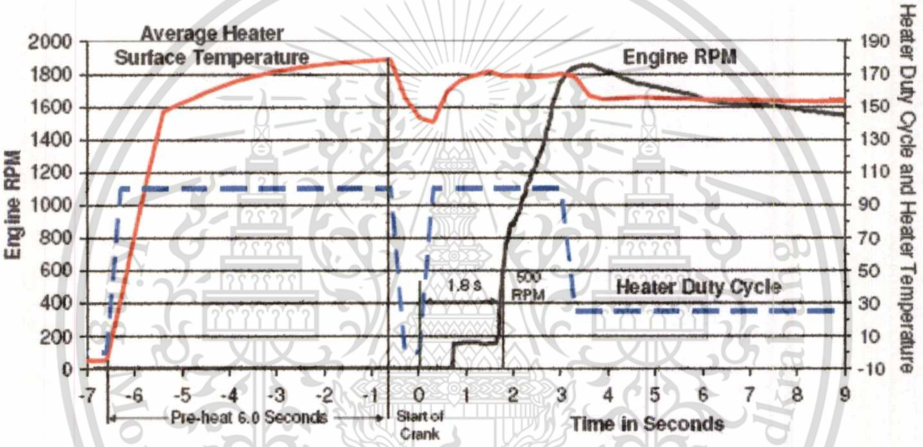


Figure 2.8 Ethanol engine at -5 °C with pre crank heating prototype injectors

Significant measures are being taken to avoid cold start problems with ethanol fuels. Current trends in engine technologies seem to suggest that less significant, or no measure at all, will be needed, other than what can be achieved with electronic engine calibration and management. Among the promising technologies are Gasoline Direct Injection (GDI), Variable Valve Timing (VVT) and, in general, a significant degree of engine management and control due to advances in sensor and Engine Control Unit (ECU) technology.

Direct cylinder fuel injection technology has recently been considered as a solution to the cold start difficulties with pure ethanol and E85. Although the direct injection technology itself is fully developed and commercial, its adaptation for higher percentage ethanol blends and FFV is still being developed. A few concept vehicles have been manufactured for showcase purposes and several automakers and research institutions are working on projects with the ethanol direct injection (EDI) engine but scientific documentation of these efforts is limited.

Tyron Dean Utley *et al.*(2008)[15] investigated low temperature starting on a pure ethanol fuelled direct injection engine by using Mie scattering with constant volume combustion chamber and engine. The conclusion of this research indicates that there is general trend of reduced spay penetration with reduced temperature. It can therefore be said with some level of confidence that spray atomization and penetration of this E93 mixture is reasonable over the range of temperatures studied in this paper, depicted in figure 2.9. The suggestions are for a direct injection engine moving the injection event closer to ignition increases the likely hood of inflammation and therefore assists in decreasing start time and separation of the single fuel-air injection event into two separate fuel-air injection events theoretically assists in fuel vaporization and reduces fuel spray impingement on the piston crown associated with late injection through reducing the fuel mass injected in the late (second) injection event. For ignition system, multi-strike ignition system with high power (high energy and short duration charges) significantly reduce start times compared to standard inductive electronic ignition system.

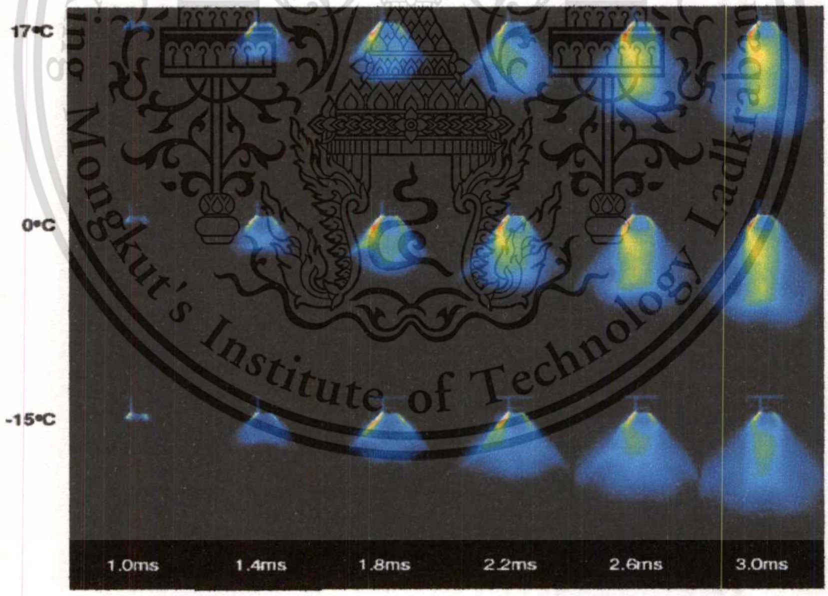


Figure 2.9 Ensemble averaged images of Mie Scattering with different temperature[15]

Takashi Tsunooka *et al.* (2007) [16] have interested on high concentration ethanol effected to SI engine cold startability. The researchers were to optimize valve timing in order to investigate on the effect of compression peak temperature then using AVL-BOOST software. Engine model was built to simulate the characteristics of airflow into the combustion chamber and investigated under the same compression peak temperature with difference in reid vapor pressure. The results can be concluded that the concentrated ethanol fuel application with spark-ignited engine, boosting the fuel vaporizability is more effective than raising fuel deliver pressure in order to improve the cold startability. Therefore, addition of gasoline (E85) radically improves its cold startability compared with E100. Moreover, valve lifting and timing control successfully improves the cold startability due to the increase in compression peak temperature. VVT enables intake and exhaust valves to open and close at different points of time and lifting height according to the conditions and needs of the engine. This technology is already widespread and Toyota has demonstrated its potential for cold starting with high level ethanol fuels. By limiting the amount of intake air with aid of VVT, the effective compression ratio is raised and an increase in peak compression temperature (more than 100°C) was obtained. As a result, the lower limit in terms of temperature for successful cold start was moved downward. In case of highly concentrated ethanol fuel application in spark-ignited engine, contribution of Butane constituent for cold start overtakes gasoline constituents under equal vapor pressure.

During cold conditions injection of more fuel with a DI fuel system can cause problems because the DI system is designed to operate at high pressure. During engine start up, there might not be sufficient pressure to provide the needed amount of fuel, in the time available for injection and the engine therefore does not start. The time duration of fuel injection in DI engines is limited compared to that in PFI engines, due to the risk of injecting fuel directly into the exhaust pipes.

Marriott. C.D. (2008)[17] has investigated the possibility of high pressure start to ensure the injection of a sufficient amount of fuel. The high pressure option enables a much shorter injection time period and makes it possible to inject fuel at the end of the compression stroke, where the compressed air is very hot, providing much improved fuel evaporation. High pressure start also enables better fuel atomization, also improving vaporization. The high pressure is provided by delaying the start by about 1 second, leaving the fuel pump time to build up pressure. The study noted that the requirement for the extra amount of fuel at cold temperatures with DI decreased by a factor 10 compared to PFI systems. Despite the lesser amount of fuel required, the maximum fuel flow still constituted a limit for low temperature start up.

Kapus, P.E. (2007)[18] study investigated the spray inside the combustion chamber during engine start up. During starting up, DI engines can significantly reduce the excessive amounts of fuel because of the high pressure and precise control of the injection. Thereby DI can reduce unburned fuel emissions, which is important, because the catalyst is not yet hot enough to reduce these emissions. In this case, effective reduction depends not only on high pressure injections but also, perhaps more importantly, on the use of multiple injection strategies (fuel injection is split up into several smaller injections).

The much lower limit obtained by fuels is due to an increased vapor pressure through the chemical formulation of the fuel. RVP has much larger effect than VVT. In this case, the higher RVP is obtained by adding butane to the ethanol along with gasoline since butane was found to have a very significant impact on RVP, more than regular gasoline constituents. The difference is so significant that hydrous E100 fuel containing a small amount of butane would have better cold start properties than an E85 fuel containing regular gasoline.

Silva, N.R. (2000)[19] focused on Methyl Tertiary Butyl Ether (MTBE) as a possible solution to the cold start problem, even though MTBE has been criticized for its unfortunate environmental properties. The results showed that using MTBE as an additive, successful engine start could be made with temperatures down to -6°C which is more than good enough for the Brazilian market.

Additives could very well be an important solution to the cold start problem, but further tests, including environmental assessments, should be conducted. However, the RVP of the gasoline used to blend with ethanol is very important.

CHAPTER 3

EXPERIMENT PROCEDURES

3.1 Apparatus and Experimental set up

This project consists of acquiring or designing and fabricating test equipment, converting the engine to operate using E100 fuel, and cold start testing. The instruments are installed on experimental environment described below.

3.1.1 Cold soak chamber

Design and Construction of an Environmental Cold-Soak Engine Chamber - A cold soak chamber was designed and manufactured in order to control ambient temperature. Figure 3.1 illustrates a conceptual drawing of this chamber. Each side of container, including chamber' door, chamber are made from 2 sheets of stainless steel filled with polyurethane foam which is thermal insulation. The cold soak chamber is capable of reducing the temperature inside to at the lowest temperature of -20 °C, however The lowest temperature in this experiment is -2 °C which is the lowest temperature in Thailand in the past 5 years, according to the temperature data of Thai Meteorological Department.[Appendix C]

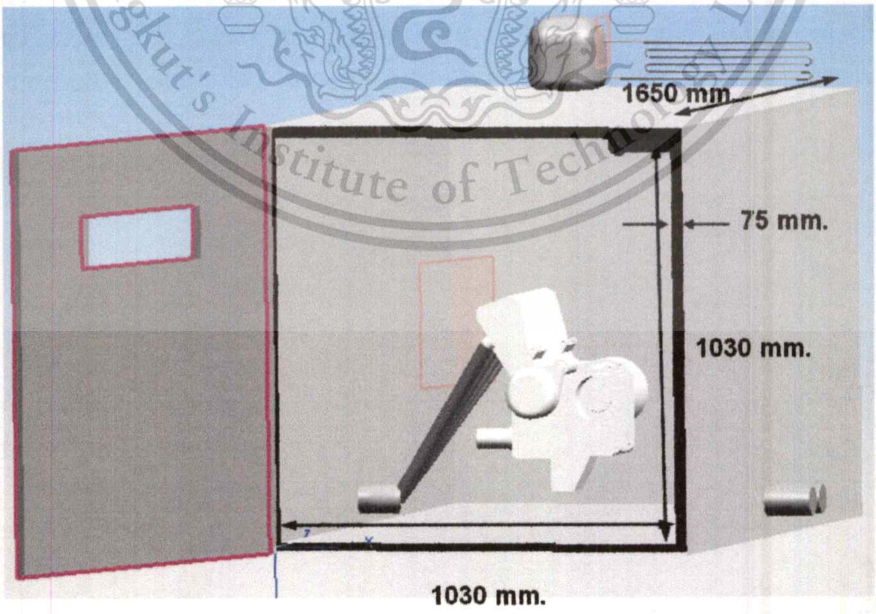


Figure 3.1 Design of soak chamber

A refrigeration system, commonly used on beverage freezer, was purchased to provide the chamber cooling. This system will remove heat at a minimum rate of 3000 W. From initial temperature of 25 °C is reduced to -2 °C in 60 minutes. A photograph of the entire chamber is shown in Figure 3.2.

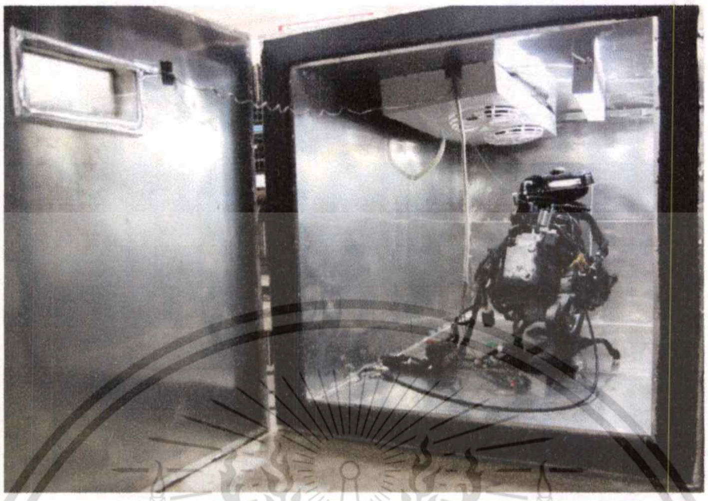


Figure 3.2 Photograph of cold soak chamber and tested engine

The Chamber was design 1 emitted outlet of emission to outside from the engine in back side in order to prevent unburnt hydro-carbon or residual gases from last combustion recirculation inside the chamber and re-combustion again. Also at the top of chamber has 1 inlet for fresh air from outside. Fresh air is conducted into the chamber by suction of the engine. For ventilation every after each testing – the front door is opened for ventilation and refreshing for new fresh air.

3.1.2 Cold start program

The testing data is captured and displayed using cold start program, running on the computer. The program communicates with micro controller device (AVR MEGA 128) to retrieve data such as Starting time, Revolution speed of engine, Injection duration, Air intake temperature, Mixture temperature and Engine oil temperature. The measurement tool of temperature is shown in Figure 3.3. Figure 3.4 shows example of software interface.

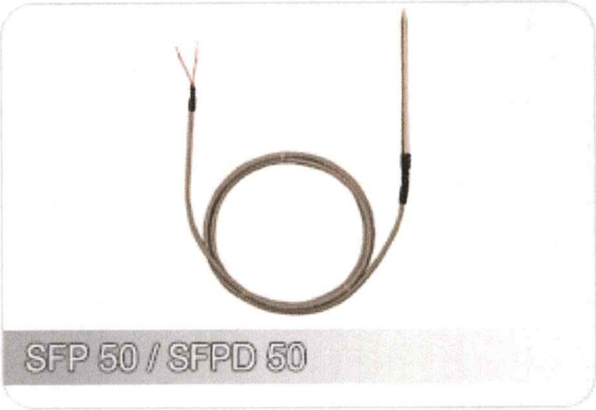
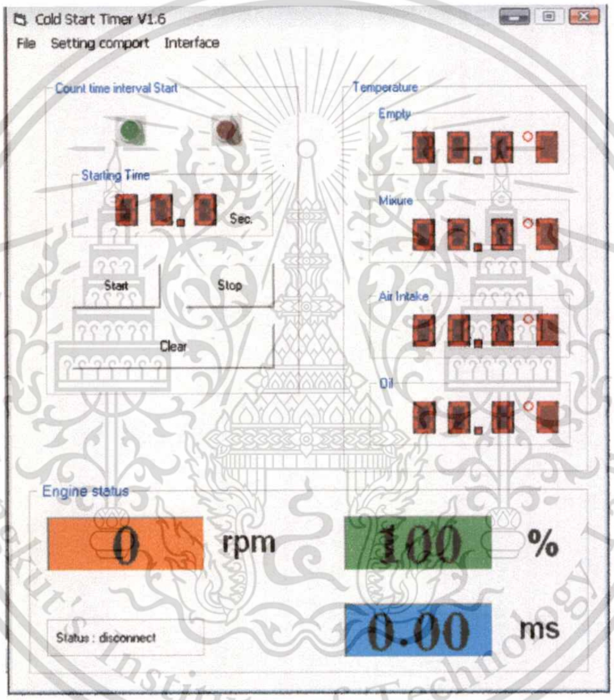


Figure 3.3 Thermo couple



Status : disconnect

Figure 3.4 Cold start counter clock software interface

3.1.3 Program interface

The program has status text field located at the left-bottom corner of the program. A successfully connection between personal computer and microcontroller board will trigger a program to change message text from “disconnect” to “connect”. User can control a starter switch of the engine by a start button of program and stop it by using a stop button. Green and red light indicate a status of electric starter. A green light is shown when electric starter is operating, while a red light is shown otherwise. The starting time counter clock will be started automatically and stop by itself when revolution speed of the engine gets over 900 RPM which is an indicator that the engine is operated in normal condition. The results of successful starting time can be retrieved from starting time counter clock displayed on this program. On the right-handed area of the program, there is a group of temperature displays which report information namely; Mixture temperature, air intake temperature and oil temperature. For an ambient temperature inside cold soak chamber is displayed by the temperature controller of refrigerator. Last, the engine status frame, located at the bottom of the program, is designed to show revolution speed of the engine, fuel injection duration which is also adjustable from this program by filling the number in box of percentage to increase fuel injection in percentage of original fuel injection signal from a main ECM.

Consider engine speed is designed at 900 RPM of engine. This point is selected from the slowest revolution speed can start the engine. From Figure 3.5 the period time for one rotation of engine can convert to revolution speed by F=1/T.

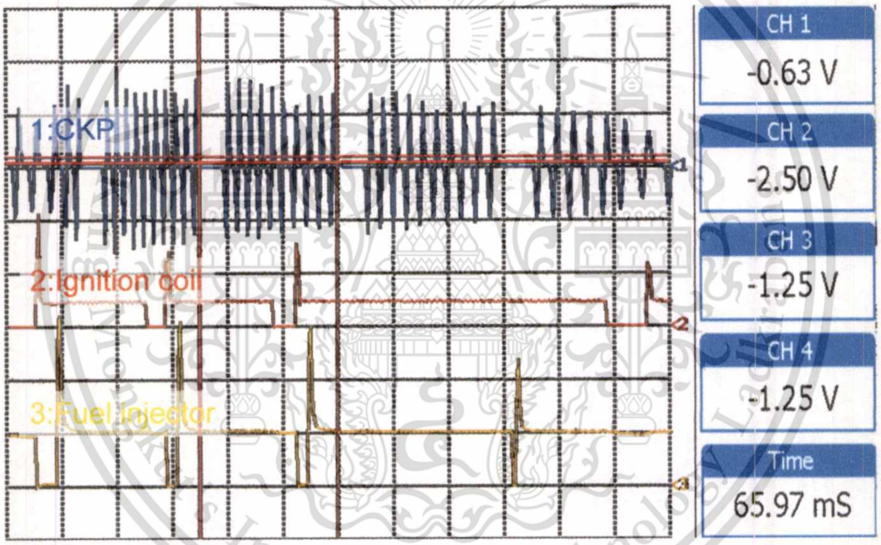


Figure 3.5 Consider engine speed at 900 RPM

3.1.4 Intake temperature sensor

An intake temperature sensor is located between a throttle valve and a fuel injector in order to measure upstream induced to the engine. The mixture temperature sensor is installed behind the fuel injector to measure a temperature of mixture of fuel and air. Figure 3.6 shows a location of glow plugs which located in cylinder head and tip of the glow plug insert through inside combustion chamber in order to heat up mixture before combusted.

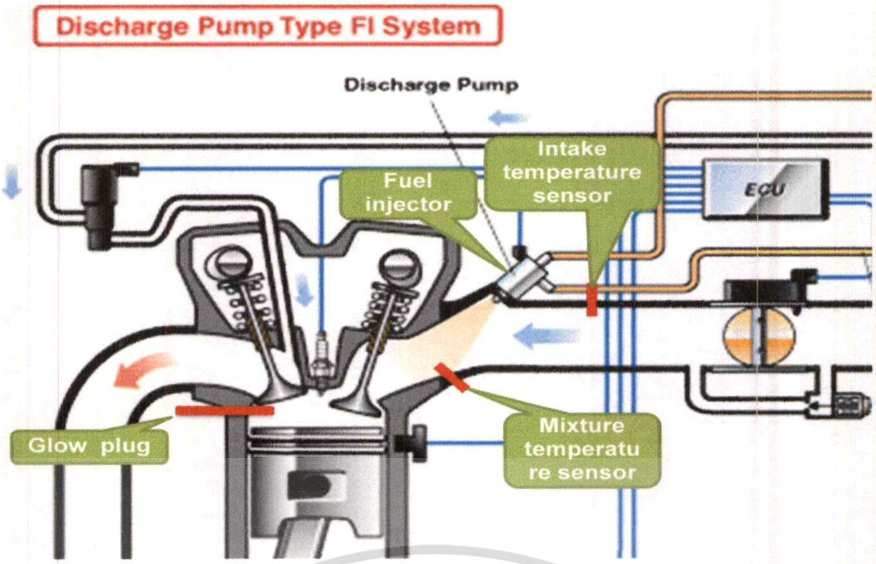


Figure 3.6 Shcemetic of temperature sensors

3.1.5 The oil temperature sensor

The oil temperature sensor is immerged in oil pan pass through oil fill gap. Figure 3.7 depicts an oil temperature sensor equipped at one end of oil level sensor. The oil temperature represents an entire temperature of the engine and it is used as a measurement to indicate that the engine is fully cool down and ready for testing in the next iteration.

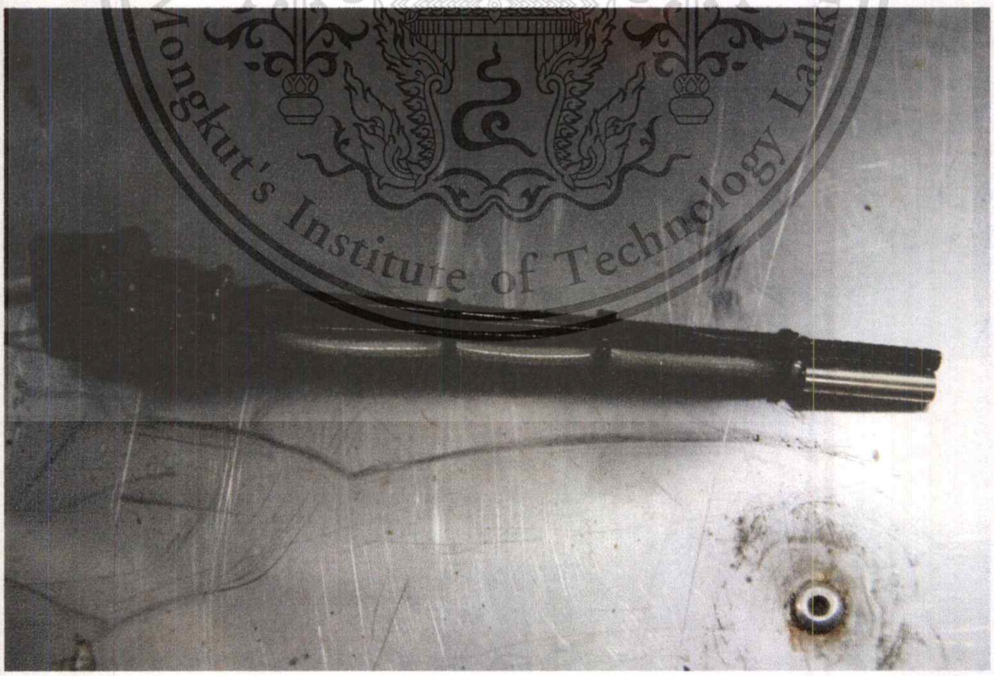


Figure 3.7 Oil level sensor and Oil temperature sensor

3.1.6 Injection signal expander

The injection duration is necessary to be extended to maintain the same air fuel ratio of ethanol as gasoline, hence additional amount of fuel needed to supply the engine. An original injection signal from the ECU alone cannot support a fuel consumption of the ethanol-fueled engine. The injection signal expander is controlled by a micro controller (AVR MEGA 128) and the author's program. The signal can be varied starting from 0 to 100 percentages of the extra injection signal from ECU. The injection signal expander controller is shown in Figure 3.8.

3.1.7 Injector signal driver

The signal from microcontroller normally operates at 5 voltages, however, for injector, it requires to operate at 12 voltages to drive the solenoid inside injector. As a result, this driver is used to step up signal voltages from 5 voltages signal to 12 voltages signal.

3.1.8 Electrical supply system

During the testing and each experimental, the voltage of battery have to maintain constant. The electrical supply system will charge energy into the battery.

