

# Study of Ethanol-Blended Fuel (E85) Effects Under Cold-Start Conditions

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## ABSTRACT

Research was conducted on cold startability with a focus on the vaporization characteristics of ethanol blended fuel (E85). Cold startability was tested with a conventional gasoline engine with standard calibration data by using gasoline and E85 of which RVP is adjusted to be equivalent to gasoline. The test engine started successfully when the gasoline was used, but failed to start when the E85 was used. A further analysis of this result indicated the fact that E85 displays lower vaporization than gasoline under cold conditions even if the RVP of both fuels are the same. The research determined that the formation of an air fuel mixture with minimum of 2 vol% fuel concentration is necessary for a successful engine start. The effects of increasing compression ratio and cranking speed as means of enhancing fuel vaporization were investigated and no major impacts were observed. To enhance the fuel vaporization in a cold environment, two effective methods, increase of injected fuel quantity and usage of a high RVP fuel, were revealed through this research. To keep the same engine startability as the gasoline in a cold environment by using the E85 fuel (ASTM Class-3), about 3 times the quantity of fuel should be injected or RVP of E85 fuel should be adjusted to about 108 kPa. From this research it is concluded that to realize more efficient cold start in terms of fuel consumption, it is necessary to reconsider the RVP standard for cold conditions.

## INTRODUCTION

Today's concern about energy issues and the reduction of CO<sub>2</sub> emissions is attracting attention to ethanol as an alternative fuel. Currently, ethanol is mainly produced by the fermentation of sugars sourced from edible plants such as corn, sugar cane, and sugar beets. In the future, commercial ethanol production may be possible using second-generation technologies. One example of this would be the use of lignocellulosic feedstocks such as wood and straw. Such second-generation technologies have the potential to substantially decrease lifecycle CO<sub>2</sub> emissions. Ethanol is presently being used as a fuel around the world, in various forms. The most common method is to use a mixture of 5% to 10% (E5-E10) ethanol in conventional gasoline. Higher concentrations of ethanol in gasoline, such as E85, are available in some areas of the US, Europe and recently Thailand. Pure hydrous ethanol (containing about 4% water) is widespread in the Brazilian market. However, the rapid expansion of ethanol use in fuels poses technical challenges for the automobile. A high concentration of ethanol leads to reduced vaporization of the fuel at low temperatures, resulting in poor cold-start performance [1-7]. In the case of pure hydrous ethanol use in Brazil, gasoline is injected from a small sub-tank to improve cold-start performance when the ambient temperature is low. In Europe and the US, the RVP of the E85 is adjusted seasonally to enhance the vaporization of fuel under low temperature conditions. A close relationship between RVP of fuel and cold engine start performance has been previously reported [8]. For the conventional ethanol free gasoline fuels, RVP is a good indicator for cold startability. This is because the appropriate fuel

Table 1 Specifications for Ethanol Fuel

| Property                    | US E85     |        |        | EU E85    |        |
|-----------------------------|------------|--------|--------|-----------|--------|
|                             | ASTM D5898 |        |        | CWA 15293 |        |
| Volatility class            | 1          | 2      | 3      | A         | B      |
| Alcohol [vol%]              | 79 min     | 74 min | 70 min |           |        |
| Ethanol [vol%]              | -          |        |        | 75 min    | 70 min |
| Methanol [vol%]             | 0.5 max    |        |        | 1 max     |        |
| High Alcohol (C3-C8) [vol%] | 2 max      |        |        | 2 max     |        |
| Hydrocarbons [vol%]         | 17-21      | 17-26  | 17-30  |           |        |
| Water [vol%]                | 1 max      |        |        | 1 max     |        |
| RVP [kPa]                   | 38-59      | 48-65  | 66-83  | 35-60     | 50-100 |

Table 2 Test fuel characteristics

| Designation      | No. 1      | No. 2 | No. 3     | No. 4      | No. 5 |
|------------------|------------|-------|-----------|------------|-------|
| Standard         | ASTM D5898 |       | CWA 15293 | ASTM D4814 |       |
| Volatility class | 1          | 3     | B         | C          | D     |
| Ethanol [vol%]   | 81         | 71    | 75        | -          |       |
| Water [vol%]     | 1          | 1     | 1         | 1          | 1     |
| RVP [kPa]        | 40         | 71    | 55        | 71         | 83    |

concentration of the air-fuel mixture is essential for successful combustion of the mixture, and fuel with higher RVP is capable of supplying more fuel vapor at low temperature. As introduced in detail in later chapters, high-ethanol gasoline and gasoline of which RVP is adjusted to be equivalent had shown a different cold startability. This indicates that high-ethanol gasoline has different evaporation characteristics from gasoline even if the high-ethanol gasoline has the same RVP value as the gasoline. To clarify the impacts of fuel composition on cold startability, a further analysis of the evaporation characteristics of the fuel is necessary. The purpose of this research, in the first place, is to investigate the evaporation characteristics of high-ethanol gasoline and secondarily, to clarify the conditions required for cold engine start with E85 fuels.