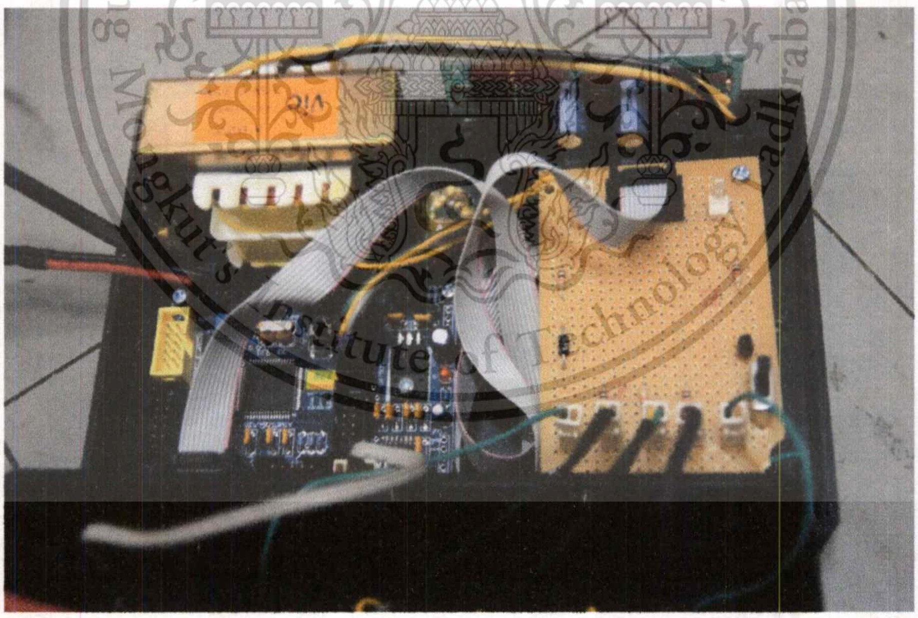


Figure 3.8 Electronic module

3.1.9 Oscilloscope meter

That measures electrical signal and frequency from sensors of engine and ECU (electronic control unit). An oscilloscope meter is required, in order to measure the injection signal from the ECU to display and compare injection signal between original signals and extended signal. Figure 3.9 shows the oscilloscope meter.

Figure 3.9 Oscilloscope meter

3.1.10 Glow plug heater

One technique of cold start assistance is heating up combustion chamber. It proposes to increase mixture temperature. This is very helpful for vaporization of ethanol at low temperature because ethanol needs much of energy to evaporate then gasoline. In this research, 60 W Glow Plug, illustrated in Figure 3.11, from a diesel engine is utilized to increase temperature in combustion chamber. It is installed inside cylinder head of engine as depicted in Figure 3.12. The glow plug is located at the opposite position of spark plug and between an intake valve and an exhaust valve. After the installation of glow plug, it is required to run an inspection to ensure that a compression pressure of engine still remain the same as the standard.

Otherwise in actually combustion chamber temperature is increased by compression by piston or peak compression temperature. In term of thermodynamic theory – Isentropic process is represented with compression stroke of engine. In Figure 3.10 - calculation can estimate peak temperature inside combustion chamber.

Isentropic process calculation formula use:

$$T_2 = T_1 \times \gamma_c^{k-1} \tag{3.1}$$

$$; \gamma_c = 9.6$$

; $k = 1.4$

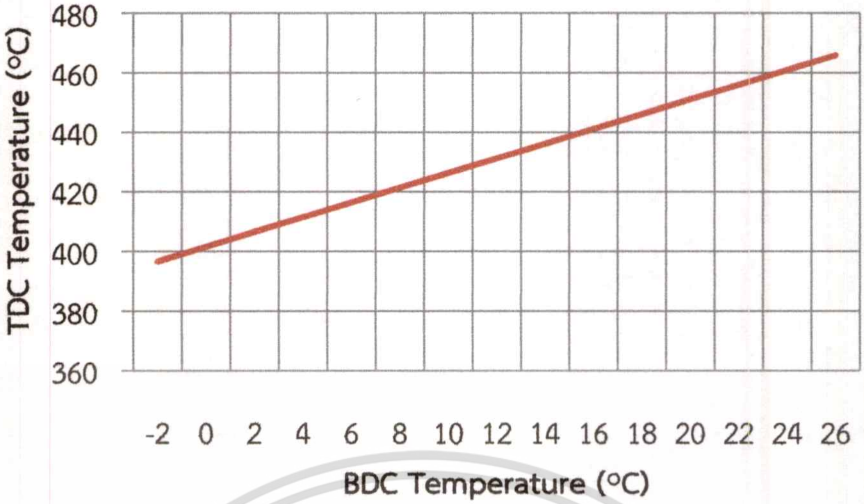


Figure 3.10 Estimation peak temperature by isentropic process

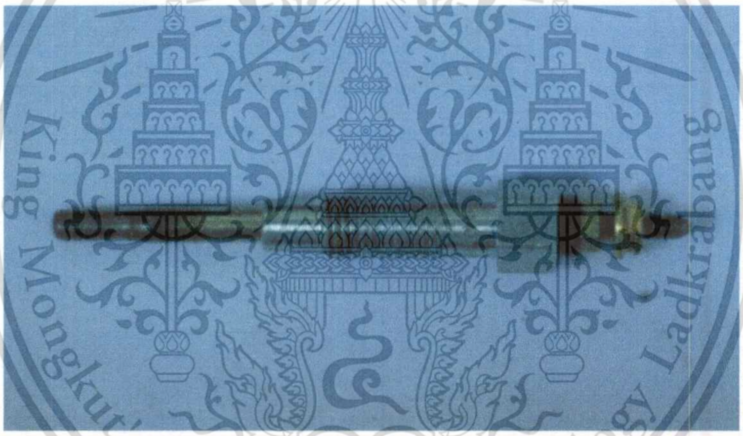


Figure 3.11 Heater (Glow Plug)

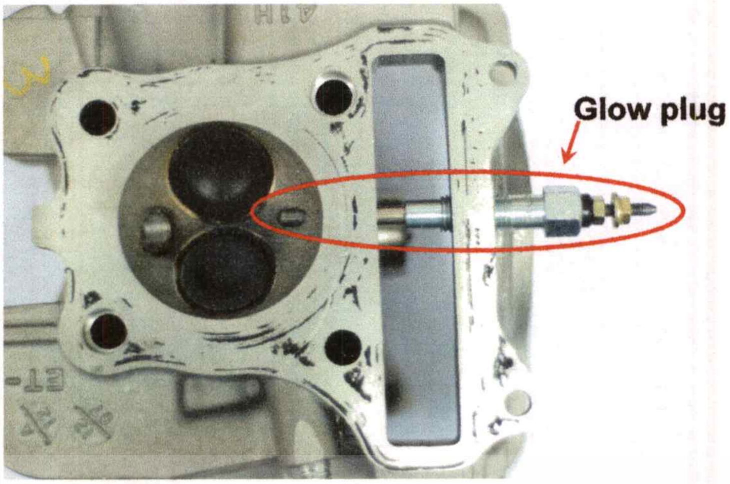
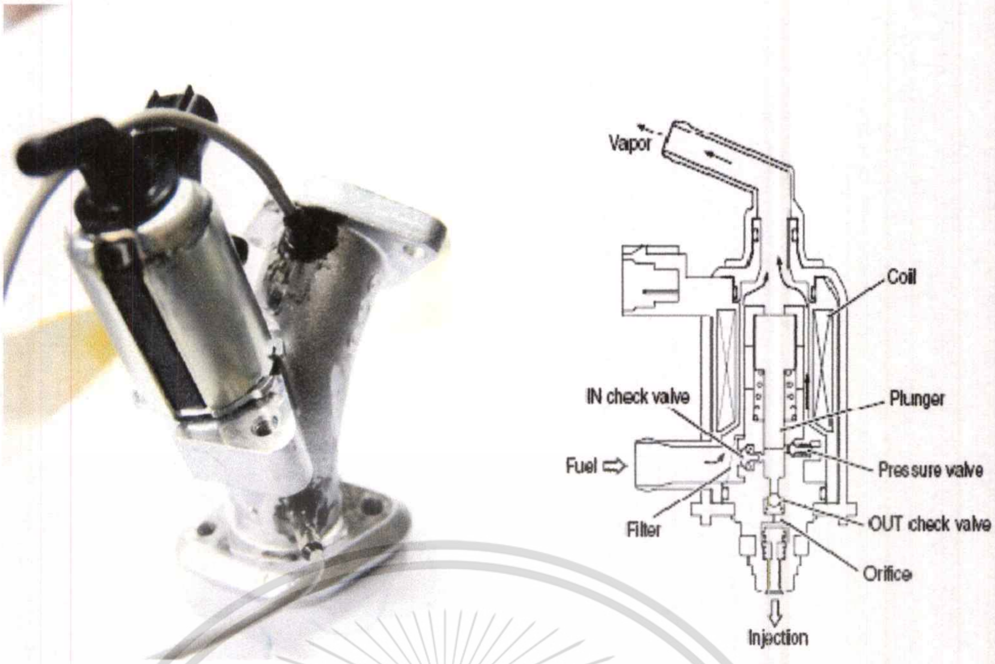


Figure 3.12 Glow plug installation

3.1.11 Discharge-pump Injector

Unlike conventional injector, discharge-pump injector has a pump plunger and regulation fuel system integrated inside the injector. If energy is supplied to a coil of plunger for a long time, it will heat up and serve as a heater for fuel. Therefore, holding of injection signal will increasing the inside injector temperature overtime. In this study, the injector is called heated injector in case of cold start assistance. Figure 3.13 shows a body of injector installed with intake manifold runner and virtualizes details inside the injector.



(a) (b)

Figure 3.13 (a) Heated injector, (b) Cross section of injector

3.1.12 Compression tester

To measure compression pressure inside combustion chamber and inspect the modified engine when installed the glow plug. The compression pressure in compression stroke of the engine is an important property which must be kept constant because a compression pressure of compression stroke has an effect to peak combustion temperature of the engine which reduces starting time since higher temperature in combustion chamber will raise up vaporization rate of fuel. Figure 3.14 shows an example of compression tester.

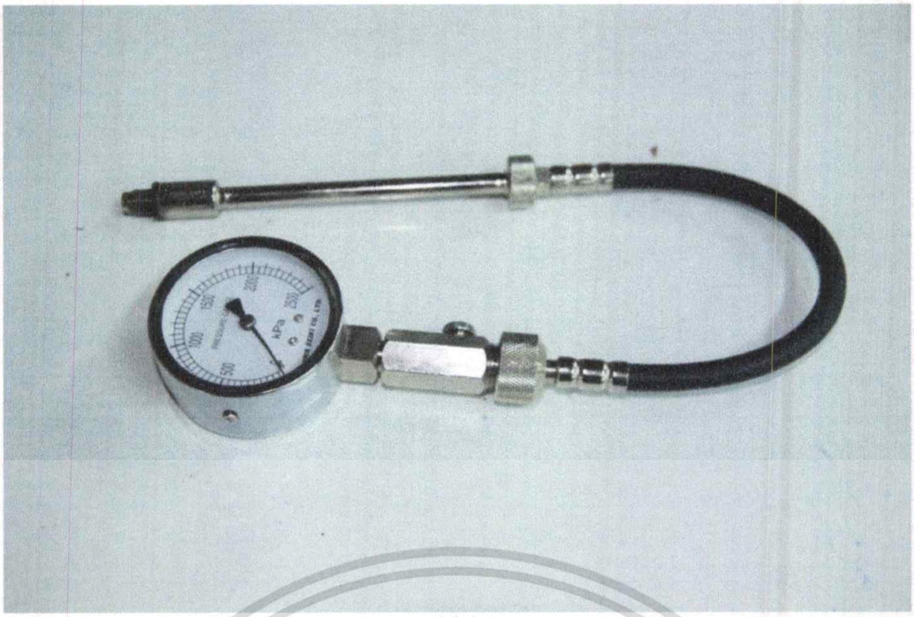


Figure 3.14 Compression tester

The compression pressure of a cylinder is a key indicator of its internal condition. The decision to overhaul the cylinder is often based on the results of a compression test. Periodic maintenance records kept at dealership should include compression readings for each maintenance service. The standard limit is 800 – 1200 kPa (8.0 – 12.0 kgf/cm^2).

3.1.13 Humidifier

The ultrasonic humidifier was used to mist ethanol fuel in order to assist vaporization of ethanol. The specifications of humidifier are 105 W, mist volume 240 ml/hour. Two humidifiers were used to ensure that sufficient ethanol mist was supplied to the engine. Figure 3.15 show body of humidifier.

Figure 3.15 Humidifier 40 ml/minute

3.2 Testing engine

The injection system engine, Suzuki model skydrive 125, is selected as a test bed for this experiment because component of this engine is a signal cylinder that is easy to modify and keep in good condition, low heating capacity making it takes short time to cool down and, more importantly, currently use in Thailand.

Table3.2 shows its specification and Figure 3.16 The testing engine inside cold soak chamber depicts the tested engine located in cold soak chamber.

Table3. 1 Testing engine specifications[26]

Description	Specification
Brand	SUZUKI
Model	UK125FS (Skydrive)
Type	Four stroke, forced air-cooled, OHC
Number of cylinders	Single cylinder
Bore	53.5 mm.
Stroke	55.2 mm.
Displacement	124 cm^3
Compression ratio	9.6 : 1
Fuel system	Fuel injection
Air cleaner	Polyurethane foam element & paper
Start system	Electric
Lubrication system	Wet sump
Idle speed	1600 ± 100 RPM
Electrical	
Ignition type	Electronic ignition (Full transistorized)
Ignition timing	10° B.T.D.C. at 1600 RPM
Spark plug	NGK CR6HSA or DENSO U20FSR-U
Battery	12 V 12.6 kC (3.5 Ah)/10 HR
Generator	Three-phase A.C. generator

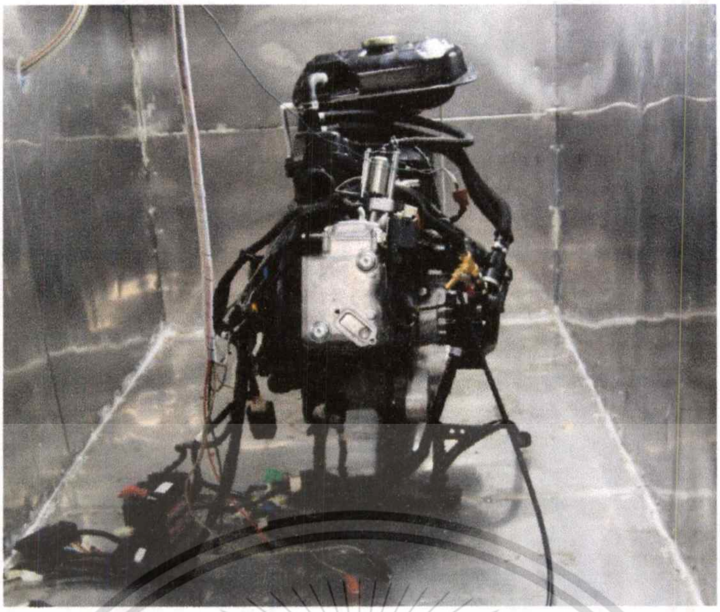


Figure 3.16 The testing engine inside cold soak chamber

3.2.1 FI system technical features

3.2.1.1 Injection time (Injection volume)

This factor determines the injection time which is calculated from the basis of intake air pressure, engine speed, throttle opening angle, and various compensations. These compensations are determined according to the signals from various sensors detected from the engine and driving conditions.

3.2.1.2 Compensation of injection time (Volume)

The following different signals are output from the respective sensors for compensation of the fuel injection time (volume) – Injection stop control, Signal description, Engine temperature sensor, Intake temperature, heated oxygen sensor signal, Acceleration/deceleration signal and starting signal. When engine and intake air temperature are low, injection time (volume) will be increased in order to raise amount of fuel vaporization. Figure 3.17 shows a trend of fuel compensation for engine temperature. Heated oxygen sensor signal-Air/fuel ratio is compensated to the theoretical ratio from density of oxygen in exhaust gas. The compensation occurs in such a way that more fuel is supplied if detected air/fuel ratio is lean. Or less fuel is supplied, if it is rich. When starting engine, additional fuel is injected during cranking engine and during acceleration, the fuel injection time (volume) is increased in accordance with the throttle opening angle and engine r/min. During deceleration, the fuel injection time (volume) is decreased.

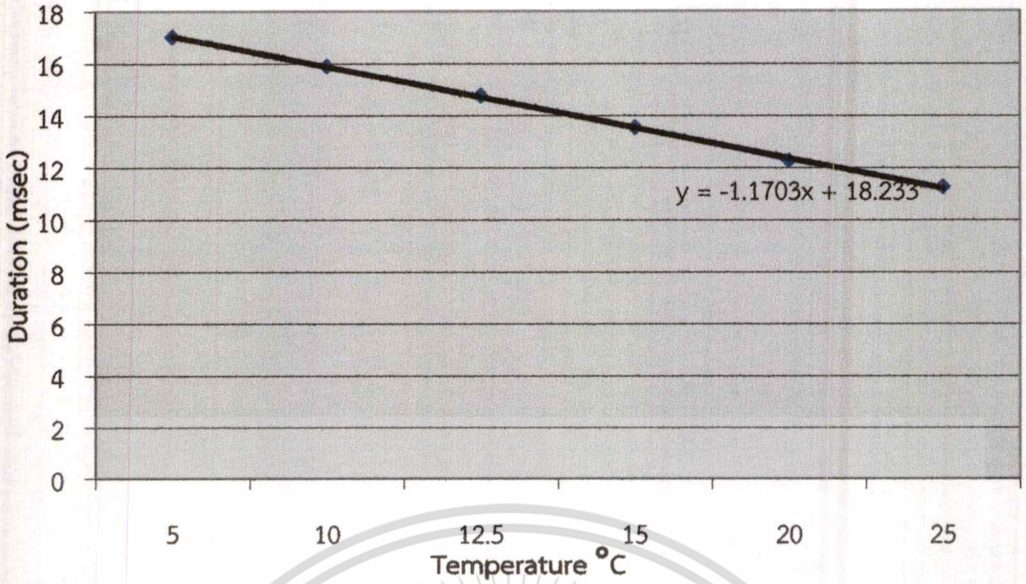


Figure 3.17 Injection compensation versus environment temperature

Figure 3.17 Injection compensation versus environment temperature illustrates effect of air intake temperature on amount of fuel injection. Injection duration is strongly depends on air intake temperature at post starting condition during open loop control system of oxygen sensor. In order to provide fuel more enough to lean limit vaporize in gaseous phase and easier to start without added fuel.

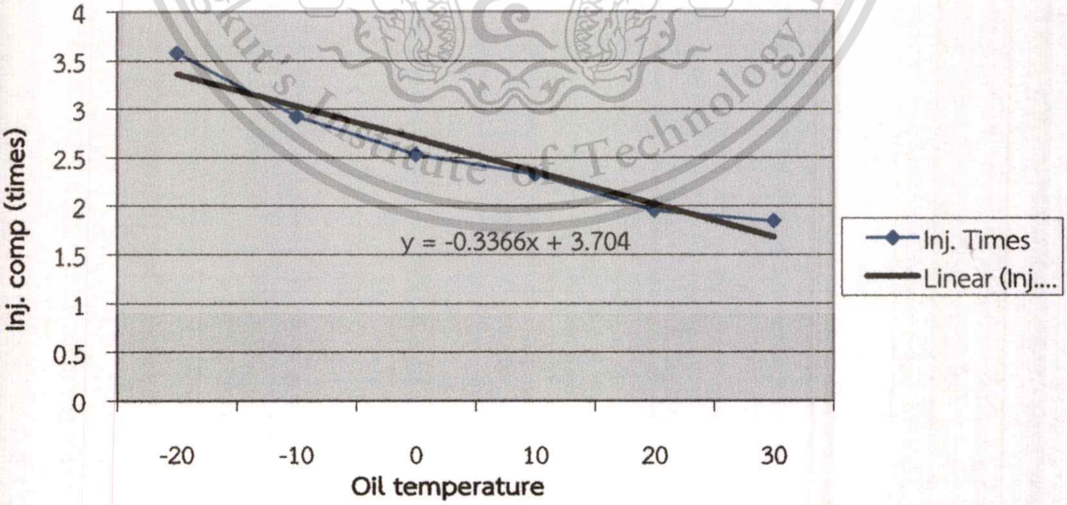


Figure 3.18 Post start compensation with oil temperature[26]

Figure 3.18 depicts fuel injection compensation related with oil temperature. Otherwise, injection duration is compensated by engine oil temperature. Oil temperature is one parameter represent engine temperature. In lower temperature vaporizability is poor. Compensation with oil temperature can achieve startability workable in low ambient temperature.

Fuel injection drive current signal – ECM detects this current and compensates the injection time (volume).

Figure 3.19 shows schematic of ECM interface with sensors.

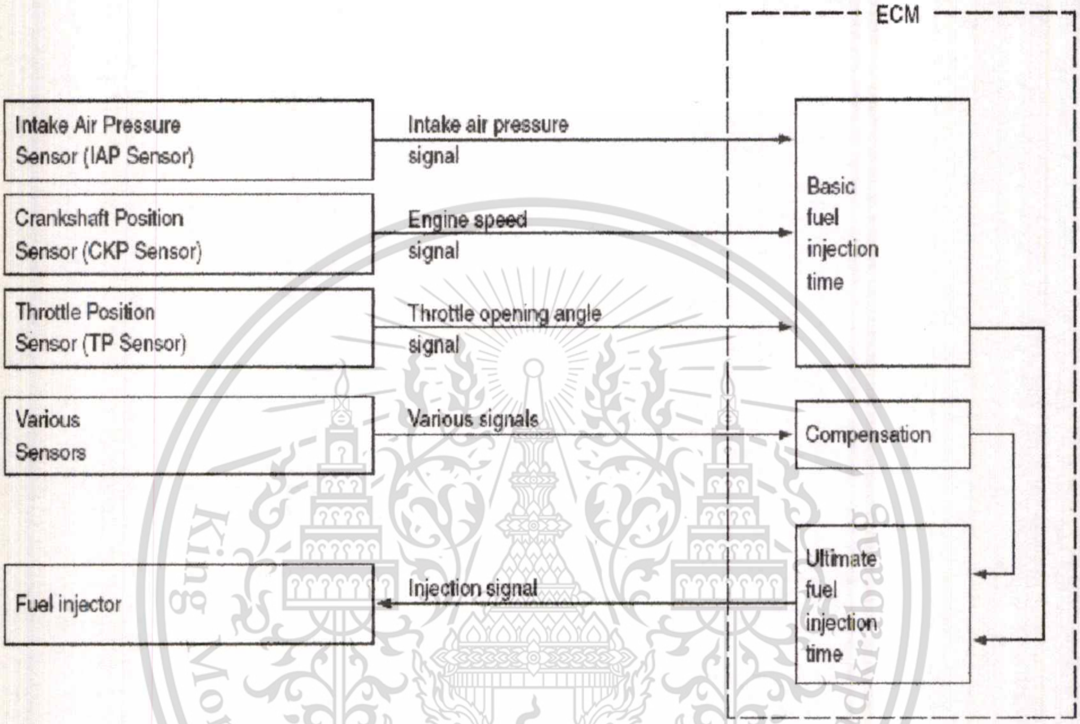


Figure 3.19 ECM and sensors diagram[26]

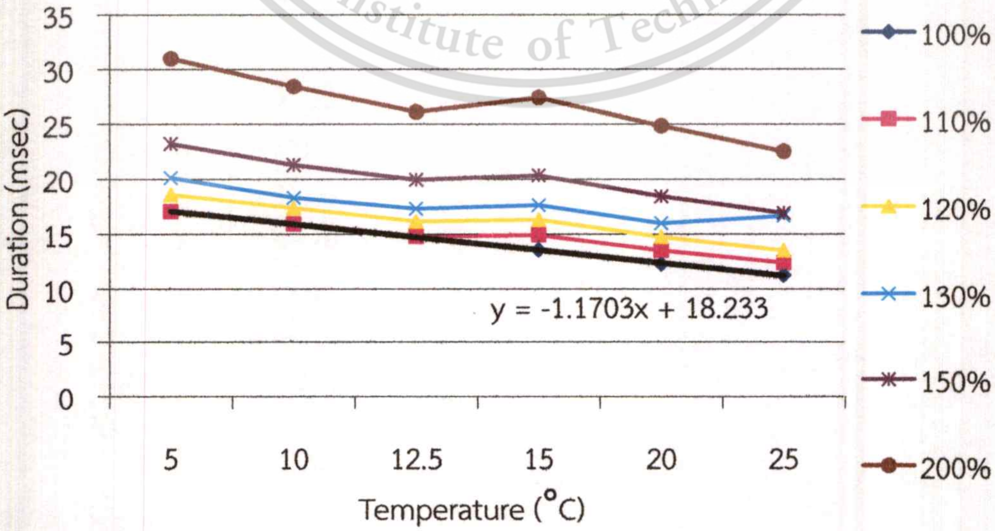


Figure 3.20 Injection duration compensation with surrounding temperature

3.3 Testing Fuel

This experiment focused on gasoline, gasohol (gasoline blend ethanol) and a neat ethanol (C_2H_5O). The commercial ethanol, 99.5% purity, was bought form Thai Agency Company and all of fuels properties are exhibited in Table3. 1. The commercial gasoline and E85 were bought from Petroleum Authority of Thailand (PTT) Plc. (Thailand) to ascertain their properties meet the regulation of Department of Energy Business, Ministry of Energy, Thailand as displayed in Appendix.