## TEST CONDITIONS

Table 1 shows the current specifications for E85 fuels in Europe and the US. The ethanol concentration and RVP of E85 differ seasonally. The minimum ethanol concentration is 70%; the maximum concentration differs depending on the region, but is around 85%. RVP becomes higher as seasonal temperatures become colder, to aid cold startability. As a test of high-ethanol gasolines, the research discussed in this paper used E85-Class 1 (Fuel No.1) and E85-Class 3 (Fuel No.2), as specified by the US ASTM's D5788-06 [9], and E85-Class B (Fuel No.3), as specified by the EU's CWA 15293 [10]. For comparison, gasoline modified to make its RVP equivalent to that of US E85 Class 3 (Fuel No.4) and Class D (Fuel No.5) gasolines as specified by the ASTM's D4814-06 [11] are used. Table 2 shows the respective characteristics of these fuels. An 1800 cc naturally aspirated 4-cylinder engine was employed to evaluate cold startability. Table 3 shows the specifications of the engine. The temperature for evaluation of cold startability was set at -30 °C.

## CHARACTERISTICS OF HIGH-ETHANOL GASOLINE

The concentration of fuel vapor in the mixture is an important factor in the consideration of cold startability. The appropriate fuel vapor concentration is essential for ignition of the mixture. The possibility of ignition is determined by whether or not the fuel vaporizes and the fuel vapor concentration of the mixture becomes high enough to enable combustion. As mentioned earlier, it has been reported that a correlation exists between the RVP of gasoline and cold startability. This is because the higher the RVP, the easier to vaporize and to control the fuel vapor concentration of the mixture to the range enabling combustion at low temperatures. In the following sections, a more detailed analysis is performed on the evaporation characteristics of high-ethanol gasoline.

**CALCULATION OF VAPOR CONCENTRATION** - The calculation of the partial vapor pressure of fuels which contain multiple chemical species, such as gasoline and E85, is complex because of the presence of interaction of the chemical species, including an azeotropy effect. Calculations in the project discussed here were conducted using the chemical engineering process simulator CHEMDAD, provided by Chemstations, Inc. The constituents of the chemical species were identified for use in the simulation using gas chromatography-mass spectrometry (GC-MS), and their quantities were determined using a hydrogen flame ionization detector (FID).

Table 3 Test engine specifications

|                                 |                    |
|---------------------------------|--------------------|
| Cylinder configuration          | In-line 4-cylinder |
| Bore × Stroke [mm]              | 81.0 × 87.3        |
| Displacement [cm <sup>3</sup> ] | 1799               |
| Compression ratio               | 11.5               |
| Valve train                     | SOHC               |
| Number of valves                | 4 valves / cyl     |
| Fuel injection system           | MPI                |



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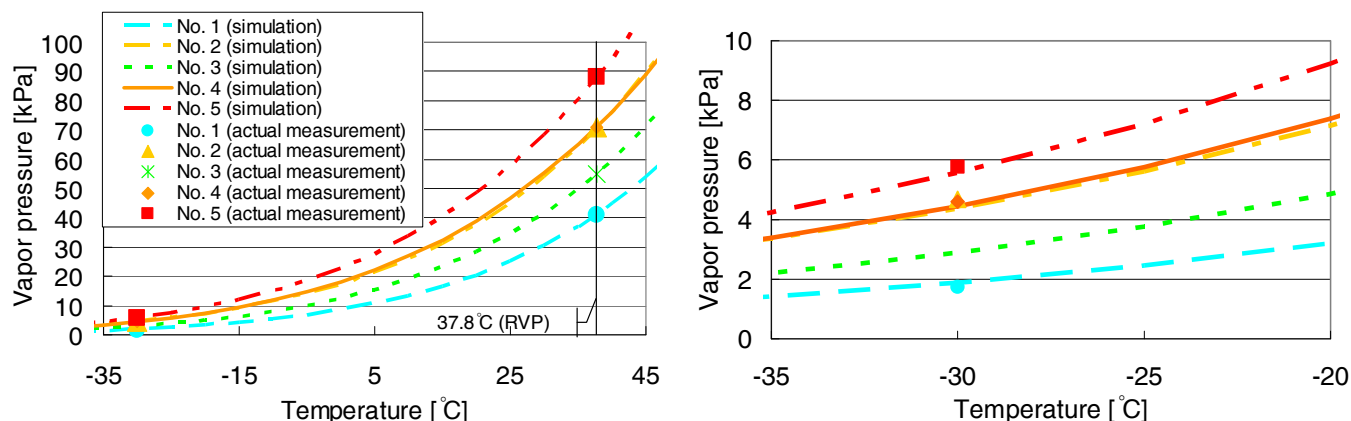