Table3.2 Fuels properties[27,28,29,30]

Properties	Gasoline	E85	Ethanol
Formula (for C=1)	CH1.814	CH2.8O0.4	CH3O0.5
Molecular weight	100-105	n/a	46.07
Carbon Content, %wt.	85-88	55.36	52.2
Hydrogen Content, %wt.	12-15	12.89	13.1
Oxygen Content, %wt.	0	31.75	34.7
Density kg/l 15 °C	0.69-0.79	0.783	0.79
Viscosity (cST)	0.4-0.9 (20°C)	n/a	1.52 (16°C)
Boiling point, 1 atm (°C)	27-225	n/a	78.4
Vapor pressure, kPa	58.8	44.4	17
LHV, MJ/l	32.2	23.9	21.3
LHV, MJ/kg	42-44	31.86	26.9
Heat of vapor (kJ/kg)	305	610-762.5	840
Flash point, °C	-43	n/a	13
Auto-ignition t, °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

Properties	Gasoline	E85	Ethanol
Octane number			
Research	97	101.6	107
Motor	80-90	91.1	92
Carbon Dioxide Emission (kg/kg fuel)	3.18	2.026	1.91

3.4 Methodology

During the test, data was acquired with the use of micro controller device that communicates and displays values read by the computer. For consistency in analyses, additional parameters were measured and recorded. These additional parameters are listed and explained below and Table3.3. The testing engine was operated by

- Crank Start: The first time that engine starts to rotate, the engine speed (RPM) is recorded by micro controller.
- Engine Start: The ignition occurs, the engine speed (RPM) reaches 900 rpm and remains above that value.

Table3.3 Testing conditions

Surrounding temperature	-2 to 25 °C
Fuel type	E0, E85 and 100
Amount of fuel injection	100, 110, 120, 130, 150 and 200 %
Cold start assistance	Glow plug Injector heater Pre-cranking (cranking w/o injection) Fuel humidifier

Before observing each of the tests, all of the tested systems especially all temperatures have to be checked. The test engine was initially cool down in the tested ambient temperature condition, as checked by oil temperature, air intake temperature and mixture temperature. The oil temperature represents inside temperature of the whole engine to ensure that the engine (cylinder head, piston and combustion chamber) and oil temperature were equal to the tested temperature condition. Then, for preventing damage from too long cranking with electric starter and relay start. The longest period of each starting is limited to 10 seconds and then immediately restart it. When the engine can be started, the result (starting time) was recorded and shown by the program. Each condition was repeat tested more than 3 stability results. The detail was shown in flow chart as Figure 3.21.

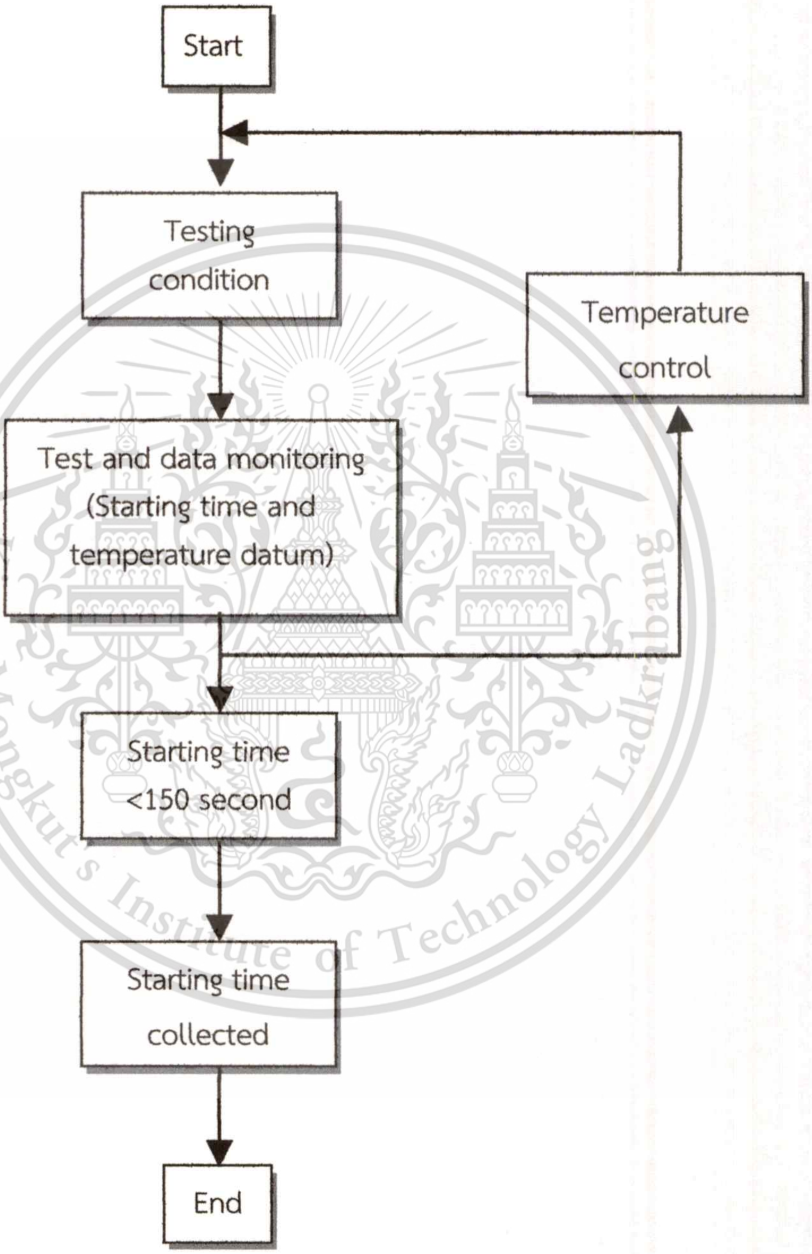


Figure 3.21 Experimental flow chart

CHAPTER 4

Effect of ethanol and Gasoline blends to cold starting

Investigation of an effect of ethanol blended with gasoline to cold starting (Gasoline, E85, and pure ethanol or E100) is to firstly evaluate the starting time of stroke engine using Gasoline. The result from the first experiment will be used as a baseline for other experiments. Then, E85 and neat ethanol are tested on the same stroke engine in surrounding temperature varied from 25 to -2 °C. which is the lowest temperature in Thailand from past 5 years.

4.1 Result of starting time in different fuel types by conventional engine

The result of starting time of each fuel type is shown in Figure 4.1. The bar graphs of results are averaged starting time in second of at least three successfully starting results. The lowest temperature results of each experimental were limited by the voltage of battery. The voltage of battery can affect to revolution speed of starter and energy for supply fuel injection will be rejected.

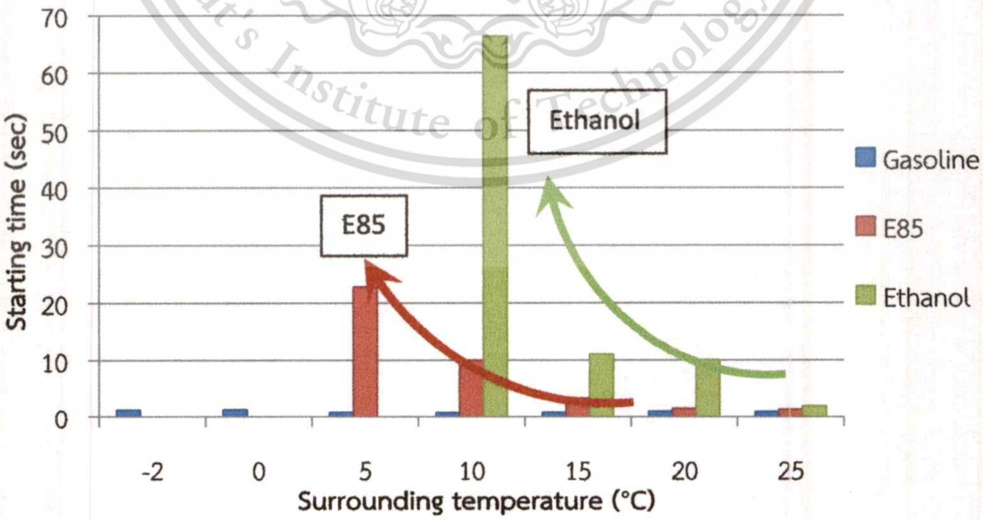


Figure 4.1 Starting time of differnt fuel types

In case of gasoline, the engine can start even at low temperature of -2 °C and take about 1 second for stabilizing e for any testing conditions from 25 °C to -2 °C. Normally, gasoline can operate at lower temperature than -2 °C without having cold start problem. In case of E85, the lowest environmental temperature that the engine can start at first try is at 15 °C. The engine can also start at second attempt under 10°C and 5°C. For example, Figure 4.1 reports a start time is 11.3 – 11.7 seconds at 10°C for ethanol which is sum of 10 seconds at the first try, which failed, and 1.3-1.7 seconds at the second attempt which engine successfully start. The conventional engine can start with anhydrous ethanol normally at 20 °C but the second start is required at 12.5 °C. It is not possible to start the conventional engine with E85 and E100 at temperature lower than 5 °C and 10 °C respectively. At normally ambient temperature in Thailand (25 °C or more than 25 °C), fuel type plays no part in an engine starting time.

After the first trial, the temperature in the combustion chamber increases due to the compression. Then, at the second start, with an additional fuel supplied, results in mixtures become rich enough for ignition. Basically, when a repeated start is done during each start, test bed engine has more fuel available to evaporate and combust; thus shortening the total starting time. This repeated start, however, is unpleasant to the customer and results in poor hydrocarbon emissions. The battery voltage is kept fully charged throughout all the experiments so there is no significant variation of spark plug power. The comparison results of all test fuels in conventional engine are shown in Figure 4.1.

Discussion of an effect of cold starting to ethanol engine on the key properties of interest is boiling point of the fuel. Gasoline has mixtures which are varied from 27 °C to 225 °C where as ethanol has a single boiling point of 78 °C. The implication of this property is that the percentage of fuel that vaporizes to form an ignitable mixture will be less for ethanol than it is for gasoline at cold temperatures. This issue will become worse, the further the temperature is below the lowest boiling point of the fuel.

4.2 Effect of cold start assistance

Five methods are proposed to solve the cold start problem.

4.2.1 Effect of increasing amount of fuel injection

The first method proposed for this experiment is increasing the amount of fuel injection in order to increase volume of fuel in gas phase. An extra fuel injection can increase amount of fuel in liquid and gas but cannot increase percentage of fuel vaporization. The injection duration is increased from 10, 20, 30, 50 to 100 % compared to the conventional one. The result of fuel injection increasing is shown in Figure 4.2.

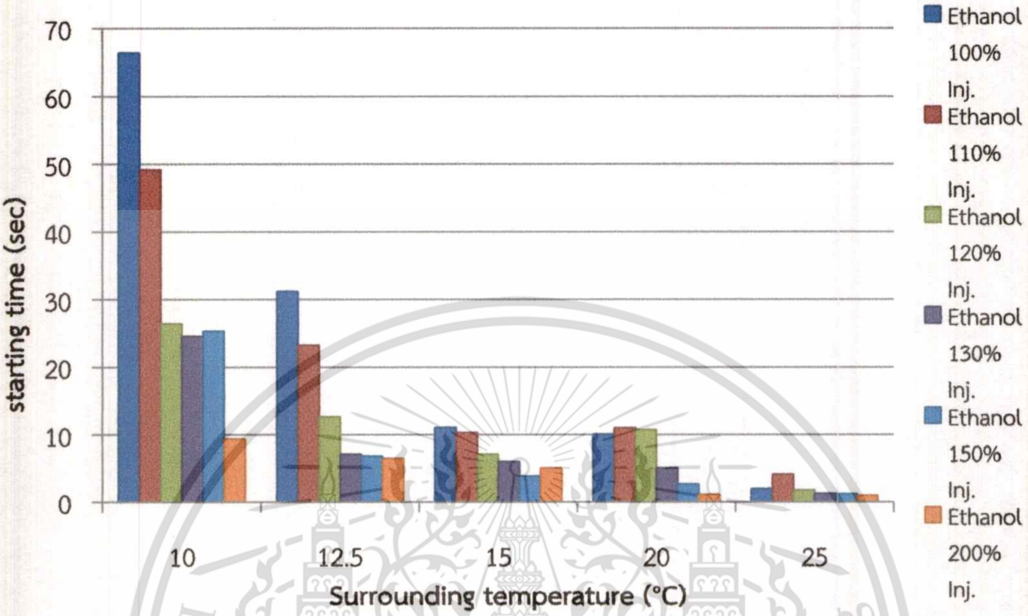


Figure 4.2 Compensation of ethanol injection with starting time

By increasing amount of fuel injection, the engine can start at the surrounding temperature lowest as 10 °C by 9.4 second for 200% of original fuel injection, about 25 second for 120%, 130%, and 150%. At maximum amount of fuel increasing (200%) can get the shortest result of starting time. For 20 - 25 °C of surrounding temperature 110% and 120% increasing amount of fuel have small effect with starting times when compare with 100% of fuel injection with an original fuel injection system. In case of surrounding temperature lower than 15 °C, increasing amount of fuel injection can reduce starting time by decreasing of starting time with increasing of amount of fuel injection. The results were drawn in Figure 4.3. When result of assistant is shown in percentage of starting time reduction – the 200% of fuel injection is the most effective solution at all conditions and another increasing fuel injection percentage can reduce starting time related with increasing amount of fuel injection by more fuel injection can correct less starting time. This solution can increase possibility of fuel evaporation in order to increase chance of ignition starting. 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).

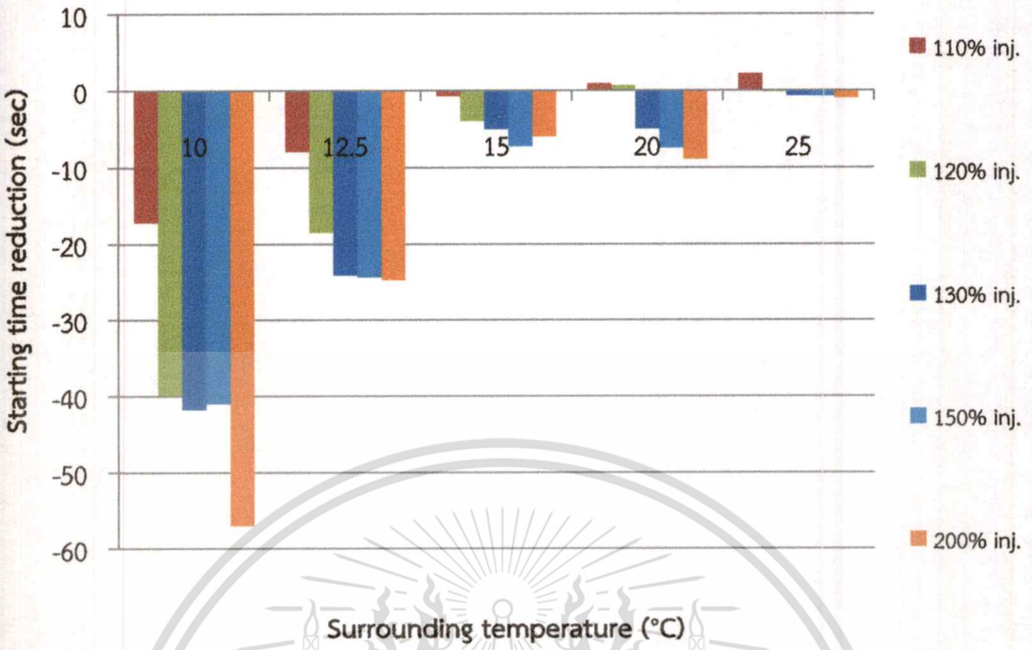


Figure 4.3 Starting time reduction in second with fuel injection compensation

4.2.2 Effect of combustion chamber temperature by heater (glow plug)

The second method is increasing combustion chamber temperature by installing the electrical heater (glow plug) at the cylinder head in order to increase combustion chamber temperature during starting the engine. The heater was turned on when engine switch on, 30 and 60 seconds or 1620 J and 3240 J before starting. According comparing the latent heat of vaporization of gasoline and ethanol, it can be observed that the amount of energy to convert the fuel from a liquid phase to gas phase per unit of mass is approximately three times more for ethanol than it is for gasoline. This implies that almost three times the amount of energy will need to be input into ethanol to vaporize the fuel droplets to form an ignitable air-fuel mixture. Therefore the electric heater (glow plug) is proposed to maintain more energy in order to increase percentage of vaporization from liquid phase to gas phase. According scope of conditions, the heater is heated up at same time with engine switch on, 30 seconds before starting, and 60 seconds before starting.

By increasing the combustion chamber temperature with electric heater (glow plug), the results of starting time can be reduced by this method at surrounding temperature of 12.5 °C and 10 °C for lowest testing condition of assisted cold starting by glow plug. For 15 °C and 20 °C this can reduce by small of starting time. According comparing the latent heat of vaporization of gasoline and ethanol included ignition lean limit of ethanol, it can be discussed like, the energy of vaporization at surrounding temperature higher than 15 °C is enough for changing phase of fuel (liquid to gas) and volume of gas fuel is sufficient for lean limit of ignition. Otherwise at lower 12.5 °C of surrounding temperature need more energy to evaporate. Therefore the higher of energy inside combustion chamber is significant to reduction of starting time as shown in figure 4.4.

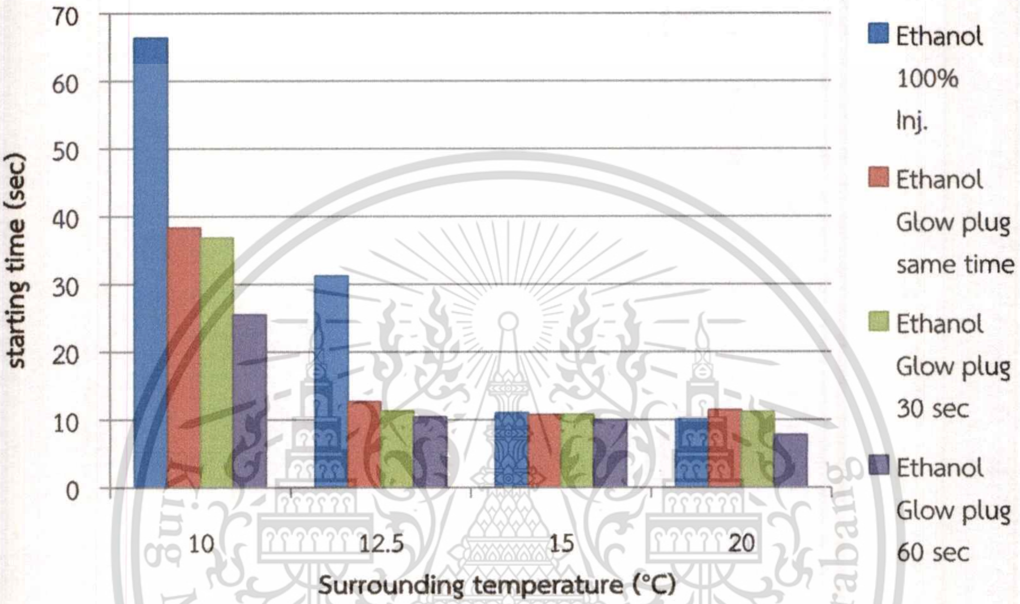


Figure 4.4 Glow plug application with starting time

The results of assist cold start by glow plug were compared with an ethanol conventional engine in reduction of starting time, the increasing of energy input inside combustion chamber is significant with reduction of starting time when surrounding temperature lower than 12.5 °C as shown in Figure 4.4. As the result – at lower temperature ethanol fuel require higher energy for vaporization to be reach lean limit of ignition and at higher temperature – increasing of energy inside combustion chamber is not significantly affect with starting time. This can explain in energy might be enough for vaporization of ethanol reach to lean limit of ignition. Otherwise the increasing combustion chamber temperature at 10 °C shorter time of heating up have not an effect in same trend of 60 second for glow plug heating up.

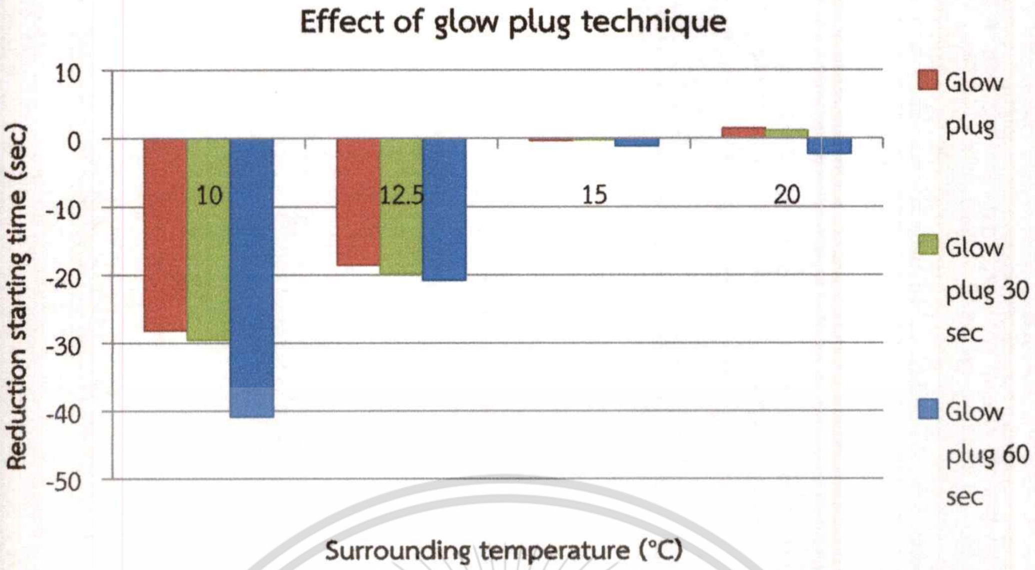


Figure 4.5 Starting time reduction in second with glow plug

4.2.3 Effect of injected fuel temperature

The third method is heating the injector by holding the electric supply to heat up fuel inside before being injected into the intake port. The holding times are 10, 20, 30 seconds and wait for the time in some case by heated up time / waiting time / and heated up again to prevent over heat is occur and for heat transferring of plunger coil and fuel inside the injector. The result of heated injector technique is shown in Figure 4.5.

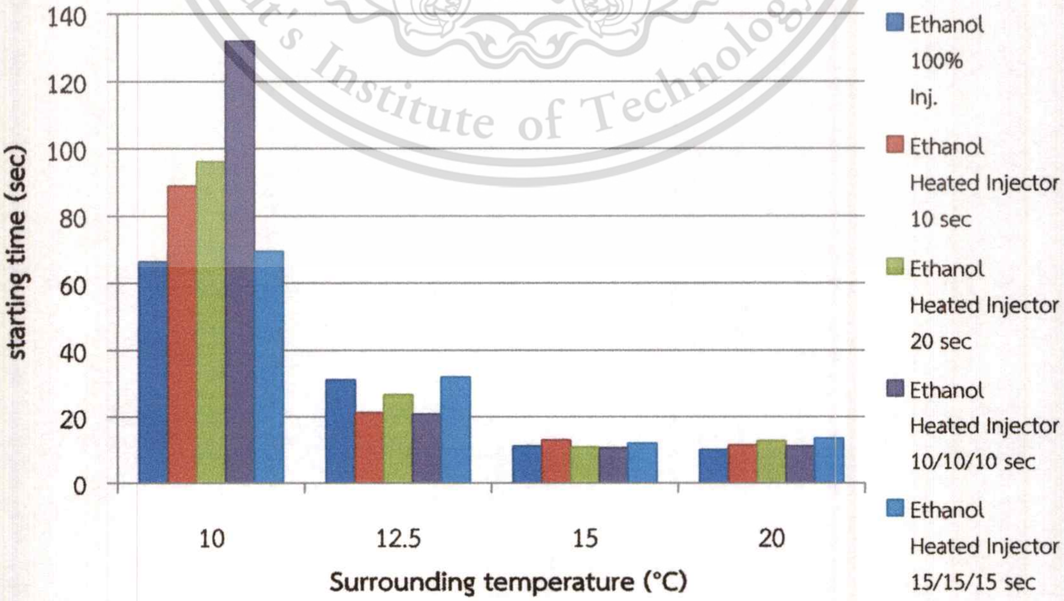


Figure 4.6 Heated injector with starting time

According to this application, the heated injector could not significantly reduce the starting time. The reason of this effect might be concluded from the character of the integrated pump injector, the holding time of injection signal can heat up a coil of plunger in order to heat up fuel in the same time while fuel is injected. Another way of this probable explanation is due to ethanol wetting on the spark plug. The poor fuel vaporization of ethanol at low temperatures causes the spark plug soaking with liquid ethanol during cranking and shortly after start up before cylinder surface and spark plug temperatures rise high enough for ignition. If the shunt resistance of an ethanol-wetted plug is less than the resistance of the air gap then the plug will short across the ethanol causing a misfire. From another research[14] the modified injector (injector tip heater) can raise fuel injected temperature from -5 °C until 170 °C average heater surface temperature. It is sufficient to start the ethanol engine at -5 °C of surrounding temperature.