Fig. 1 Temperature dependencies of saturated vapor pressure of test fuels

**RELATIONSHIP BETWEEN SATURATED VAPOR PRESSURE AND COLD STARTABILITY** - Figure 1 shows the temperature dependencies of the saturated vapor pressures of the test fuels. The measured values are plotted as points, while the values predicted by the simulation are shown as lines. RVP was measured by SETAVAP TESTER, provided by Setanhope-seta, Inc. The saturated vapor pressures under cold conditions were measured in the stainless steel vessel in which the fuel was supplied. Fuel No.2 and the gasoline (Fuel No.4), modified to make its RVP identical to that of Fuel No.2, display largely identical values of not only RVP but also saturated vapor pressures at various temperatures. A temperature dependency of the vapor pressures of HC species and ethanol are also plotted in Fig.2, indicating only lighter HC species such as butane (C4) and pentane (C5) have a significant amount of vapor pressure and very little ethanol vapor pressure is expected to be formed at -30 °C. According to the results of the temperature dependency of vapor pressure, it is expected that Fuel NO.2 and Fuel NO.4 form similar vapor constituents at low temperature due to the identical saturated vapor pressure characteristics and the absence of the ethanol vapor pressure at this temperature. The same fuel vapor constituent and thus the same cold engine start performance is expected. Figures 3 (a) and (b) respectively show the engine speed during the cold (-30 °C) start condition using Fuel

NO.2 and Fuel NO.4. To eliminate the disturbance factors from the results, the fuel injection quantity, fuel injection timing and ignition timing are kept unchanged for each test. Contrary to expectations, there was a significant difference in startability between the fuels, the engine failed to start when No.2 was used. From this result it is assumed that the vaporization characteristics of fuels under real engine conditions differ from the laboratory data which is measured under the saturated vapor condition.

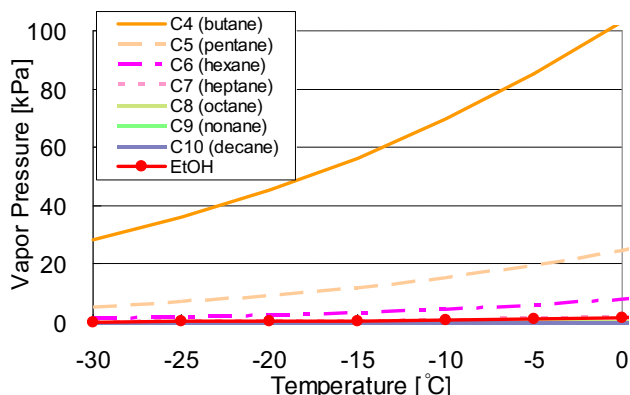
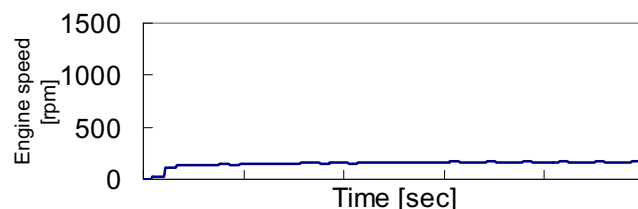
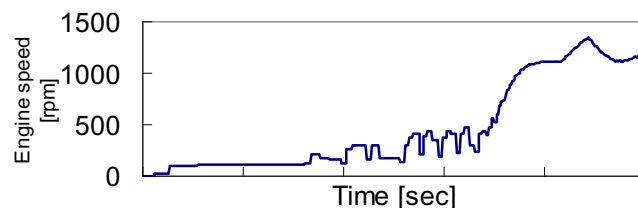


Fig. 2 Vapor pressures of ethanol and hydrocarbon species [C4-C10]



(a) Fuel No. 2 (E85, RVP 71)



(b) Fuel No. 4 (Gasoline, RVP 71)

Fig. 3 Cold startability with Fuel No. 2 and No. 4 at -30 °C

**RELATIONSHIP BETWEEN FUEL INJECTION QUANTITY AND FUEL CONCENTRATION OF AIR-FUEL MIXTURE** - RVP is a good indication for the estimation of fuel characteristics, however, it is necessary to be aware that RVP only shows a saturated vapor pressure and it is measured at the fuel-rich condition. In reality, during cold engine start, fuel quantity with respect to air quantity is not large enough