4.2.4 Effect of combustion chamber temperature by pre-cranking

Forth method is the pre-cranking technique by starting the engine without fuel injection. For the testing condition at surrounding temperature 10 °C, the starting time can be reduced by this method. When the engine is pre-cranking started 10 second before fuel injection, the result of starting time is reduced by 14% or 11.57 sec compare with original starting and using 20 seconds of pre-cranking can reduce starting time by 55% or 36.54 sec. The result of starting time at 10 °C when pre-cranking technique applied is shown in Figure 4.7 and

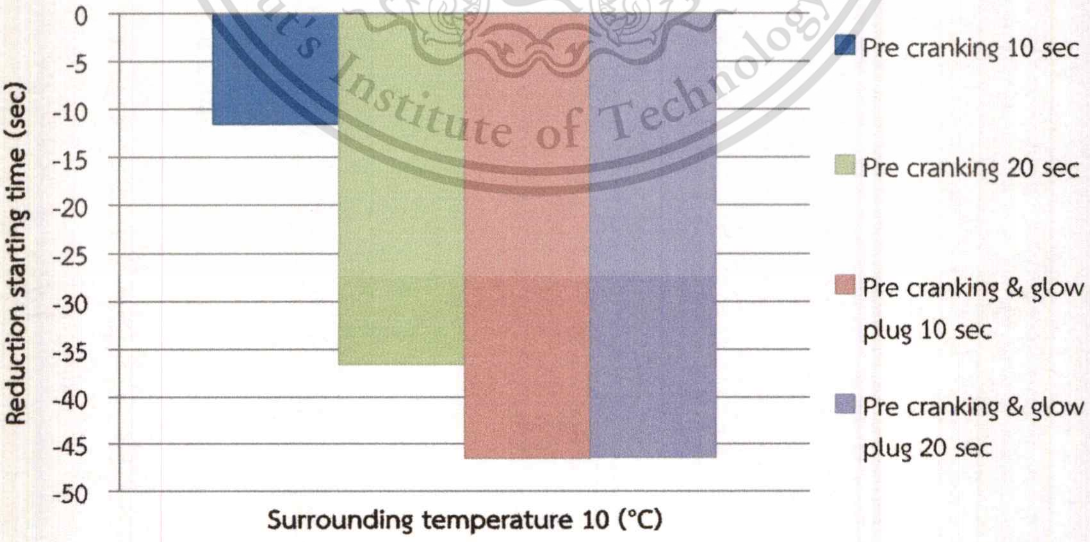


Figure 4.8.

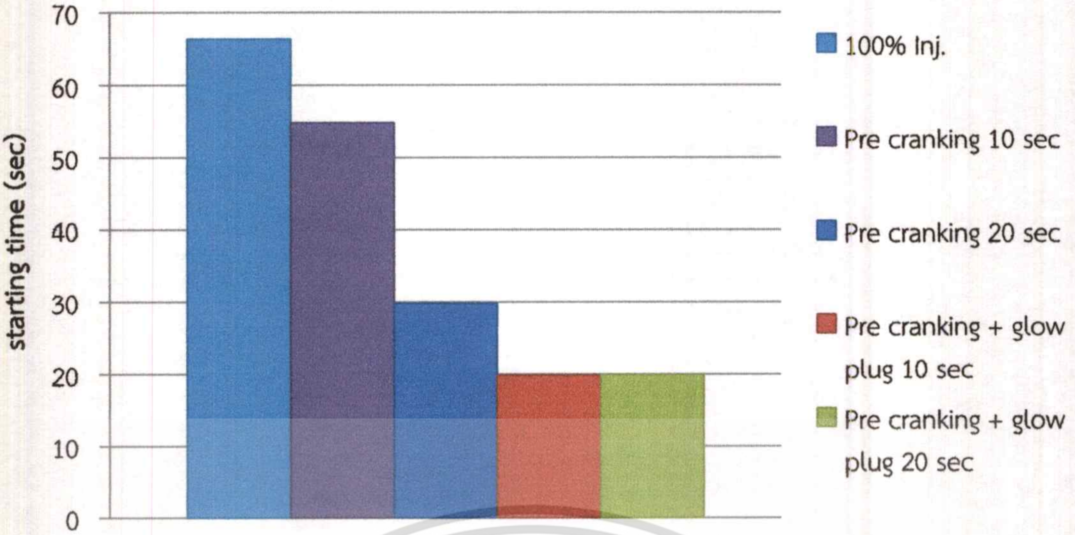
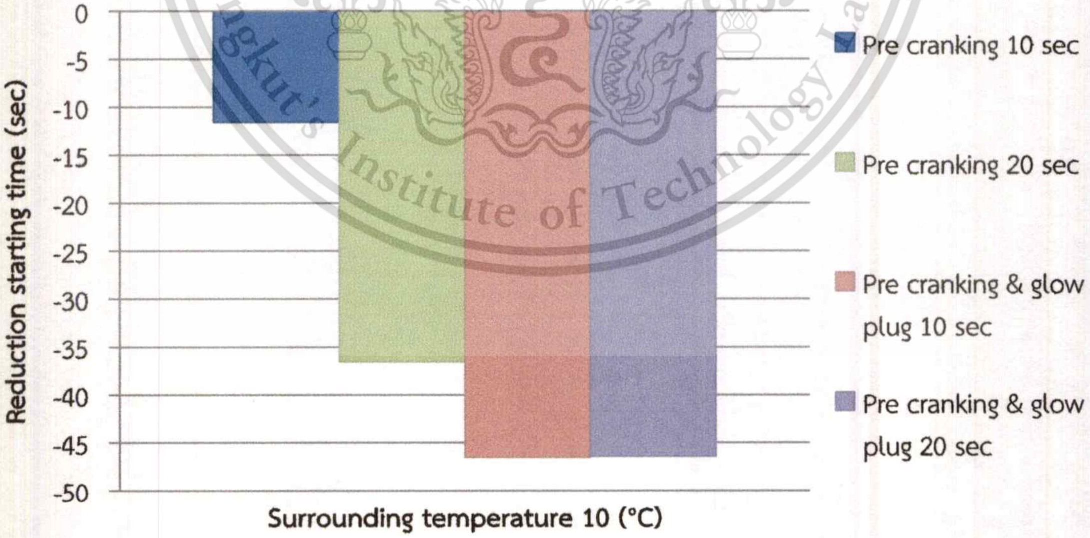


Figure 4.7 Pre-cranking & glow plug application with Starting time at 10 °C

The objective of third and forth method is to raise a temperature in the combustion chamber to increase possibility of vaporization in order to richer of the fuel-air mixture ratio. Then, next experiment is to combine glow plug technique with pre-cranking technique in order to increase the temperature of combustion chamber. The experiment is conducted at 10 °C surrounding temperature. By this combined technique, at 10 and 20 seconds for heating up, can reduce starting time by 70 % or 46.5 sec as shown in Figure 4.8. However, the pre-cranking & glow plug technique results are insignificantly different between 10 seconds and 20 seconds. It can be explained that those result of pre cranking with glow plug at 10 second and 20 second are similar. There are no benefits gained for a pre cranking time with glow plug supported more than 10



seconds at 10 °C surrounding temperature because engine pre cranking air intake absorbs energy of glow plug.

In case of pre cranking and glow plug can provide more energy input into to the engine and can reduce with starting time result. When the ethanol engine is started in low temperature – engine cannot start immediately because of air/fuel ration is too lean for ignition and after motoring and heating up by glow up, ethanol can absorb more surrounding energy to convert in gas phase and then start of ignition is occur. That can conclude the important one parameter might be energy for vaporization of ethanol and temperature of ignition should higher than flash point property. By pre cranking can provide energy from friction force of motion between piston and cylinder wall. As figure shown in Figure 3.10 that is the one reason of thermodynamic. Top dead center temperature compare with bottom dead center temperature by theory of thermodynamic.

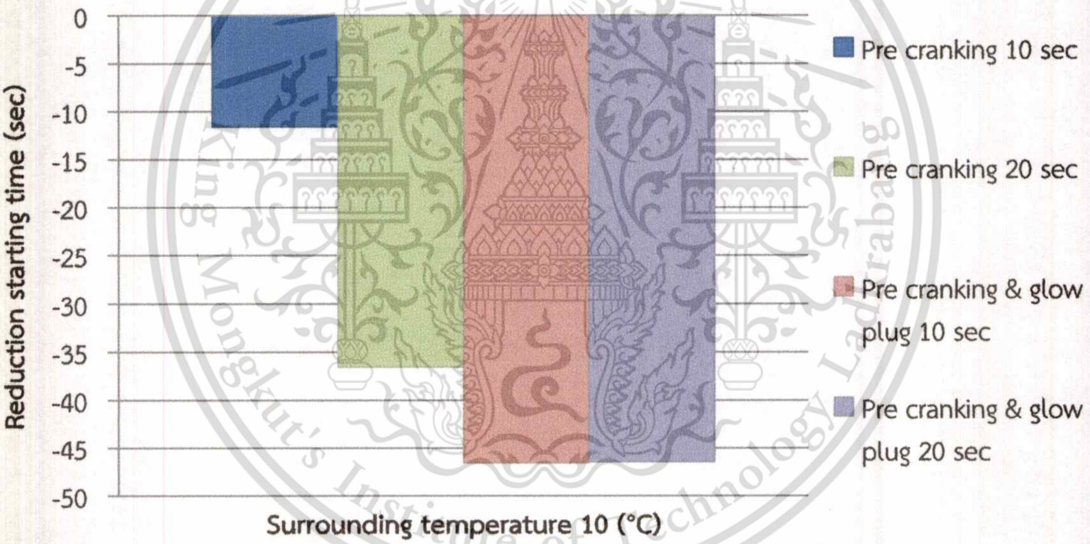


Figure 4.8 Starting time reduction in second with pre-cranking & glow plug

4.2.5 Effect of combustion chamber temperature by combined technique

When surrounding temperature at 10 °C, 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 by increasing combustion chamber temperature 49 % of starting time was reduced when compared with only 150% of amount of fuel injection , which exhibited similar staring time to twice fuel injection, as shown in

Figure 4.9. Otherwise pre-cranking is proposed to reduce the starting time in 70 % of starting time when compared with 100% (original) amount of fuel injection is significant but it spends more time for starting to heat up combustion chamber.

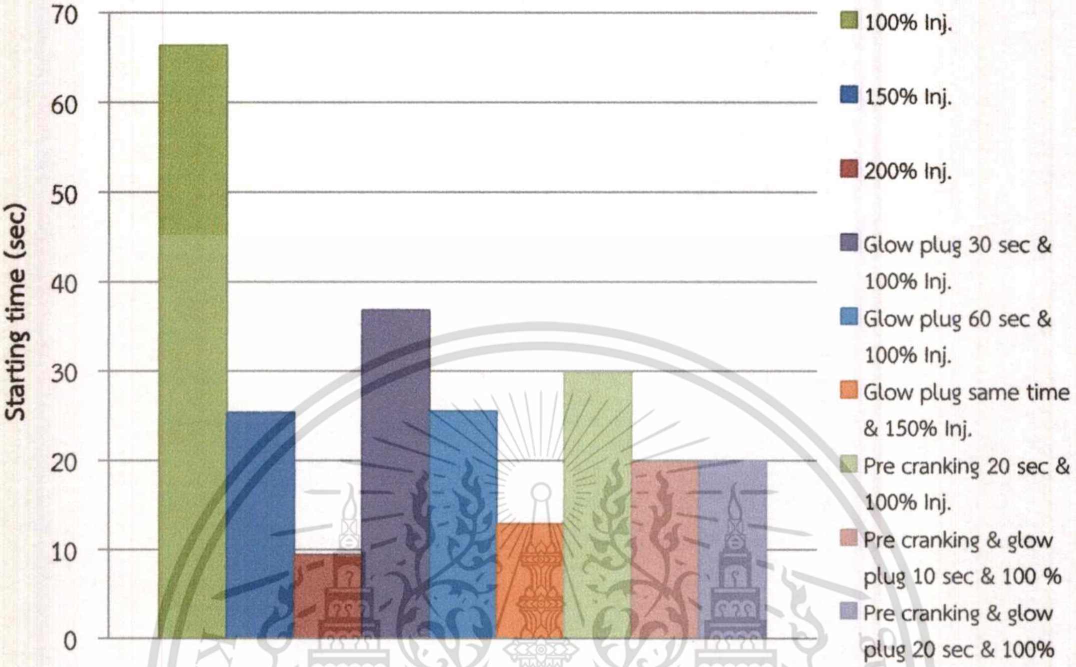


Figure 4.9 Combined technique with Starting time at 10 °C

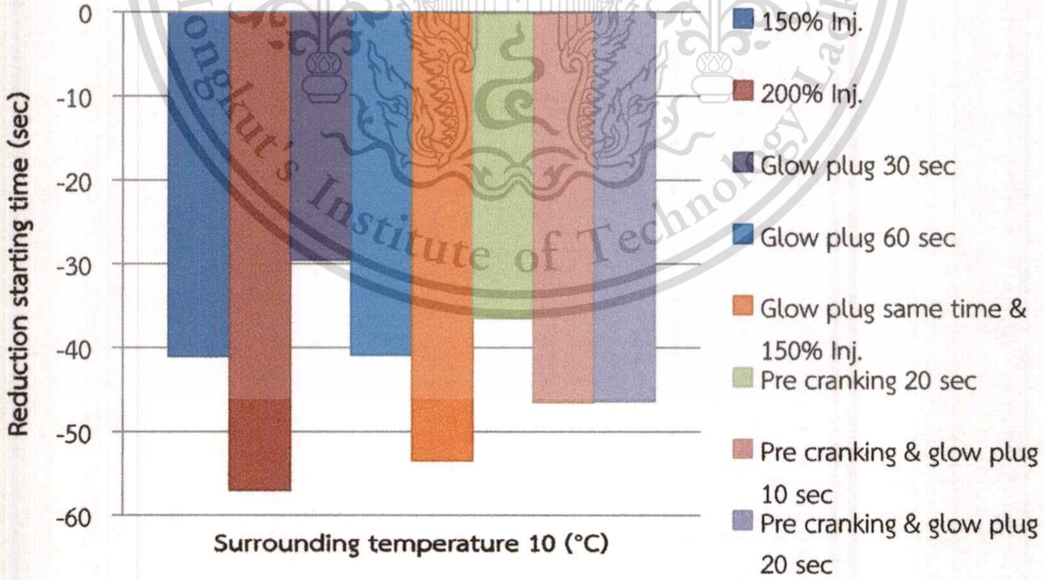


Figure 4.10 Starting time reduction in second with combined technique at 10 °C

Combination technique (50% increasing fuel injection, 20 second of glow plug heated up and pre cranking 20 second in same time with glow plug heated up) was assisted cold starting problem at the lower than 10 °C of surrounding temperature. Normally the original ethanol engine cannot start at these conditions. By this technique the ethanol engine can start until 6 °C of ambient temperature in 58 seconds, 6.5 °C can start in 25 seconds and 18.5 seconds for start the ethanol engine at 8.5 °C of surrounding temperature. For this combination was selected from all of technique were used to assist cold starting that perform for starting of the engine. The result is shown in Figure 4.11.

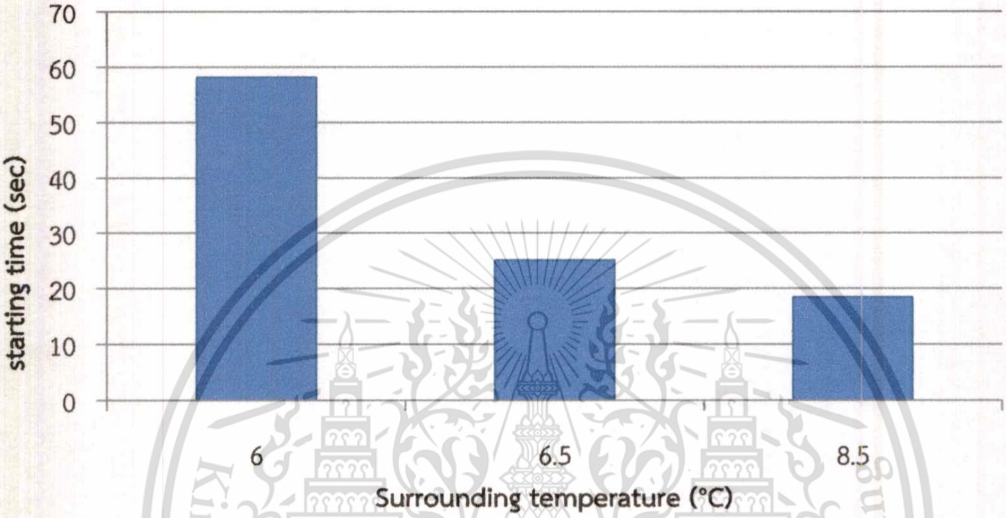


Figure 4.11 Pre-cranking & glow plug in 20 sec. & 150% Inj.

4.3 Modification technique at low temperature

The different techniques were compared when the starting temperature at 6 °C. For 100% amount of fuel injection cannot start the ethanol engine. Hence, 50% increasing fuel injection is the first technique was assisted cold start problem but cannot accept in the starting time result. Then a glow plug was heated up 60 second before the engine cranking. The result of starting time can reduce in 80 second or 64.6% when compare 150% amount of fuel injection. After that glow plug and pre cranking technique were used to increase combustion chamber in 20 second before the engine cranking. 65.6 second or 53% was reduced by this cold start technique. Finally, heat up time was extended to 30 second that can reduce the starting time by 100.6 second or 81% when compare with the first technique without attended heated up time before engine cranking as shown in Figure 4.12.

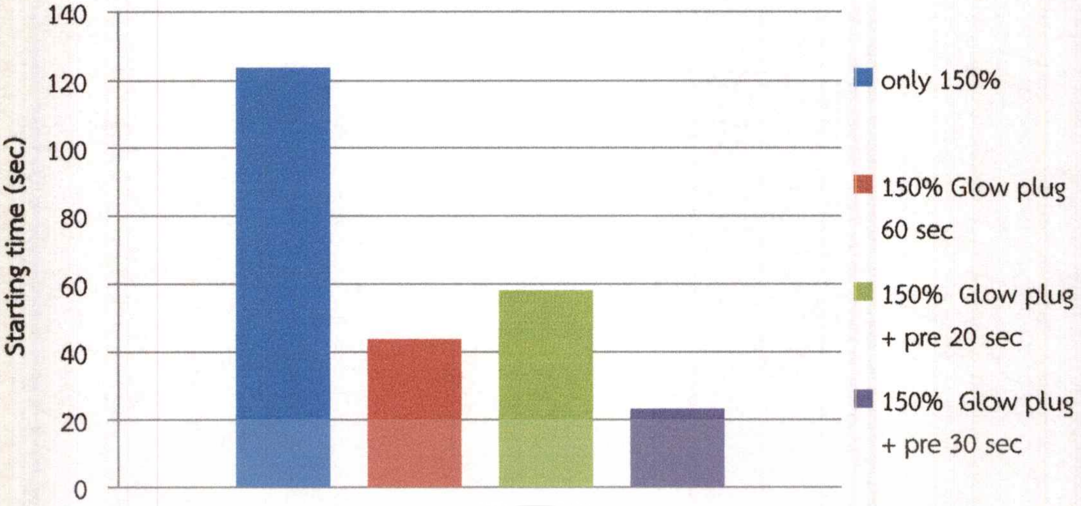


Figure 4.12 Different techniques at 6 °C of surrounding temperature

Otherwise heated up time was concerned for all of the time for cold starting because is not impartial for technique has not heat up process. Firstly, when 60 second of glow plug heating up was included with starting time the result of starting time was reduced 20 second or 16% different in percentage. The 150% amount of fuel injection combined with glow plug and pre-cranking technique in 20 second can reduce the starting time around 45.6 second or 37% when compared with result of only 150% amount of fuel injection. Last the warm up time was tensed to 30 seconds, the starting time can reduce 70.2 seconds or 57% when compared with only technique. The result is presented as figure 4.12.

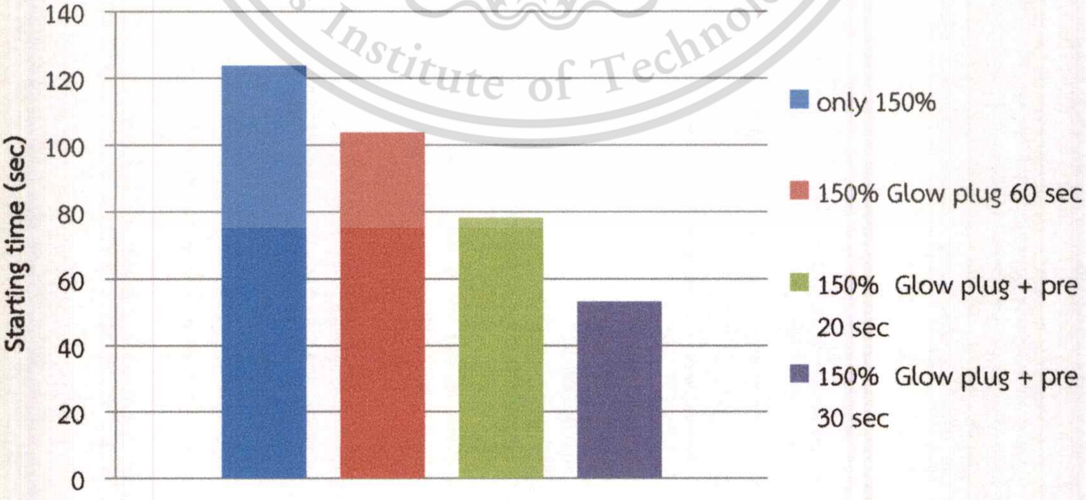


Figure 4.13 Different techniques by included warm up time at 6 °C

The surrounding temperature still decreased than 6 °C (The lowest land temperature in Thailand) until 4 °C in order to find out the best solution and minimum surrounding temperature that the ethanol engine can start. From last figure can conclude, the 150% amount of fuel injection combined glow plug and pre-cranking at 30 second is the best solution at all. The all of combination technique was used to assist cold start problem. At 5 °C of surrounding temperature the combination technique can start the engine in 42.6 second not included warm up time and have to add 30 second for include warm up time. At 4.5 °C of surrounding temperature the ethanol engine can start in 49.5 second and 67.6 second for surrounding temperature cool down to 4 °C. The glow plug and pre-cranking was increased to 40 second for more input energy. It is significantly solution because the result of starting time can reduce 15.7 second when compared with 30 second of glow plug and pre-cranking. But if warm up time was include in result of starting time, the decreasing of starting time is 5.7 second. As shown in Figure 4.14.

Figure 4.14 Different techniques at lower than 6 °C

At the minimum surrounding temperature is 3.5 °C that the ethanol engine can start by all of assist cold start problem method. The heat up time for glow plug and pre cranking was extended to 60 second and amount of fuel injection to 200%. The humidifier also was set up for extreme case. The result of starting time at 3.5 °C of surrounding temperature is shown in Figure 4.15. The first of all solutions is 150% amount of fuel injection combined with glow plug and pre-cranking at 30 second can start the engine in 99.4 second. That is too long time for starting then heated up time was extended to 40 second in order to put more energy in combustion chamber. The result of starting time is 86.8 second the engine can be started and short than last result at 12.6 second. In the same time of heat up, the amount of fuel was increased to 200% injection in order to increase chance of fuel vaporization. The ethanol engine can start 85 second. By this method can conclude not significant for amount of fuel injection higher than 150%.

Finally fifth method humidifier was used for fuel atomization and reduction energy to vaporize liquid fuel. The engine can start in 42.6 second and 56.8 second shorter than the first method at this surrounding temperature. According to ethanol properties in term of heat of vaporization, ethanol consumes energy to vaporize more than gasoline in 2-3 times. The method of fuel humidifier is used to reduce energy for evaporization and atomization.

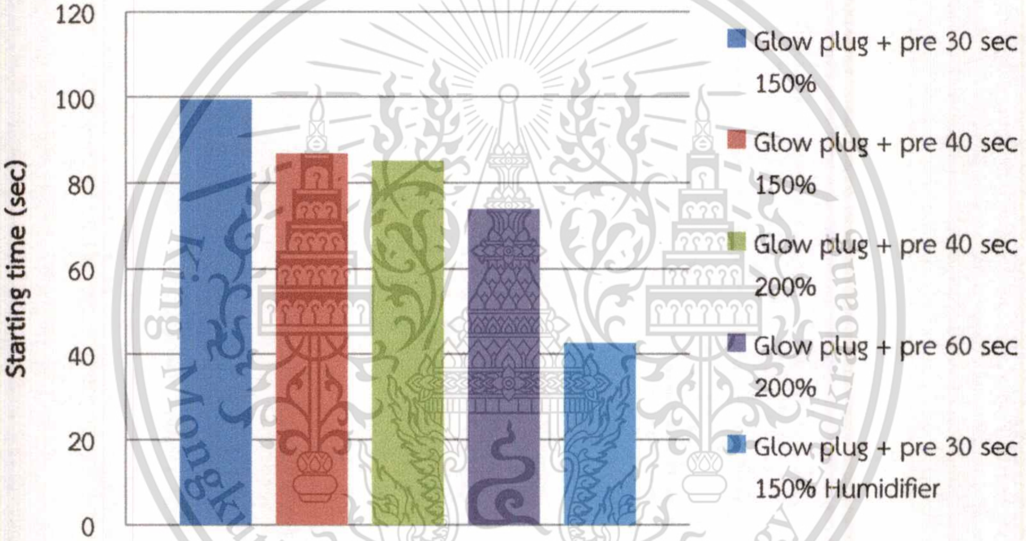


Figure 4.15 Different techniques by not included warm up time at 3.5 °C

If a warm up time was included in result of starting time, the result of starting time will be similar but not for humidifier method. The engine can start with a fuel humidifier at 72.6 second when included warm up time.

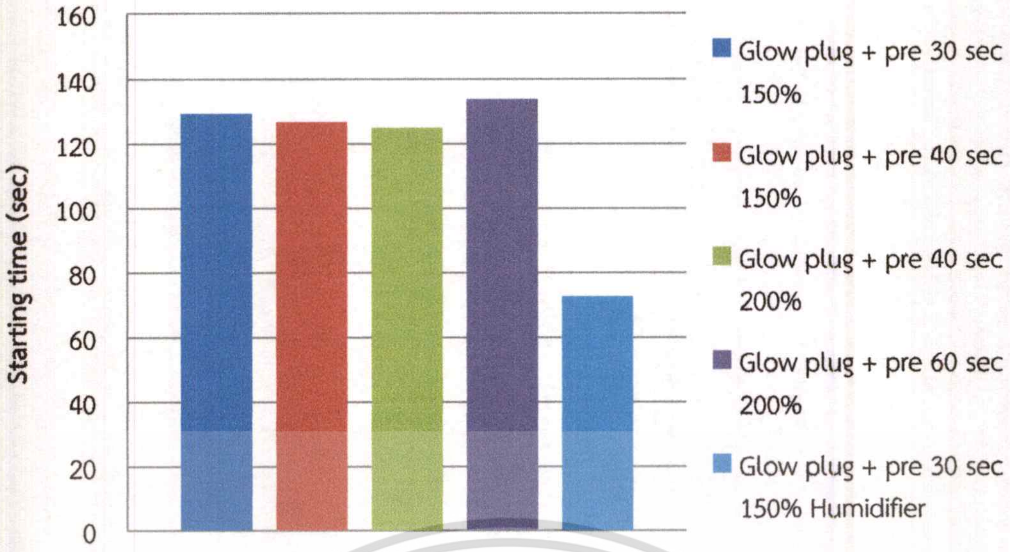


Figure 4.16 Different techniques by included warm up time at 3.5 °C

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS

5.1 Conclusions

The present study has focused on testing of ethanol and ethanol gasoline blend in ethanol for using in a conventional spark-ignition engine to access the limitations of this engine type and fuel properties. 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 overall investigations and assistance cold-start technique used were generally successful. This approach allows for modifications to made and tested with minimum effort. The following conclusions and suggestions have drawn.

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, and possible to start at 10 °C with 66 second starting time. However, the total starting time still very long and may not satisfy the customers.

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 technique with original amount of fuel injection make the engine possible to start at 10 °C of surrounding temperature. The ethanol engine can start within 30 seconds included operating time 10 seconds for warm up time. For the most users convenient, the combination between pre-cranking with glow plug in 10 second before engine cranking was appropriated.

5. For heated injector technique, the starting time cannot be reduced for all of surrounding temperatures, not because heating of injected fuel did not help but rather too much fuel being injected from holding the electric supply during heating.

6. The most effective technique at 10 °C is 200% injection by 86% or 57 seconds of reduction starting time. Glow plug 60 seconds and pre cranking 20 seconds can reduced by 62% or 41 seconds and 55% or 36.5 second respectively. 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 at 125 seconds since attempt to start the engine by combination technique of pre-cranking, glow plug 40 seconds and doubling amount of fuel injection.

7. Atomization and extra fuel from humidifier can reduce the engine cranking time of ethanol engine at 3.5°C of surrounding temperature. Thus, according Thailand's minimum temperature, the ethanol engine can be started throughout except at some mountain during winter.

8. By using glow plug and pre cranking technique with 150% of injection makes the engine possible to start at 6 °C. The ethanol engine can start within 53 seconds included waiting time 30 seconds for pre cranking and glow plug.

9. The ethanol engine can start at 3.5°C using combination techniques of using humidifiers, 150% fuel injection, 30 seconds pre-cranking and glow plug. The minimum total starting time at 3.5 °C for this study is 82.6 seconds.

5.2 Suggestions

Although this work is finished, it is only the first step towards to use ethanol/gasoline blended and ethanol in the gasoline conventional engine. in order to promote the use of ethanol/gasoline blended and ethanol fuel in gasoline engines. 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. There are some suggestions that the following opinions have been provided the further work to study as follow:

- According to heated fuel injector result is not significant but main idea of heated injector is not so bad. But limitation of this study and experimental set up (integrated pump injector) cannot control heater and fuel injection signal separately that the heated injector should be modified more than this.
- 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.

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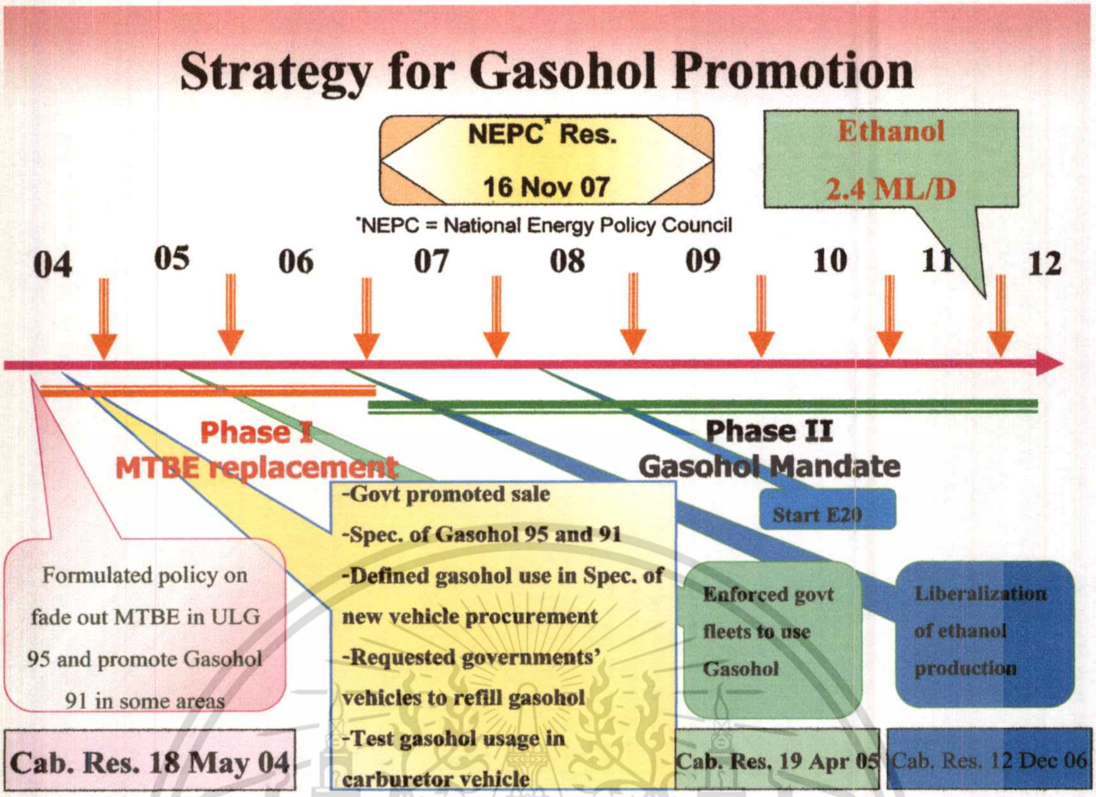
APPENDIX

APPENDIX A

Thailand's energy policy



Strategy for Gasohol Promotion

NEPC* Res.
16 Nov 07

*NEPC = National Energy Policy Council

Ethanol
2.4 ML/D

Phase I
MTBE replacement

Phase II
Gasohol Mandate

Formulated policy on fade out MTBE in ULG 95 and promote Gasohol 91 in some areas

Cab. Res. 18 May 04

- **Govt promoted sale**
- **Spec. of Gasohol 95 and 91**
- **Defined gasohol use in Spec. of new vehicle procurement**
- **Requested governments' vehicles to refill gasohol**
- **Test gasohol usage in carburetor vehicle**

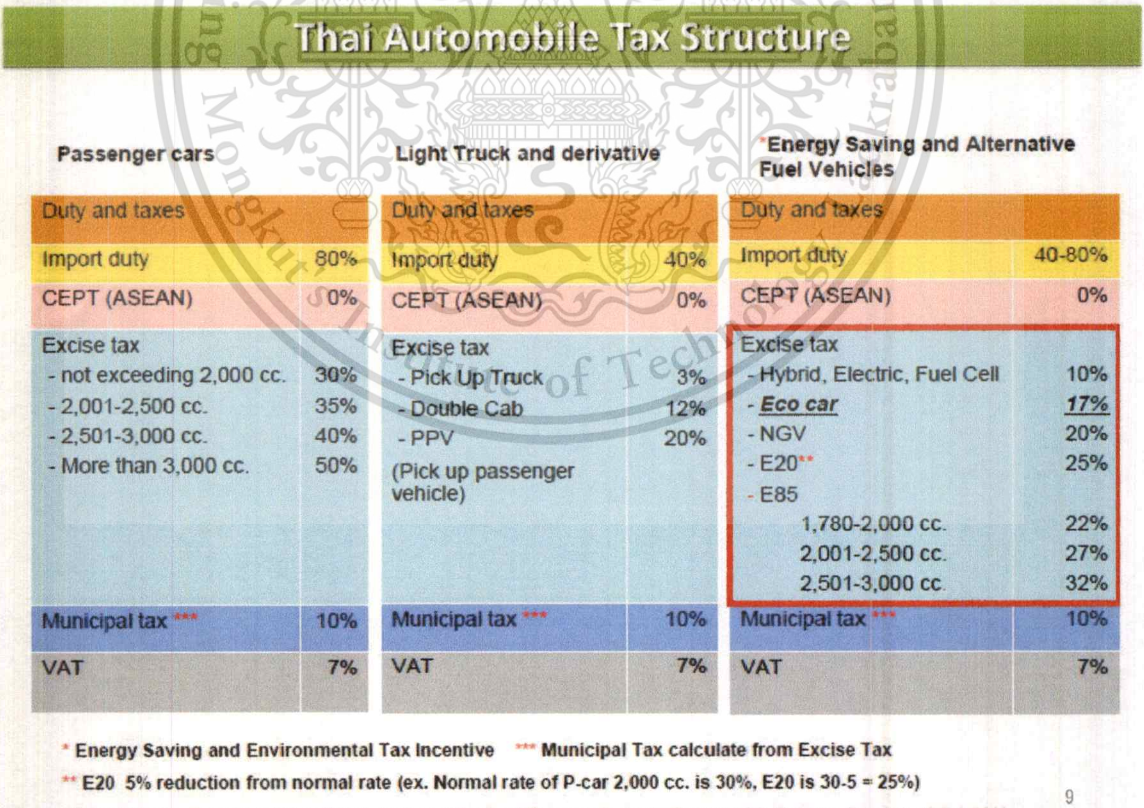
Start E20

Enforced govt fleets to use Gasohol

Cab. Res. 19 Apr 05

Liberalization of ethanol production

Cab. Res. 12 Dec 06



Thai Automobile Tax Structure

Passenger cars

Duty and taxes	
Import duty	80%
CEPT (ASEAN)	0%
Excise tax - not exceeding 2,000 cc. - 2,001-2,500 cc. - 2,501-3,000 cc. - More than 3,000 cc.	 30% 35% 40% 50%
Municipal tax ***	10%
VAT	7%

Light Truck and derivative

Duty and taxes	
Import duty	40%
CEPT (ASEAN)	0%
Excise tax - Pick Up Truck - Double Cab - PPV (Pick up passenger vehicle)	 3% 12% 20%
Municipal tax ***	10%
VAT	7%

***Energy Saving and Alternative Fuel Vehicles**

Duty and taxes	
Import duty	40-80%
CEPT (ASEAN)	0%
Excise tax - Hybrid, Electric, Fuel Cell - ***Eco car*** - NGV - E20** - E85 1,780-2,000 cc. 2,001-2,500 cc. 2,501-3,000 cc.	 10% ***17%*** 20% 25% 22% 27% 32%
Municipal tax ***	10%
VAT	7%

* **Energy Saving and Environmental Tax Incentive** *** **Municipal Tax calculate from Excise Tax**

** **E20 5% reduction from normal rate (ex. Normal rate of P-car 2,000 cc. is 30%, E20 is 30-5 = 25%)**

9

Source: T. Boonyamarn, Expert meeting on Survey Analysis of the Road Transport Sector for Reducing CO_2 Emission, Bangkok, 15 Feb 2011

APPENDIX B

Standard and properties of fuel

รายละเอียดแนบท้าย ๑

ประกาศกรมธุรกิจพลังงาน

เรื่อง กำหนดลักษณะและคุณภาพของน้ำมันแก๊สโซฮอล์

พ.ศ. ๒๕๕๓

รายการ	ข้อกำหนด	อัตราสูงต่ำ	น้ำมันแก๊สโซฮอล์อี 10			น้ำมันแก๊สโซฮอล์อี 20	วิธีทดสอบ[1/]
			ออกเทน 91	ออกเทน 95			
				ชนิดที่ 1	ชนิดที่ 2		
1	ค่าออกเทน (Octane Number)						
	1.1 โดยวิธีวิจัย (Research Octane Number ; RON)						ASTM D 2699
	(1) ผู้ผลิตจำหน่าย ณ จุดส่งมอบ	ไม่ต่ำกว่า	91.0	95.0	95.0	95.0	
	(2) ผู้จำหน่าย	ไม่ต่ำกว่า	90.6	94.6	94.6	94.6	
	1.2 โดยวิธีมอเตอร์ (Motor Octane Number ; MON)						ASTM D 2700
	(1) ผู้ผลิตจำหน่าย ณ จุดส่งมอบ	ไม่ต่ำกว่า	80.0	84.0	84.0	84.0	
	(2) ผู้จำหน่าย	ไม่ต่ำกว่า	79.6	83.6	83.6	83.6	
2	ตะกั่ว *กรัม/ลิตร* (Lead, *g/L*)						ASTM D 5059
	ก่อนวันที่ 1 มกราคม พ.ศ. 2555	ไม่สูงกว่า	0.013	0.013	0.013	0.013	
	ตั้งแต่วันที่ 1 มกราคม พ.ศ. 2555 เป็นต้นไป	ไม่สูงกว่า	0.005	0.005	0.005	0.005	
3	กำมะถัน *ร้อยละโดยน้ำหนัก* (Sulphur, *%wt.*)						
	ก่อนวันที่ 1 มกราคม พ.ศ. 2555	ไม่สูงกว่า	0.05	0.05	0.03	0.05	ASTM D 4294
	ตั้งแต่วันที่ 1 มกราคม พ.ศ. 2555 เป็นต้นไป	ไม่สูงกว่า	0.005	0.005	0.005	0.005	ASTM D 2622
4	ฟอสฟอรัส *กรัม/ลิตร* (Phosphorus, *g/L*)	ไม่สูงกว่า	0.0013	0.0013	0.0013	0.0013	ASTM D 3231[2/]
5	การกัดกร่อนแผ่นเงิน (Silver Strip Corrosion)	ไม่สูงกว่า	หมายเลข 1	หมายเลข 1	หมายเลข 1	หมายเลข 1	ASTM D 4814 (ANNEX A)
6	เสถียรภาพต่อการเกิดปฏิกิริยาออกซิเดชัน *นาที* (Oxidation Stability, *minutes*)	ไม่ต่ำกว่า	360	360	360	360	ASTM D 525
7	ยางเหนียว *มิลลิกรัม/100 มิลลิลิตร* (Solvent Washed Gum, *mg/100 mL*)	ไม่สูงกว่า	4	4	4	4	ASTM D 381
8	การกลั่น *องศาเซลเซียส* (Distillation, *°C*)						ASTM D 86
	8.1 อุณหภูมิ						
	(1) การระเหยในอัตราร้อยละ 10 โดยปริมาตร (10% Evaporated)	ไม่สูงกว่า	70	70	70	65	
	(2) การระเหยในอัตราร้อยละ 50 โดยปริมาตร (50% Evaporated)	ไม่ต่ำกว่า และ	70	70	70	65	
		ไม่สูงกว่า	110	110	110	110	
	(3) การระเหยในอัตราร้อยละ 90 โดยปริมาตร (90% Evaporated)	ไม่สูงกว่า	170	170	170	170	
	(4) จุดเดือดสุดท้าย (End Point)	ไม่สูงกว่า	200	200	200	200	

(ต่อ - ๒ -)

รายการ	ข้อกำหนด	อัตราสูงต่ำ	น้ำมันแก๊สโซฮอล์อี 10			น้ำมันแก๊สโซฮอล์อี 20	วิธีทดสอบ[1/]
			ออกเทน 91	ออกเทน 95			
				ชนิดที่ 1	ชนิดที่ 2		
	8.2 กากน้ำมัน *ร้อยละโดยปริมาตร* (Residue, *%vol.)*	ไม่สูงกว่า	2.0	2.0	2.0	2.0	
9	ความดันไอ ณ อุณหภูมิ 37.8 °ซ. *กิโลปาสคาล* (Vapour Pressure @ 37.8 °C , *kPa)*	ไม่สูงกว่า	62	62	62	64	ASTM D 4953
10	เบนซีน *ร้อยละโดยปริมาตร* (Benzene, *%vol.)*						ASTM D 5580
	ก่อนวันที่ 1 มกราคม พ.ศ. 2555	ไม่สูงกว่า	3.5	3.5	3.5	3.5	
	ตั้งแต่วันที่ 1 มกราคม พ.ศ. 2555 เป็นต้นไป	ไม่สูงกว่า	1.0	1.0	1.0	1.0	
11	อะโรมาติก *ร้อยละโดยปริมาตร* (Aromatics, *%vol.)*						ASTM D 5580
	ก่อนวันที่ 1 มกราคม พ.ศ. 2555	ไม่สูงกว่า	35	35	38	35	
	ตั้งแต่วันที่ 1 มกราคม พ.ศ. 2555 เป็นต้นไป	ไม่สูงกว่า	35	35	35	35	
12	โอเลฟิน *ร้อยละโดยปริมาตร* (Olefins, *%vol.)*						ASTM D 6839
	ก่อนวันที่ 1 มกราคม พ.ศ. 2555		-	-	-	-	
	ตั้งแต่วันที่ 1 มกราคม พ.ศ. 2555 เป็นต้นไป	ไม่สูงกว่า	18	18	18	18	
13	สี (Colour)						(1) เปรียบเทียบสีและปริมาณเนื้อสีกับน้ำมันมาตรฐานที่เตรียมขึ้นใหม่โดยใช้สีละลายในน้ำมันก่อนการย้อมสีให้มีปริมาณเท่ากับที่กำหนด แล้วบรรจุแยกกันในภาชนะที่ใช้วัดสีตามวิธีทดสอบ ASTM D 1500 แล้วตรวจพินิจด้วยสายตา หรือ (2) ASTM D 2392
	13.1 ชนิดของสี (Hue)		เขียว[3/]	ส้ม[4/]	ส้ม[4/]	-	
	13.2 เนื้อสี *มิลลิกรัม/ลิตร* (Dye, *mg/L)*	ไม่ต่ำกว่า	4.0	10.0	10.0	-	
14	น้ำ *ร้อยละโดยน้ำหนัก* (Water, *%wt.)*	ไม่สูงกว่า	0.7	0.7	0.7	0.7	ASTM E 203

(ต่อ - ๓ -)

รายการ	ข้อกำหนด	อัตราสูงต่ำ	น้ำมันแก๊สโซฮอล์อี 10			น้ำมันแก๊สโซฮอล์อี 20	วิธีทดสอบ[1]
			ออกเทน 91	ออกเทน 95			
				ชนิดที่ 1	ชนิดที่ 2		
15	เอทานอลแปลงสภาพ *ร้อยละโดยปริมาตร* (Denatured Ethanol, *%vol.*)	ไม่ต่ำกว่า และ ไม่สูงกว่า	9 10	9 10	9 10	19 20	ASTM D 4815
16	สารออกซิเจนเนตอื่น (Oxygenates)	ให้เป็นไปตามที่ได้รับความเห็นชอบจากอธิบดีกรมธุรกิจพลังงาน					ASTM D 4815
17	ลักษณะทั่วไปที่ปรากฏ (Appearance)	เป็นของเหลวใส ไม่ขุ่น ไม่แยกชั้น และไม่มีสารแขวนลอย					ตรวจพินิจด้วยสายตา
18	มีสารเติมแต่ง ที่มีคุณสมบัติชะล้างทำความสะอาด (Detergent Additive)						
	18.1 หัวฉีด (Port Fuel Injector)	ให้เป็นไปตามที่ได้รับความเห็นชอบจากอธิบดีกรมธุรกิจพลังงาน					
	18.2 ลิ้นไอดี (Intake Valve)	ให้เป็นไปตามที่ได้รับความเห็นชอบจากอธิบดีกรมธุรกิจพลังงาน					
19	สารเติมแต่งอื่น (ถ้ามี) (Additive)	ให้เป็นไปตามที่ได้รับความเห็นชอบจากอธิบดีกรมธุรกิจพลังงาน					

<u>หมายเหตุ</u>

1/ วิธีทดสอบอาจใช้วิธีอื่นที่เทียบเท่าก็ได้ แต่ในกรณีที่มีข้อโต้แย้งให้ใช้วิธีที่กำหนดในรายละเอียดแนบท้ายนี้

2/ ทดสอบเฉพาะกรณีที่เติมสารเติมแต่ง (Additive) ที่มีธาตุฟอสฟอรัสเป็นองค์ประกอบ

3/ ใช้น้ำมันเบนซินที่มีความเข้มของสีตามมาตรฐาน ASTM D 1500 ไม่สูงกว่า 0.5 ผสมกับสารประกอบประเภท 1,4-dialkylamino anthraquinone และ 1,3-benzenediol, 2,4-bis[(alkylphenyl) azo-] ในอัตราส่วน 9 : 4 โดยน้ำหนัก หรือใช้อัตราส่วนแตกต่างจากสีที่กำหนดก็ได้ แต่ต้องมีความเข้มของสีเทียบเท่าสีเขียวมาตรฐานที่กำหนดไว้ข้างต้น และใช้วิธีทดสอบตาม (1) หรือ (2)

4/ ใช้น้ำมันเบนซินที่มีความเข้มของสีตามมาตรฐาน ASTM D 1500 ไม่สูงกว่า 0.5 ผสมกับสารประกอบประเภท 2-naphthalenol [(phenylazo) phenyl] azo alkyl derivatives และ 1,3-benzenediol, 2,4-bis [(alkylphenyl) azo-] ในอัตราส่วน 1 : 3 โดยน้ำหนัก หรือใช้อัตราส่วนแตกต่างจากสีที่กำหนดก็ได้ แต่ต้องมีความเข้มของสีเทียบเท่าสีส้มมาตรฐานที่กำหนดไว้ข้างต้น และใช้วิธีทดสอบตาม (1) หรือ (2)

รายละเอียดแนบท้าย ๒

ประกาศกรมธุรกิจพลังงาน

เรื่อง กำหนดลักษณะและคุณภาพของน้ำมันแก๊สโซฮอล์

พ.ศ. ๒๕๕๓

รายการ	ข้อกำหนด		อัตราสูงต่ำ	น้ำมันแก๊สโซฮอล์อี 85	วิธีทดสอบ[1/]
1	ค่าออกเทน (Octane Number)				
	1.1 โดยวิธีวิจัย (Research Octane Number ; RON)				ASTM D 2699
	(1) ผู้ผลิตจำหน่าย ณ จุดส่งมอบ		ไม่ต่ำกว่า	95.0	
	(2) ผู้จำหน่าย		ไม่ต่ำกว่า	94.6	
	1.2 โดยวิธีมอเตอร์ (Motor Octane Number ; MON)				ASTM D 2700
	(1) ผู้ผลิตจำหน่าย ณ จุดส่งมอบ		ไม่ต่ำกว่า	85.0	
	(2) ผู้จำนน่าย		ไม่ต่ำกว่า	84.6	
2	ตะกั่ว	*กรัม/ลิตร*	ไม่สูงกว่า	0.005	ASTM D 5059
	(Lead,	*g/L)*			
3	กำมะถัน	*ร้อยละโดยน้ำหนัก*			ASTM D 2622
	(Sulphur,	*%wt.)*			
	ก่อนวันที่ 1 มกราคม พ.ศ. 2555		ไม่สูงกว่า	0.0125	
	ตั้งแต่วันที่ 1 มกราคม พ.ศ. 2555 เป็นต้นไป		ไม่สูงกว่า	0.005	
4	ฟอสฟอรัส	*กรัม/ลิตร*	ไม่สูงกว่า	0.0013	ASTM D 3231[2/]
	(Phosphorus,	*g/L)*			
5	การกัดกร่อนแผ่นเงิน		ไม่สูงกว่า	หมายเลข 1	ASTM D 4814
	(Silver Strip Corrosion)				(ANNEX A)
6	เสถียรภาพต่อการเกิดปฏิกิริยาออกซิเดชัน	*นาที*	ไม่ต่ำกว่า	360	ASTM D 525
	(Oxidation Stability,	*minutes)*			
7	ยางเหนียว	*มิลลิกรัม/100 มิลลิลิตร*	ไม่สูงกว่า	5	ASTM D 381
	(Solvent Washed Gum,	*mg/100mL)*			
8	การกลั่น	*องศาเซลเซียส*			ASTM D 86
	(Distillation,	*°C)*			
	8.1 จุดเดือดสุดท้าย		ไม่สูงกว่า	200	
	(End Point)				
	8.2 กากน้ำมัน	*ร้อยละโดยปริมาตร*	ไม่สูงกว่า	2.0	
	(Residue,	*%vol.)*			
9	ความดันไอ ณ อุณหภูมิ 37.8 °ซ.	*กิโลปาสคาล*	ไม่ต่ำกว่า	35	ASTM D 4953
	(Vapour Pressure @ 37.8 °C ,	*kPa)*	และ		
			ไม่สูงกว่า	70	
10	เบนซีน	*ร้อยละโดยปริมาตร*	ไม่สูงกว่า	1	ASTM D 5580
	(Benzene,	*%vol.)*			
11	อะโรมาติก	*ร้อยละโดยปริมาตร*	ไม่สูงกว่า	35	ASTM D 5580
	(Aromatics,	*%vol.)*			

(ต่อ - ๒ -)

รายการ	ข้อกำหนด		อัตราสูงต่ำ	น้ำมันแก๊สโซฮอล์อี 85	วิธีทดสอบ[1/]
12	โอเลฟิน (Olefins,	*ร้อยละโดยปริมาตร* *%vol.)*			ASTM D 6839
	ก่อนวันที่ 1 มกราคม พ.ศ. 2555		-	-	
	ตั้งแต่วันที่ 1 มกราคม พ.ศ. 2555 เป็นต้นไป		ไม่สูงกว่า	18	
13	สี (Colour)		รายงาน		
14	น้ำ (water,	*ร้อยละโดยน้ำหนัก* %wt.)	ไม่สูงกว่า	0.7	ASTM E 203
15	เอทานอลแปลงสภาพ (Denatured Ethanol,	*ร้อยละโดยปริมาตร* *%vol.)*	ไม่ต่ำกว่า	75	ASTM D 5501
16	ไฮโดรคาร์บอน/อลีฟาติก อีเทอร์ (Hydrocarbon/aliphatic ether	*ร้อยละโดยปริมาตร* *%vol.)*	ไม่ต่ำกว่า และ ไม่สูงกว่า	14 25	[(100 – (water + alcohol)][3/]
17	เมทานอล (Methanol,	*ร้อยละโดยปริมาตร* *%vol.)*	ไม่สูงกว่า	0.5	ASTM D 5501
18	แอลกอฮอล์ที่มีจำนวนคาร์บอนอะตอมตั้งแต่ 3-5 อะตอม (Higher (C_3-C_5) alcohols	*ร้อยละโดยปริมาตร* *%vol.)*	ไม่สูงกว่า	2.0	ASTM D 4815
19	ความเป็นกรด คำนวณเป็นกรดอะซิติก (Acidity, as acetic acid	*มิลลิกรัม/ลิตร* *mg/L)*	ไม่สูงกว่า	30	ASTM D 1613
20	คลอไรด์อนินทรีย์ (Inorganic chloride	*มิลลิกรัม/ลิตร* *mg/L)*	ไม่สูงกว่า	1	ISO 6227
21	ความเป็นกรด-ด่าง (pHe)		ไม่ต่ำกว่า และ ไม่สูงกว่า	6.5 9.0	ASTM D 6423
22	ทองแดง (Copper	*มิลลิกรัม/กิโลกรัม* *mg/kg)*	ไม่สูงกว่า	0.07	ASTM D 1688
23	ลักษณะทั่วไปที่ปรากฏ (Appearance)		เป็นของเหลวใส ไม่แยกชั้น ไม่ขุ่นและไม่มีสารแขวนลอย		ตรวจพินิจด้วยสายตา
24	มีสารเติมแต่ง ที่มีคุณสมบัติชะล้างทำความสะอาด (Detergent Additive)				
	24.1 หัวฉีด (Port Fuel Injector)		ให้เป็นไปตามที่ได้รับความเห็นชอบจากอธิบดีกรมธุรกิจพลังงาน		
	24.2 ลิ้นไอดี (Intake Valve)		ให้เป็นไปตามที่ได้รับความเห็นชอบจากอธิบดีกรมธุรกิจพลังงาน		
25	สารเติมแต่งอื่น (ถ้ามี) (Additive)		ให้เป็นไปตามที่ได้รับความเห็นชอบจากอธิบดีกรมธุรกิจพลังงาน		

(ต่อ - ๓ -)

รายละเอียดแนบท้ายประกาศกรมธุรกิจพลังงาน
เรื่อง กำหนดลักษณะและคุณภาพของเอทานอลแปลงสภาพ
พ.ศ. 2548

รายการ	ข้อกำหนด	อัตราสูงต่ำ		วิธีทดสอบ$^{1/}$
1	ปริมาณเอทานอลและแอลกอฮอล์ชนิดอิ่มตัวที่มีจำนวนคาร์บอนอะตอมสูงกว่าเอทานอล *ร้อยละโดยปริมาตร* (Ethanol plus higher saturated alcohols, *%vol.*)	ไม่ต่ำกว่า	99.0	EN 2870 Appendix 2 Method B
2	โมโนแอลกอฮอล์ชนิดอิ่มตัวที่มีจำนวนคาร์บอนอะตอมตั้งแต่ 3- 5 อะตอม *ร้อยละโดยปริมาตร* {Higher saturated (C_3-C_5) mono alcohols , *%vol.*}	ไม่สูงกว่า	2.0	EN 2870 Method III
3	เมทานอล *ร้อยละโดยปริมาตร* (Methanol, *%vol.*)	ไม่สูงกว่า	0.5	EN 2870 Method III
4	ยางเหนียว *มิลลิกรัม/100มิลลิลิตร* (Solvent Washed Gum, *mg/100mL*)	ไม่สูงกว่า	5.0	ASTM D 381
5	น้ำ *ร้อยละโดยน้ำหนัก* (Water, *%wt.*)	ไม่สูงกว่า	0.3	ASTM E 203
6	คลอไรด์อนินทรีย์ *มิลลิกรัม/ลิตร* (Inorganic chloride, *mg/L*)	ไม่สูงกว่า	20	ASTM D 512
7	ทองแดง *มิลลิกรัม/กิโลกรัม* (Copper , *mg/kg*)	ไม่สูงกว่า	0.07	ASTM D 1688
8	ความเป็นกรดคำนวณเป็นกรดอะซีติก *มิลลิกรัม/ลิตร* (Acidity as acetic acid, *mg/L*)	ไม่สูงกว่า	30	ASTM D 1613
9	ความเป็นกรด-ด่าง (pHe)	ไม่ต่ำกว่า และ ไม่สูงกว่า	6.5 9.0	ASTM D 6423
10	สภาพตัวนำไฟฟ้า *ไมโครซีเมนส์/เมตร* (Electrical conductivity, *µS/m*)	ไม่สูงกว่า	500	ASTM D 1125
11	ลักษณะที่ปรากฏ (Appearance)		เป็นของเหลวใส ไม่ขุ่น ไม่แยกชั้น และไม่มีสารแขวนลอย	ตรวจพินิจด้วยสายตา
12	สารเติมแต่ง(ถ้ามี) (Additive)	**ให้เป็นไปตามที่ได้รับความเห็นชอบจากอธิบดีกรมธุรกิจพลังงาน**		

หมายเหตุ 1/วิธีทดสอบอาจใช้วิธีอื่นที่เทียบเท่าก็ได้ แต่ในกรณีที่มีข้อโต้แย้งให้ใช้วิธีที่กำหนดในรายละเอียดแนบท้ายนี้

APPENDIX C.

Thailand’s temperature

สถิติอุณหภูมิต่ำที่สุดในช่วงฤดูหนาวของประเทศไทยคาบ 60 ปี พ.ศ. 2494 - 2553

สถานี	พฤศจิกายน			ธันวาคม			มกราคม			กุมภาพันธ์			คาบ	ตั้งแต่
	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(ปี)	พ.ศ.
ภาคเหนือ														
1.เชียงราย	5.0	21	2514	1.5	25	2542	1.5	2	2517	6.5	11	2506	59	2494
2.สกษ.เชียงราย(อ.เมือง)	4.8	30	2526	1.0	25	2542	5.6	1	2539	6.7	2	2536	31	2522
3.แม่ฮ่องสอน	9.3	21	2544	3.9	25	2542	6.0	27	2496	8.2	4	2500	59	2494
4.แม่สะเรียง(จ.แม่ฮ่องสอน)	6.5	22	2514	3.3	25	2542	3.3	6	2517	6.2	7	2523	59	2494
5.พะเยา	6.9	30	2526	2.5	25	2542	6.0	23 8	2527 2529	7.0	3	2536	28	2524
6.ศูนย์อุตุนิยมวิทยา ภาคเหนือ(จ.เชียงใหม่)	6.0	21	2514	3.8	25	2542	3.7	2	2517	7.3	3	2517	59	2494
7.สกษ.แม่โจ้ (อ.สันทราย จ.เชียงใหม่)	8.3	21 30	2514 2526	3.9	25	2542	4.0	2	2517	8.4	10	2528	38	2512-2549
8.น่าน	6.2	30	2526	2.7	25	2542	3.5	1	2517	7.0	3	2511	59	2494
9.สกษ.น่าน(อ.เมือง)	4.2	22	2514	1.2	26	2542	1.0	2	2517	6.3	14 2	2517 2550	41	2512
10.สอท.ท่าวังผา(จ.น่าน)	6.2	29	2526	1.7	25	2542	1.9	2	2517	5.4	11	2528	40	2513
11.สอท.ทุ่งช้าง(จ.น่าน)	9.3	29	2544	2.6	26	2542	7.0	16	2552	8.6	16	2541	13	2540
12.ลำพูน	9.3	30	2526	3.5	25	2542	7.8	9	2529	9.2	1	2536	29	2524
13.ลำปาง	7.1	21	2514	3.7	25	2542	3.9	5	2517	8.1	9	2498	59	2494
14.เถิน(จ.ลำปาง)	12.9	30	2551	10.0	22,24	2549	8.2	16	2552	10.8	3,4	2550	6	2547
15.สกษ.ลำปาง(อ.ห้างฉัตร)	8.2	30	2526	4.0	25	2542	7.5	27	2526	9.5	11	2540	26	2525-2550
16.แพร่	8.8	21,22	2514	5.0	25	2542	4.6	2	2517	8.9	2	2506	58	2495
17.อุตรดิตถ์	10.2	18,19	2514	7.5	27	2516	4.5	13	2498	10.0	5	2505	59	2494
18.สุโขทัย	13.9	28	2544	13.0	22 9 23	2546 2547 2549	11.4	14,15	2552	12.8	2	2550	10	2543
19.สกษ.ศรีสำโรง(จ.สุโขทัย)	9.8	18,20	2514	6.2	31	2518	5.5	4	2517	10.1	13	2517	39	2512-2550
20.ตาก	9.3	30	2526	5.8	27	2516	4.7	13	2498	10.5	14	2517	56	2497
21.เขื่อนภูมิพล (อ.สามเงา จ.ตาก)	10.7	30	2526	6.3	25	2542	7.0	2	2517	11.0	12,13	2517	50	2503
22.แม่สอด (จ.ตาก)	8.4	30	2526	4.5	26	2542	4.8	13	2498	9.2	21	2500	59	2494
23.อุ้มผาง (จ.ตาก)	6.4	30	2526	0.8	27	2542	4.3	14	2552	3.9	13	2535	33	2520
24.สกษ.ดอยมูเซอ (อ.เมือง จ.ตาก)	6.0	6	2543	3.2	27	2542	5.5	2	2539	6.0	3	2550	16	2535-2550
25.สกษ.พิจิตร(อ.เมือง)	14.0	30	2550	7.5	25	2542	9.8	15	2552	11.7	1	2536	18	2535
26.พิษณุโลก	12.1	29	2526	8.9	26	2542	7.5	13	2498	13.0	1	2536	59	2494
27.เพชรบูรณ์	7.9	30	2499	5.1	30	2518	2.0	13	2498	8.5	1	2506	59	2494
28.หล่มสัก(จ.เพชรบูรณ์)	8.6	29	2526	5.5	31	2518	6.7	1	2519	10.6	13	2517	40	2513
29.วิเชียรบุรี(จ.เพชรบูรณ์)	9.3	16,18	2514	5.5	30	2518	7.5	2	2517	10.9	13	2517	40	2513
30.กำแพงเพชร	12.6	27,29	2526	8.2	26,27	2542	10.1	9	2529	12.2	1	2536	29	2524

สถิติอุณหภูมิต่ำที่สุดในช่วงฤดูหนาวของประเทศไทยคาบ 60 ปี พ.ศ. 2494 - 2553

สถานี	พฤศจิกายน			ธันวาคม			มกราคม			กุมภาพันธ์			คาบ	ตั้งแต่
	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(ปี)	พ.ศ.
ภาคตะวันออกเฉียงเหนือ 1.หนองคาย	8.8	29	2526	4.9	24	2542	5.2	2	2517	9.6	13 1	2517 2536	42	2511
2.เลย	5.6	30	2499	2.2	31 31	2516 2518	0.1	13 2	2498 2517	6.2	1	2506	56	2497
3.สกษ.เลย(อ.เมือง)	2.6	21	2514	0.0	23	2518	-1.3	2	2517	4.5	13	2517	40	2513
4.อุดรธานี	8.4	28,30 29	2499 2526	4.2	25	2542	2.5	12	2498	9.4	28	2506	59	2494
5.นครพนม	7.2	23	2498	4.1	30	2518	1.8	12	2498	8.0	13	2517	57	2496
6.สกษ.นครพนม(อ.เมือง)	8.6	30	2551	1.7	25,26	2542	4.2	11	2552	6.5	3	2550	27	2526
7.สกลนคร	6.9	30	2499	4.0	30 24	2518 2542	0.5	12	2498	7.6	11	2517	58	2495
8.สกษ.สกลนคร(อ.เมือง)	5.5	16,21	2514	1.8	31	2516	-1.4	2	2517	4.9	11	2517	41	2512
9.มุกดาหาร	9.4	25	2516	5.3	23	2518	3.2	15	2506	9.2	5	2505	57	2496
10.ขอนแก่น	9.4	16	2514	5.6	29	2518	5.7	15	2506	10.4	11	2517	59	2494
11.สกษ.ท่าพระ (อ.เมือง จ.ขอนแก่น)	9.4	16	2514	5.1	24	2542	4.0	2	2517	9.7	12	2517	41	2512
12.สอท. โกสุมพิสัย (จ.มหาสารคาม)	6.6	17	2514	5.3	25	2542	5.6	2	2517	9.0	12	2517	40	2513
13.ร้อยเอ็ด	11.4	28 16	2499 2514	6.7	24	2542	6.3	15	2506	9.8	12	2517	57	2496
14.สกษ.ร้อยเอ็ด (อ.เมือง)	10.8	29	2526	5.4	24	2542	8.9	10 30	2527 2536	11.1	4	2550	27	2526
15. สอท.กมลาไสย (จ.กาฬสินธุ์)	12.0	30	2551	5.5	24	2542	9.5	2	2548	10.2	2	2543	12	2541
16.ชัยภูมิ	10.4	24	2506	6.8	25	2542	6.3	4	2503	11.5	13	2517	53	2500
17.ศูนย์อุตุนิยมวิทยา ภาคตะวันออกเฉียงเหนือ (จ.อุบลราชธานี)	12.5	22	2497	8.5	30	2518	7.6	12	2498	11.7	22 11	2498 2520	59	2494
18.สกษ.อุบลราชธานี (อ.วารินชำราบ จ.อุบลราชธานี)	9.4	18	2519	6.7	30	2518	7.5	16	2519	9.6	11	2520	38	2515
19.สุรินทร์	11.9	27	2499	8.2	30	2518	6.4	17	2510	11.0	17 5	2505 2510	59	2494
20.สกษ.สุรินทร์(อ.เมือง)	10.2	17	2514	6.7	25	2542	8.0	25	2526	10.2	13	2517	41	2512
21.สอท.ท่าตูม(จ.สุรินทร์)	11.5	25	2516	7.1	31	2518	7.1	2	2517	10.6	13	2517	40	2513
22.นครราชสีมา	9.1	30	2499	6.2	31	2518	4.9	12	2498	10.6	21	2498	59	2494
23.สกษ.ปากช่อง (จ.นครราชสีมา)	7.7	18	2514	3.6	31	2518	4.5	1	2519	8.1	13	2517	41	2512

สถิติอุณหภูมิต่ำที่สุดในช่วงฤดูหนาวของประเทศไทยคาบ 60 ปี พ.ศ. 2494 - 2553

สถานี	พฤศจิกายน			ธันวาคม			มกราคม			กุมภาพันธ์			คาบ	ตั้งแต่
	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(ปี)	พ.ศ.
24.โชคชัย(จ.นครราชสีมา)	9.7	17	2514	6.5	30	2518	7.2	2	2517	10.3	13	2517	40	2513
25.สกษ.ศรีสะเกษ(อ.เมือง)	13.3	30	2550	6.8	25	2542	9.2	10 2	2527 2548	10.0	2	2543	27	2526
26.บุรีรัมย์	12.5	29	2550	11.5	23	2549	10.0	2	2548	10.5	4	2550	7	2546
27.นางรอง(จ.บุรีรัมย์)	12.0	25	2518	7.8	29	2525	9.2	1	2519	10.7	4	2550	40	2513
ภาคกลาง 1.นครสวรรค์	11.9	28 19 29	2499 2514 2526	7.7	25	2542	6.1	13	2498	12.0	13 1	2517 2536	59	2494
2.สกษ.ตากฟ้า (จ.นครสวรรค์)	11.9	18	2514	8.1	25	2542	10.1	1	2519	13.0	4	2550	41	2512
3.สกษ.สรรพยา(จ.ชัยนาท)	13.1	29	2526	8.3	25	2542	9.7	19	2519	14.0	13	2517	40	2513
4.ลพบุรี	10.5	21	2497	10.2	25	2542	8.4	4	2503	13.5	6 27	2500 2507	59	2494
5.สอท.บัวชุม (อ.ชัยบาดาล จ.ลพบุรี)	7.4	18	2514	5.7	25	2542	6.4	1	2519	11.6	4	2550	40	2513
6.สุพรรณบุรี	14.5	30 18	2499 2514	10.0	31	2518	9.2	13	2498	12.0	6	2500	58	2495
7.สกษ.อู่ทอง(จ.สุพรรณบุรี)	11.7	26	2516	7.5	25	2542	8.5	12	2552	10.2	5	2550	41	2512
8.กาญจนบุรี	11.6	17	2514	6.8	31	2518	5.5	13	2498	12.1	13	2517	58	2495
9.ทองผาภูมิ(จ.กาญจนบุรี)	9.4	17	2514	5.2	27	2536	5.4	5	2517	8.1	1	2536	40	2513
10.สกษ.กำแพงแสน (จ.นครปฐม)	12.2	29	2526	6.5	30	2518	8.2	2 1	2517 2519	10.5	13	2517	37	2516
11.สกษ.ราชบุรี(อ.เมือง)	15.5	30	2550	9.8	25	2542	12.6	2	2539	14.4	4	2550	18	2535
12.สกษ.อยุธยา (อ.ท่าเรือ จ.พระนครศรีอยุธยา)	14.3	28	2550	11.1	26	2542	12.0	6	2538	13.2	6	2536	18	2535
13.สกษ.ปทุมธานี(อ.คลองหลวง	14.8	29	2550	11.5	25	2542	14.5	12	2552	16.0	2	2543	11	2542
14.กรุงเทพมหานคร	14.2	17	2514	10.5	30	2518	9.9	12	2498	14.9	13	2517	59	2494
15.ท่าอากาศยานกรุงเทพ (เขตดอนเมือง กทม.)	15.0	25	2518	10.0	30	2518	11.4	12	2498	16.0	11 22	2517 2518	59	2494
16.สกษ.บางเขน (เขตจตุจักร กทม.)	15.1	25	2518	10.5	30	2518	12.4	4	2517	13.6	11	2539	30	2512-2541
17.สกษ.บางนา (เขตบางนา กทม.)	15.0	17	2514	11.5	31	2518	11.0	15	2519	14.5	12	2517	41	2512
18.สนง.อุตุนิยมวิทยาท่าเรือ (เขตคลองเตย กทม.)	19.0	20	2539	14.2	26	2542	15.8	12	2540	18.9	6	2538	16	2537
19.สถานีนำร่อง (อ.เมือง จ.สมุทรปราการ)	19.0	29	2526	16.0	25 23	2542 2548	17.5	25	2526	19.8	2	2543	29	2524

สถิติอุณหภูมิต่ำที่สุดในช่วงฤดูหนาวของประเทศไทยคาบ 60 ปี พ.ศ. 2494 - 2553

สถานี	พฤศจิกายน			ธันวาคม			มกราคม			กุมภาพันธ์			คาบ	ตั้งแต่
	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(ปี)	พ.ศ.
ภาคตะวันออก														
1.สกษ.ฉะเชิงเทรา (อ.สนามชัยเขต)	14.0	6	2543	8.8	25	2542	11.3	12	2552	12.7	4	2550	21	2532
2.ปราจีนบุรี	13.8	21	2497	10.8	10	2495	10.2	13	2498	14.5	4	2543	59	2494
3.สอท.กบินทร์บุรี (จ.ปราจีนบุรี)	13.4	16	2514	8.5	30	2518	10.1	14	2519	13.0	4	2543	40	2513
4.อรัญประเทศ (จ.สระแก้ว)	10.2	22	2497	10.0	31	2518	7.6	16	2506	12.5	6	2512	59	2494
5. สอท.สระแก้ว	14.7	6	2543	9.0	24	2542	11.4	12	2552	13.7	5	2550	12	2541
6.ชลบุรี	14.2	16	2514	12.0	29	2518	9.9	12	2498	16.5	7	2505	59	2494
7.เกาะสีชัง(จ.ชลบุรี)	15.5	24	2518	14.8	23,24	2542	15.2	16	2510	17.0	4	2543	51	2502
8.พัทยา (อ.บางละมุง จ.ชลบุรี)	16.7	29	2526	14.6	24	2542	16.4	10	2527	18.5	10	2547	29	2524
9.สัตหีบ จ.ชลบุรี	15.0	17	2514	11.2	25	2542	12.3	12	2498	16.0	4	2543	59	2494
10.แหลมฉบัง (จ.ชลบุรี)	17.0	23	2552	14.0	25	2542	14.9	11	2552	16.5	14	2547	18	2535
11.ระยอง	17.0	6	2543	13.3	25	2542	14.5	24	2526	16.5	18	2524	29	2524
12.สกษ.ห้วยโป่ง (อ.เมือง จ.ระยอง)	14.3	25	2518	12.5	30	2518	12.7	3	2519	13.3	14	2517	41	2512
13.จันทบุรี	13.0	23	2497	8.9	16	2497	11.2	12	2498	14.8	21	2505	59	2494
14.สกษ.พลิ้ว (อ.ขลุง จ.จันทบุรี)	14.2	29	2526	10.7	30 25	2518 2542	11.7	13	2524	14.5	18	2524	41	2512
15.คลองใหญ่ (จ.ตราด)	14.5	21	2497	15.0	23	2518	13.0	15	2506	15.0	4	2505	58	2495
ภาคใต้ฝั่งตะวันออก														
1.เพชรบุรี	15.6	29	2526	12.4	25	2542	14.0	25 10	2526 2527	16.0	4	2550	29	2524
2.ประจวบคีรีขันธ์	13.0	22	2497	11.4	31	2499	10.5	19	2506	12.2	6	2500	59	2494
3.หัวหิน (จ.ประจวบคีรีขันธ์)	17.2	21	2497	13.9	30	2518	13.9	13	2498	15.4	6	2500	56	2497
4.สกษ.หนองพลับ (อ.หัวหิน จ.ประจวบคีรีขันธ์)	10.5	30	2526	6.4	26	2542	8.3	1	2519	11.3	4	2543	36	2517
5.ชุมพร	15.1	18	2514	12.2	30	2518	12.1	15	2519	14.4	5	2543	59	2494
6.สกษ.สวี (จ.ชุมพร)	16.1	28	2518	12.5	29	2518	10.5	15	2519	14.0	5	2543	41	2512
7.สุราษฎร์ธานี	16.3	23	2497	16.6	7	2519	12.4	4	2500	14.2	7	2505	48	2494-2541
8.ท่าอากาศยานสุราษฎร์ธานี (อ.พุนพิน จ.สุราษฎร์ธานี)	19.5	16	2534	17.2	24,25	2542	16.2	30 31	2535 2536	16.5	20	2535	22	2531
9.สอท.พระแสง (จ.สุราษฎร์ธานี)	19.0	26	2544	16.8	27	2549	16.0	2,31	2550	14.4	6	2550	15	2538
10.เกาะสมุย(จ.สุราษฎร์ธานี)	20.3	15	2535	18.8	6	2539	18.6	15	2519	19.5	6	2543	42	2511
11.สกษ.สุราษฎร์ธานี (อ.กาญจนดิษฐ์ จ.สุราษฎร์ธานี)	17.6	29	2550	16.6	29	2539	16.5	15	2540	16.4	26	2537	18	2535

สถิติอุณหภูมิต่ำที่สุดในช่วงฤดูหนาวของประเทศไทยคาบ 60 ปี พ.ศ. 2494 - 2553

สถานี	พฤศจิกายน			ธันวาคม			มกราคม			กุมภาพันธ์			คาบ	ตั้งแต่
	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(°ซ.)	วันที่	พ.ศ.	(ปี)	พ.ศ.
12.นครศรีธรรมราช	18.0	23	2499	17.1	16	2498	17.2	16	2519	17.2	7	2505	59	2494
13.สกษ.นครศรีธรรมราช (อ.เมือง)	18.5	1	2551	18.4	29	2539	17.4	4 15	2539 2540	17.5	13,23	2538	27	2526
14.ท่าเรือการไฟฟ้าขนอม (อ.ขนอม จ.นครศรีธรรมราช)	21.7	13	2544	18.3	28	2539	18.9	7	2542	18.8	6	2543	9	2537-2545
15.สอท.ฉวาง (จ.นครศรีธรรมราช)	17.7	29	2550	16.5	25,26	2542	15.0	9	2542	16.2	22	2551	15	2538
16. สอท.สะเดา (จ.สงขลา)	17.3	10	2543	16.8	7	2543	16.4	1,5	2544	18.4	20	2542	14	2539
17.สกษ.พัทลุง (อ.เมือง)	19.8	11	2553	19.7	25	2542	18.4	8	2542	18.0	17	2532	29	2524
18.ศูนย์อุตุนิยมวิทยา ภาคใต้ฝั่งตะวันออก (จ.สงขลา)	19.9	22	2499	20.5	11	2495	19.1	18	2504	20.3	6 9	2497 2510	59	2494
19.หาดใหญ่ (จ.สงขลา)	20.3	27	2521	19.1	27	2524	17.7	20	2519	18.2	17 5	2532 2550	37	2516
20.สกษ.คอหงส์ (อ.หาดใหญ่ จ.สงขลา)	20.5	29	2521	20.0	31 18	2514 2518	17.5	3	2515	14.0	18	2544	41	2512
21.ท่าอากาศยานปัตตานี	20.0	20	2514	19.4	28	2522	17.5	26	2508	16.7	23	2536	46	2507
22.สกษ.ยะลา (อ.เมือง)	19.0	19	2530	17.4	20	2530	16.0	19	2531	16.9	15 23	2532 2536	28	2525
23.นราธิวาส	18.7	29	2501	19.0	16	2547	17.1	26	2508	17.5	24	2511	59	2494
ภาคใต้ฝั่งตะวันตก 1.ระนอง	16.0	18	2514	15.1	21 17 26	2495 2498 2501	13.7	21	2499	15.0	24	2502	59	2494
2.ตะกั่วป่า(จ.พังงา)	19.9	5	2531	17.4	15	2529	16.0	14	2524	17.3	8	2526	29	2524
3.ภูเก็ต	19.3	23	2497	18.4	1	2525	17.4	4	2500	18.6	18	2526	59	2494
4.ท่าอากาศยานภูเก็ต	17.0	6	2551	16.9	17	2498	13.9	4	2500	15.8	7	2500	58	2495
5.กระบี่	17.7	4	2551	18.5	12	2552	15.3	11	2552	16.3	23	2552	12	2537-2545 2550
6.เกาะลันตา(จ.กระบี่)	21.0	11,15, 16	2535	19.5	25,26	2542	19.0	8	2542	18.9	20	2535	29	2524
7.ท่าอากาศยานตรัง	17.3	30	2501	16.2	27	2501	15.9	14	2517	15.0	16	2532	59	2494
8.สตูล	19.4	16,18	2529	18.0	14	2529	17.6	4,5	2530	17.0	12,25, 26	2530	32	2521

หมายเหตุ : ฤดูหนาว 2552 หมายถึง พฤศจิกายน 2552 - กุมภาพันธ์ 2553

ศูนย์ภูมิอากาศ สำนักพัฒนาอุตุนิยมวิทยา
กรมอุตุนิยมวิทยา

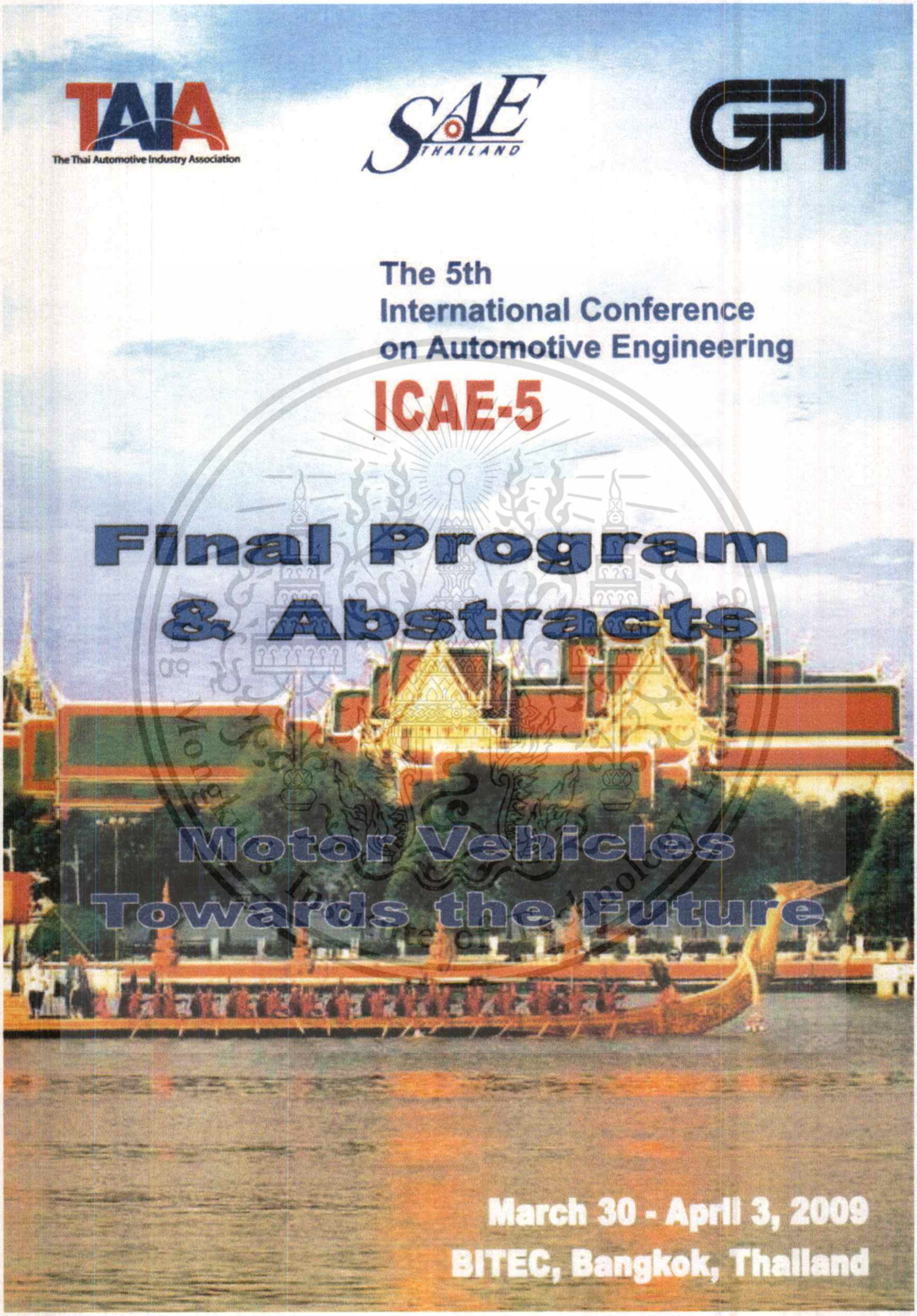
APPENDIX D.

Publications

Appendix D-1: The 5th International Conference on Automotive Engineering (ICAE-5) March 30 – April 3, 2009, BITEC, Bangkok, Thailand

Appendix D-2: The First TSME International Conference on Mechanical Engineering 20-22 October, 2010, Ubon Ratchathani, Thailand

Appendix D-3: The 17th Small Engine Technology Conference (SETC2011), November 8-10, 2011, Sapporo, Hokkaido, Japan



TAIA
The Thai Automotive Industry Association

SAE THAILAND

GPI

The 5th
International Conference
on Automotive Engineering

ICAE-5

Final Program & Abstracts

Motor Vehicles Towards the Future

March 30 - April 3, 2009
BITEC, Bangkok, Thailand

The 5th International Conference on Automotive Engineering (ICAE-5)
March 30 – April 3, 2009, BITEC, Bangkok, Thailand

Cold Start Characteristics of an Ethanol Engine

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Tokyo Institute of Technology, Japan

ABSTRACT

This objective of this study is to investigate starting characteristics of ethanol at low temperature, which is related to the cold-start operation of engines fueled with ethanol. The test engine is a single cylinder four stroke SI engine which fuel injection and ignition timing are controlled by ECU (electronic control unit). Cold starting performance tests were conducted using ethanol fuel with different purity of fuel, surrounding temperature, compression ratio, A/F ratio, % of water in ethanol and strength of sparking flame. The results will show what are important parameters effected on starting characteristics at low temperature. Furthermore, optimization for cold starting of ethanol engine is one factor to reduce fuel consumption and emission as well.

INTRODUCTION

All kind of vehicle engines work with fuels produced from crude oil. However, crude oils are running up and decrease crude oil import. Limited energy sources warn of a potential lack of energy in the future. So we need renewable energy for substitute crude oils. Thailand is agricultural country. We have a lot of agricultural product to produce ethanol. So ethanol is a good choice for renewable in Thailand. And ethanol is Thailand's policy. But ethanol using with SI engine must modify. Because as well known if we use ethanol with SI engine in the winter or low temperature the engine is hard to start. That is the main problem of ethanol using. So that why interesting it?

At the moment Thailand's the petroleum oil price is very expensive. So we need renewable energy for substitute petroleum oils. But we need to develop or modify the engine to use for renewable energy. Particularly start at low temperature. Because the important problem of ethanol fuel in SI engine is cold starting. I want to research about problem of starting at low temperature by vary some parameter such as ambient temperature, A/F ratio, compression ratio, strength of sparking flame, % of ethanol in fuel, % of water in ethanol and have to control voltage of battery, speed of starter and ignition timing. What do parameters relate with this problem?

EXPERIMENTAL APPARATUS AND PROCEDURE

Experimental apparatus included three major systems, i.e. the engine system, the cold soak chamber, and microcontroller & Instruments. The engine system used in this experiment, whose technical data are shown in Table 1, was the Suzuki skydrive engine. Properties of the fuels used are given in Table 2.

Table 1. Suzuki skydrive specification [1]

Engine type	SOHC 2-valve 4 strokes air-cooled
Displacement	124cc.
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]

Fuel properties	Ethanol	Gasoline
Formula	C_2H_5OH	C_4 to C_{12}
Molecular weight	46.07	100-105
Density, kg/l, 15/15 °C	0.79	0.69-0.79
Freezing point, °C	-114	-40
Boiling point, °C	78	27-225

Vapor pressure, kPa at 38 °C	15.9	48-103
Specific heat, kJ/kg K	2.4	2.0
LHV, 1000 kJ/L	21.1	30-33
Flash point, °C	13	-43
Auto-ignition temperature, °C	423	257
Flammability limit, vol%		
Lower	4.3	1.4
Higher	19.0	7.6
Stochiometric air-fuel ratio	9.0	14.7
Octane number		
Research	108.9	88-100
Motor	89.7	80-90

The experimental parameters and result were measure by microcontroller & electronic system which monitor and data log by computer.(Fig. 1)

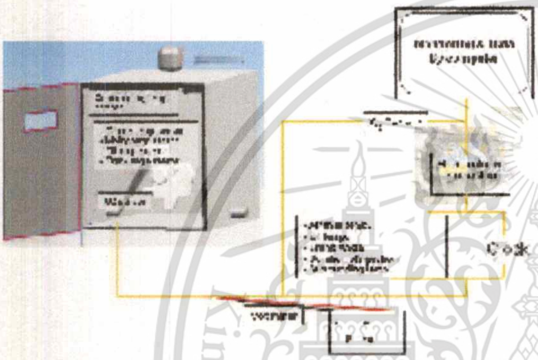

Fig.1 Schematic diagram of the experimental system

Design and Construction of an Environmental Cold-Soak Engine Chamber - An environmental cold-soak chamber was designed and built in order to provide controlled conditions for testing E100 engines. 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 to add durability. Chamber can operate the lowest temperature @ -10 °C that temperature lower than the lowest testing temperature (-2 °C)

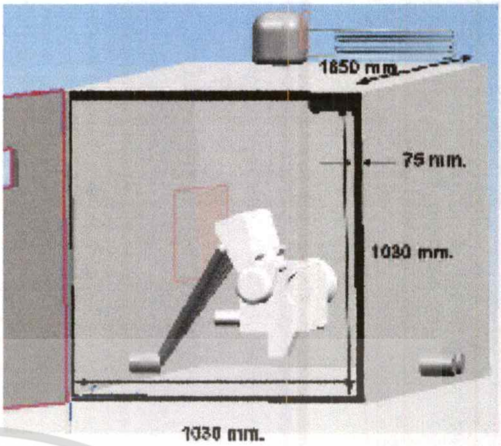

Fig. 2 Schematic of Cold-Soak Chamber

In the SI engine used, the air and fuel are mixed together in the intake port system prior to entry to the engine cylinder by using a fuel injector. The engine under the investigation was tested with original DCP (Discharge Pump)-injector (Fig 3). Then, the injection duration was adjusted to be able to use ethanol as a fuel. Then, the ECU (Electronic Control Unit) need a sub module to adjustable the injection duration.

Fig. 3 Suzuki skydrive engine [1]

Because of the lack of availability of an environmental chamber, testing was conducted outdoors in cold weather. Temperature control was not possible and so

there were slight variations in the temperatures between different tests. The lowest temperature reached was 25 °C (25" F), which is warmer than the initial desired goal of -2 °C. Oil and intake port temperature inside the engine block was used as the control temperature for the experiments. This was continuously monitored. During the test, data was acquired with the use of AVR micro controller device that communicates and displays 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: First time the Engine Speed (RPM) recorded by micro controller was more than zero.

Engine Start: The Engine Speed (RPM) reached 900 rpm and remained above that value. Engine oil Temperature, Air intake Temperature, Mixing Temperature, Duration Injection and Battery Voltage: as read from my cold start timer program.

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

RESULT AND DISCUSSION

Following experimental the starting time of E85 and pure ethanol compare with the conventional fuel in same condition the result shown in (Fig. 4, 5& 6)

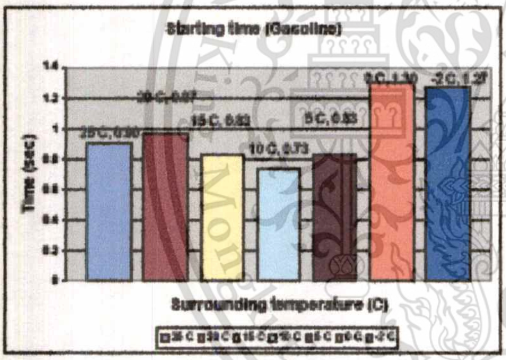

Fig. 4 Experiment result graph between starting time of E0 VS surrounding temperature

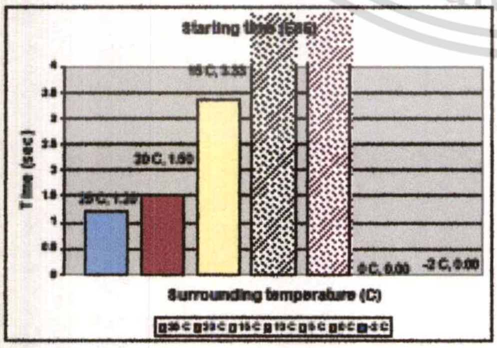

Fig. 5 Experiment result graph between starting time of E85 VS surrounding temperature

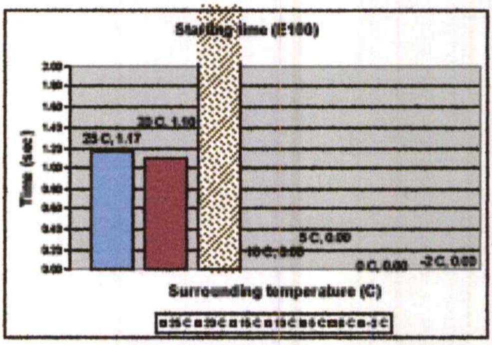

Fig. 6 Experiment result graph between starting time of E100 VS surrounding temperature

There are a few possible reasons for the data variations. These include: test inconsistencies, battery voltage, surrounding temperature, air intake temperature, and oil temperature. At 5, 10 degree Celsius of E85 and 15 degree Celsius the engine start in twice times which each time spend 10 seconds.

So when a re-start occurs during the test, additional fuel prime pulses are added during the start, which results in richer mixtures. Basically, when a re-start is done during a test, the engine has more fuel available to evaporate and combust; thus shortening total cranking time. This re-start, however, is unpleasant to the customer and results in poor hydrocarbon emissions. The battery voltage was easily controllable and the battery was fully charged throughout all the experiments so it did not vary significantly. The temperature of the fuel will influence the amount of fuel vapor that will be produced. A higher fuel temperature will produce more fuel vapor and thus will assist the cold start.

In the worst case the engine can not start when surrounding temperature below than 0 degree Celsius for E85 and below than 10 degree Celsius. These result were integrated in Fig.7

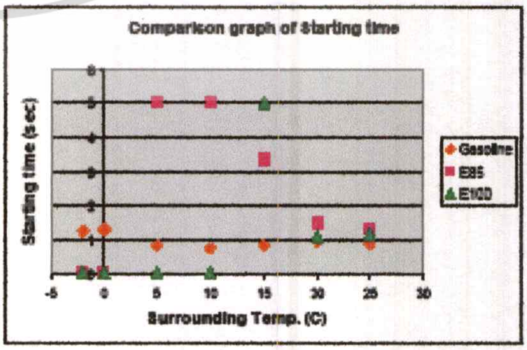

Fig. 7 Comparison graph of gasoline, E85 and E100 VS surrounding temperature

From comparison graph can see the problem occur when we use alcohol fuel at surrounding temperature below than 10 degree Celsius then we find out the solution to solve this problem. First solution is installation heater at intake port to heat up the temperature until intake port is 40 degree Celsius. The engine can start in only 10 degree Celsius of surrounding temperature. After that the injection duration was increased duration around 20 percentage of conventional injection. The engine can start until the surrounding temperature cool down to 0 degree Celsius. The result shown in Fig.8

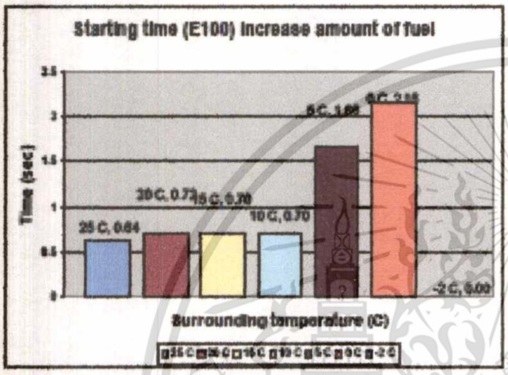

Fig. 8 Experiment result graph between starting time of E100 increase amount of fuel VS surrounding temperature

CONCLUSION

From result of experiment

- When the ethanol blend in the fuel. Ethanol can effect about Starting time of the engine. That from characteristic of ethanol which is disadvantage when compare with gasoline about vaporization properties such as raid vapor pressure, boiling point and flash point.

- For E85 the effect of cold start occur when surrounding temperature is lower than 15 deg C but can start in many times until 5 deg C. In this case solution is increasing injection duration. It's enough for E85 when we use in -2 degree Celsius for surrounding temperature

- For ethanol the effect of cold start occur when surrounding temperature is lower than 20 deg C but can start in many times until 15 deg C. But for solution of this case can start only 0 degree Celsius in this time

In another way if injection duration was increased more than this. May be this problem does not occur.

- If heater was installed at intake port @ 40 deg C the ethanol engine can start in many time at 10 deg C.

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ACKNOWLEDGE

Thank you Suzuki company for supporting the engine and information, Automotive laboratory of KMITL, Mr.Naren Chaithanee for electronic supporting

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BOOK OF ABSTRACTS

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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)	$CH_{1.814}$	$CH_{2.8}O_{0.4}$	$CH_3O_{0.5}$
Moleculer weight	100-105	n/a	46.07
Density kg/l 15 °C	0.69-0.79	0.76	0.79
Oxygen cont.(wt%)	0	30	35
Boiling point, °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, °C	-43	n/a	13
Auto-ignition t, °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.

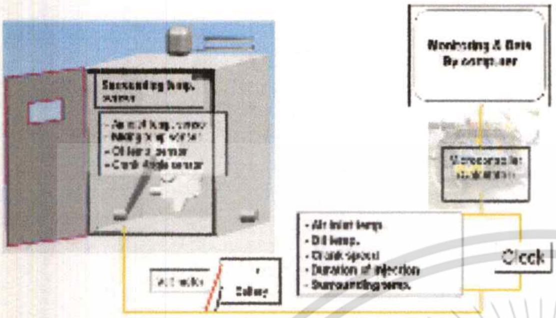


Fig.1 Schematic diagram of the experimental setup

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 °C while the lowest temperature of this experiment is -2 °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).

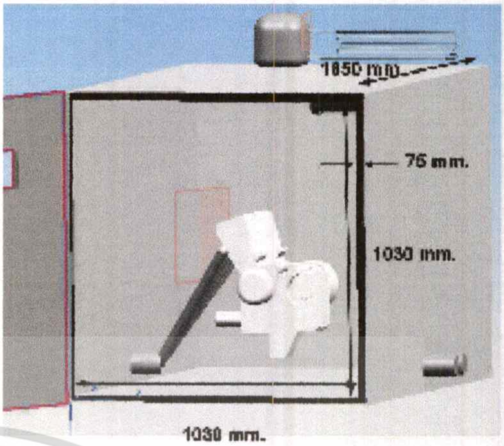


Fig. 2 Design of the cold-soak chamber

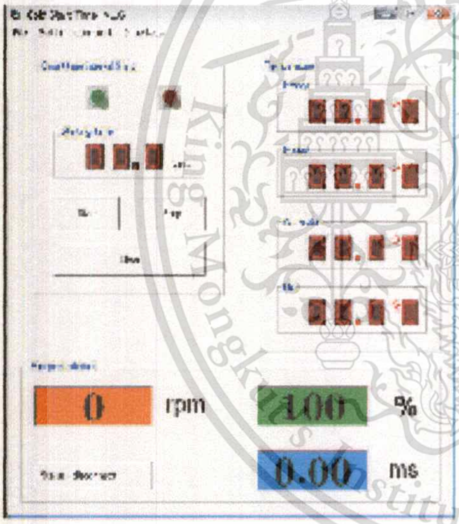
Fig. 3 Suzuki Skydrive engine in the cold soak chamber

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.



0 rpm

100 %

0.00 ms

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.

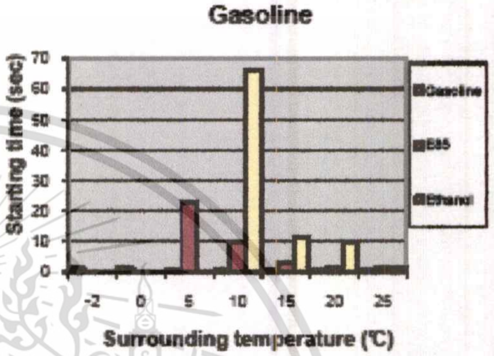


Fig. 5 The starting time of conventional engine with different fuels

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.

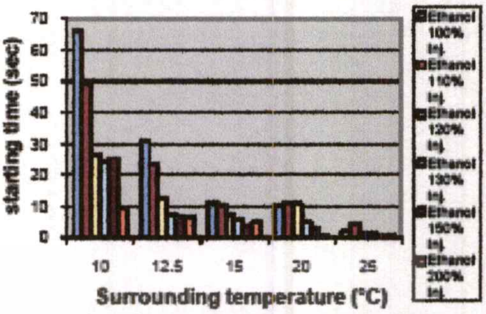


Fig. 6 The starting time of E100 with increasing amount of fuel

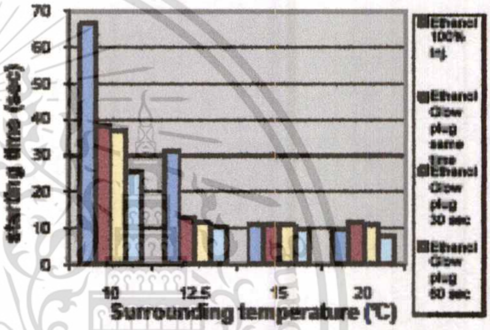


Fig. 7 The starting time of E100 with glow plug technique

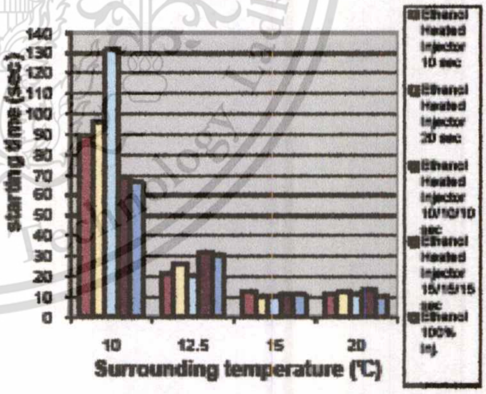


Fig. 8 The starting time of E100 with heated injector technique

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 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.

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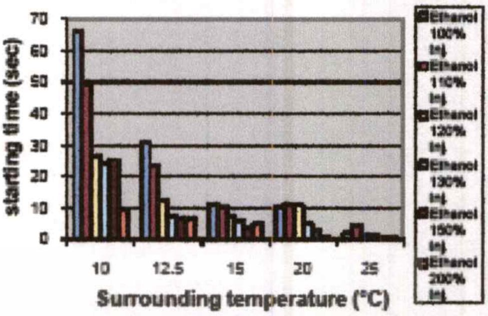

Fig. 6 The starting time of E100 with increasing amount of fuel

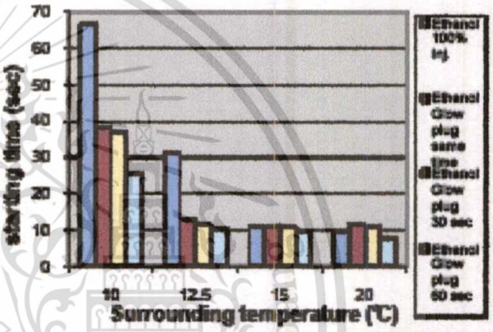

Fig. 7 The starting time of E100 with glow plug technique

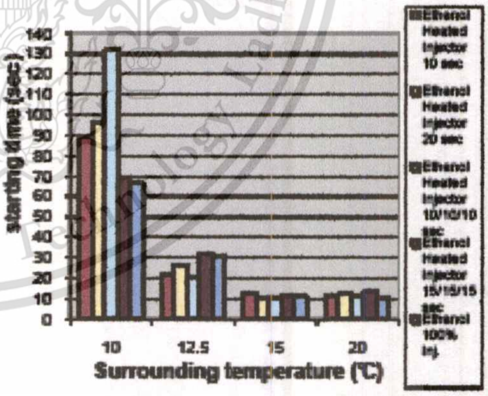

Fig. 8 The starting time of E100 with heated injector technique

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 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

The authors would like to express sincere thank to Suzuki company Thailand for supporting the engine and useful information

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Low Temperature Starting Techniques for Ethanol Engine without Secondary Fuel Tank

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Katsunori Hanamura
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ABSTRACT

The present study aims to investigate the parameters affecting cold start characteristics of ethanol at low temperature, and suggest a solution to avoid cold starting problem without the installation of second fuel tank. The testing engine is a 125 CC. volume displacement, single cylinder four strokes SI engine with fuel injection and ignition timing system controlled by ECU (electronic control unit). The cold starting performance tests were extensively conducted with different percentage of ethanol blends, surrounding temperatures, heating inside combustion chamber, heater injector, pre-cranking without fuel injection, and amount of fuel injection. From the experimental results, when using ethanol fuel in conventional engine, the problem of cold starting was observed at surrounding temperature lower than 20 °C for ethanol. Increasing of injection duration can lower the possible cold start temperature of neat ethanol. Glow plug and pre-cranking heating methods can help the engine start at much lower temperature. The combination of many techniques can make the ethanol engine start at the temperature as low as 3.5 °C. These findings offer solutions to the cold start problem in engine fueled with neat ethanol fuel in Thailand.

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 plenty of agricultural product as sources for ethanol production. The ethanol is an attractive fuel 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 in comparison 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. [2] In conventional gasoline engines, the cold start problem is usually solved by over-fueling during a 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 secondary 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. However, in order to produce E85, the neat ethanol must be delivered from Ethanol factory to the petroleum company. The customers have to pay for ethanol delivery and blending process. In case of ethanol, the ethanol fuel will be delivered direct to the fuel station. The most areas in Thailand have minimum temperature about 10 °C. Then the ethanol is considered as good choice for Thailand if the starting problem can be solved.

The current study will explore other alternatives to secondary 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 with potential solution suggested.

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 (PTT Plc). The properties of gasoline, E85 and ethanol used in this experiment are shown in Table 2.

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

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 °C while the lowest temperature of this experiment is -2 °C, corresponding to 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 run with ethanol fuel. A sub-module to adjust the injection duration was added to the original ECU (Electronic Control Unit).

Table. 1 Suzuki Skydrive specification

Engine type	SOHC 2-valve 4 strokes air-cooled
Number of cylinder	Single cylinder
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 [3, 4, 5, 6]

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 °C	0.69-0.79	0.76	0.79
Oxygen cont,(wt%)	0	31.75	34.7
Boiling point, °C	27-225	n/a	78.4
Vapor pressure, kPa	58.8	44.4	17
LHV, MJ/l	32.2	23.9	21.3
LHV, MJ/kg	42-44	31.8	26.9
Heat of vapor (kJ/kg)	305	610-762.5	840
Flash point, °C	-43	n/a	13
Auto-ignition t, °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	101.6	107
Motor	80-90	91.1	92

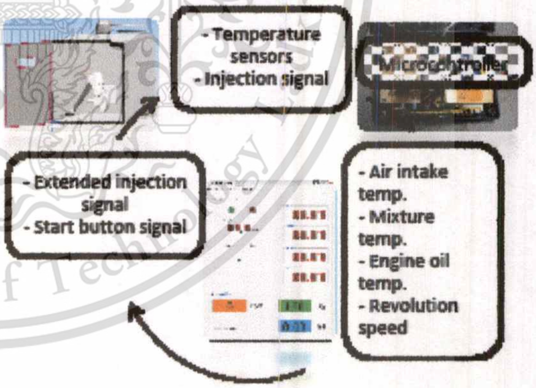

Fig.1 Schematic diagram of the experimental setup

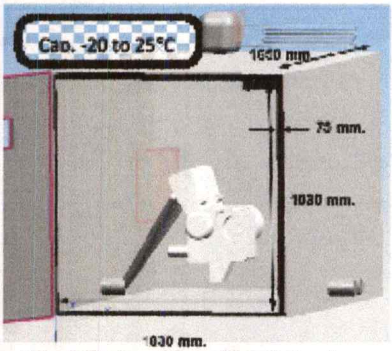

Fig. 2 Design of the cold-soak chamber

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.

- The engine cranking time: The first time the engine starts to rotate with the engine speed (RPM) recorded by micro controller greater than zero. It is stopped suddenly when the ignition occurs. The engine speed (RPM) reaches 900 rpm and remains above that speed. The total starting time is included time for pre-cranking, heating up by glow plug or heated injector and engine cranking time.
- The temperature of engine oil , air intake, and mixture
- Engine speed revolution per minute
- Injection duration in millisecond
- Increasing percentage of main injection duration

These data were displayed by cold start timer program developed by the authors. Figure 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 testing.

Various testing 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 [7].

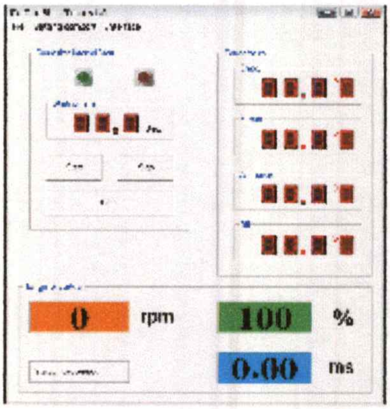

Fig. 4 Program interface

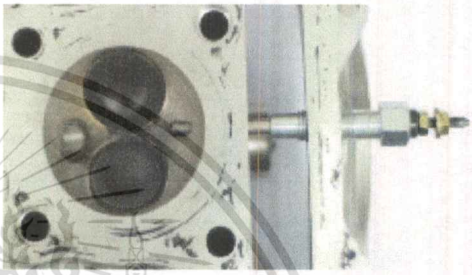

Fig. 5 Electric heater location

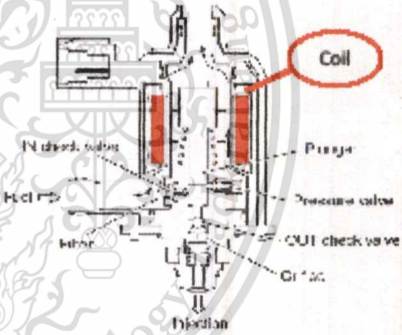

Fig. 6 Cross section of heated injector

The test fuels were gasoline (RON91) 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 with an electric heater (glow plug), heated injector, and pre-cranking. The 54 W electric heater or glow plug was located in cylinder head of the test engine and supplied power by battery. The tip of glow plug with the hottest zone was inserted into combustion chamber as shown in Fig. 5. The heated injector was heated up by electric power of injection signal supply to coil inside injector illustrated in Fig. 6.

The ultrasonic humidifier was used to mist ethanol fuel in order to assist vaporization of ethanol. The specifications of humidifier are 105 W, mist volume 240 ml/hour. Two humidifiers were used to ensure that sufficient ethanol mist was supplied to the engine.

RESULT AND DISCUSSION

The conventional gasoline engine was tested with three fuels at different temperatures in order to investigate fuel properties with cold starting. Amount of fuel injection of each fuel type were compensated by standardize oxygen sensor and electronic control unit (ECU) from factory. The total starting time of each fuel are shown in Fig. 7.

In case of gasoline, the engine can start even at low temperature of -2 °C. For ethanol, the lowest temperature that the conventional engine can start normally is 20 °C. At 15°C the engine must be started with two trial times. The time for 1st trial start of E100 at 15°C is 10 seconds and the 2nd start is 1.3-1.7 seconds. The multiple starting protocol was adopted in purpose of prevent damaging of starting system from too long engine cranking time according factory recommended. Time interval between first and second start is 2 seconds. After the first trial start, the temperature in the combustion chamber increases due to the compression and friction between piston, piston rings and cylinder wall. As a result during the second start, the additional fuel was supplied, which results in rich 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 tested fuels in conventional engine are shown in Fig. 7.

Five methods were proposed to assist the cold temperature starting. 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. That injects 11.26, 12.28, 13.56, 14.78 and 15.91ms at 25, 20, 15, 12.5 and 10°C respectively. By only increasing amount of fuel injection, the engine can start at the surrounding temperature as low as 10 °C. The result of fuel injection increasing is shown in Fig. 8. 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 turned on when engine switch on, 30 and 60 seconds or 1620 J and 3240 J before starting. The engine can start at 10 °C as shown in Fig. 9. The cranking time in the figure is not included time for heating up.

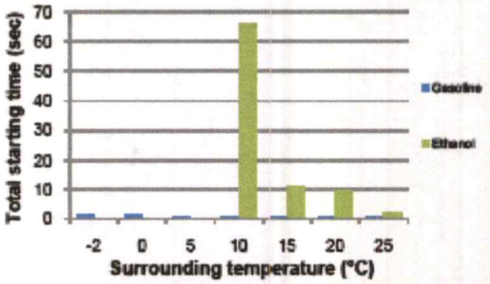

Fig. 7 The total starting time of conventional engine with different fuels

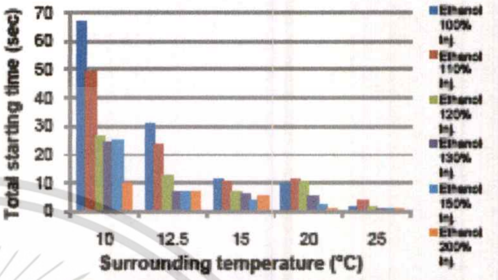

Fig. 8 The total starting time of E100 with increasing amount of fuel

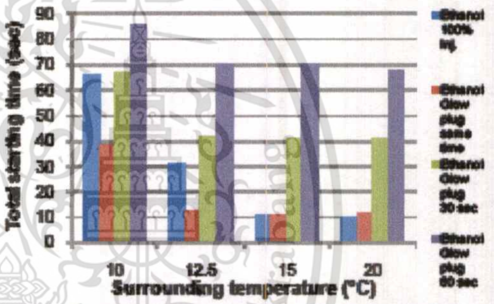

Fig. 9 The total starting time of E100 with glow plug technique

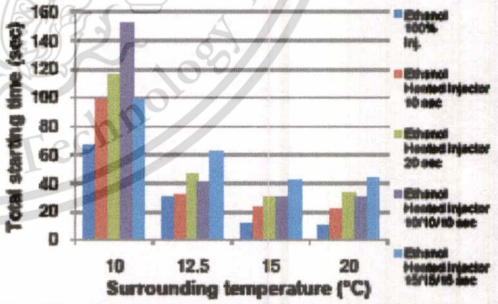

Fig. 10 The total starting time of E100 with heated injector technique

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 seconds and wait for the time in some case by heated up time / waiting time / and heated up again to prevent over heat is occur and for heat transferring. The result of heated injector technique is shown in Fig. 10. According to this application, the heated injector could not reduce the total starting time, not because heating of injected fuel did not help but rather too much fuel being injected from holding the electric supply during heating.

The forth method was the pre-cranking technique by starting the engine without injection. For the testing condition at surrounding temperature 10 °C, the total starting time can be reduced by this method. With combination of glow plug method, the engine start was improved, as shown in Fig. 11.

Overall, the shortest total 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 case, as shown in Fig. 12.

Combination technique (50% increasing fuel injection, 20 seconds of glow plug heated up and pre-cranking of 20 seconds in same time with glow plug heated up) was able to assist cold starting problem at temperature lower than 10 °C of surrounding temperature. Normally the conventional engine cannot start with neat ethanol at these conditions. By this technique, the ethanol engine can start as low as 6 °C of ambient temperature in 78 seconds, 6.5 °C in 45 seconds and 8.5 °C in 38.5 seconds. This combination selected from all of techniques was used to assist cold starting in the engine, which is shown in Fig. 13.

The different techniques were compared at the starting temperature at 6 °C. For 100% amount of fuel injection, ethanol fuel cannot start the engine. Hence, 50% increase in fuel injection is the first technique but the total starting time result is too long. Then, a glow plug was heated up for 60 seconds before the engine cranking, which can reduce the total starting time by 20 seconds (or 16.2%) compared to the case of 150% amount of fuel injection alone. Furthermore, glow plug and pre-cranking technique were used to increase combustion chamber temperature in 20 second before the engine cranking. Up to 45.6 seconds (or 36.8%) total starting time was reduced by this cold start technique. Finally, heat up time was extended to 30 seconds that can reduce the total starting time by 60.6 seconds (or 48.9%) compared to the first technique without heat up time, as shown in Fig. 14.

The case of 150% amount of fuel injection combined with glow plug and pre-cranking at 30 seconds seems to be the best solution among all of combination techniques.

At the minimum surrounding temperature of 3.5 °C, ethanol engine can start by all assisted cold start problem methods. The heat up time for glow plug and pre-cranking were extended to 60 seconds and amount of fuel injection to 200%. Finally fifth method humidifier also was set up for extreme case was used for fuel atomization and reduction energy to vaporize liquid fuel. The engine can start in 72.6 second with humidifier at same time of engine cranking and 56.8 second shorter than the first method at this surrounding temperature. According to ethanol properties in term of heat of vaporization, ethanol consumes energy to vaporize more than gasoline in 2-3 times. The method of fuel humidifier is used to reduce energy for evaporization and atomization. The result of total starting time at 3.5 °C of surrounding temperature is shown in Fig. 15.

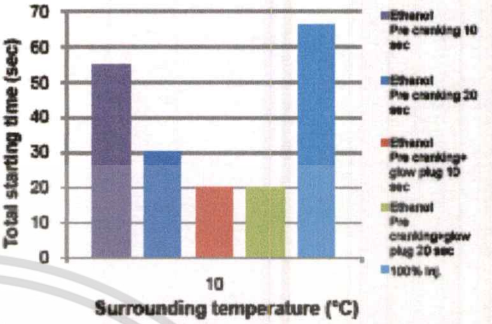

Fig. 11 The total starting time of E100 with pre-cranking technique

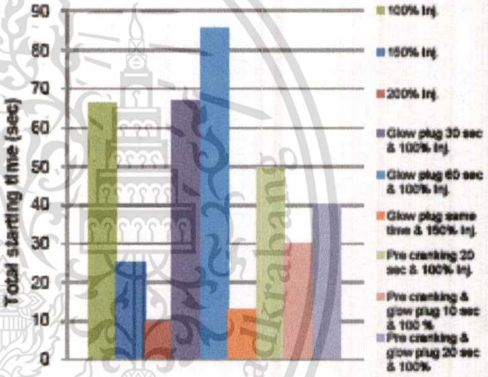

Fig. 12 The total starting time of E100 with combination techniques at 10°C of surrounding temperature

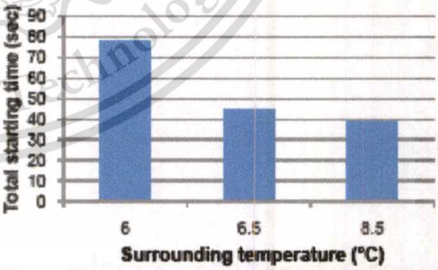

Fig. 13 The total starting time of E100 with combination techniques (Pre cranking, glow plug 20 sec, & 150% Injection)

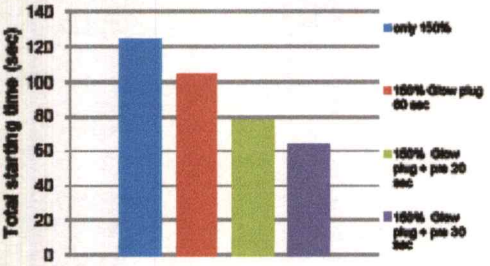

Fig. 14 The total starting time of E100 with combination techniques at 6°C of surrounding temperature

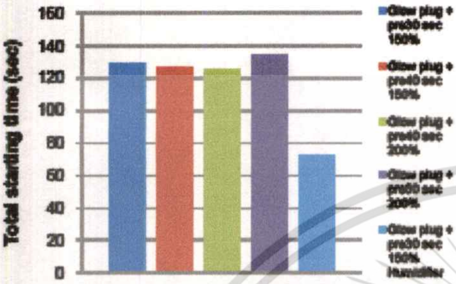

Fig. 15 The total starting time of E100 with combination techniques at 3.5 °C of surrounding temperature

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 E100, conventional engine can start normally at 20 °C. The second trial start is required at 15 °C. The lowest temperature to start is 10 °C with 60 seconds total starting time. However, the total starting time still very long and may not satisfy the customers.

2. Heating the combustion chamber by using glow plug and pre-cranking technique makes the engine possible to start at 10 °C of surrounding temperature. The ethanol engine can start within 30 seconds included operating time 10 seconds for pre-cranking and glow plug.

3. The best case at 6 °C is 150% fuel injection combined with 30 seconds pre-cranking and glow plug. The total starting time is 53.2 seconds.

4. The ethanol engine can start at 3.5°C using combination techniques of using humidifiers, 150% fuel injection, 30 seconds pre-cranking and glow plug. The minimum total starting time at 3.5 °C for this study is 72.6 seconds.

The further study such as discovering other techniques to shortening the total starting time or the effect of increasing fuel injection on hydrocarbon emission is necessary.

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