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Vapor to Liquid Ratio Test as an Indicator of Volatility

Marc Zemel

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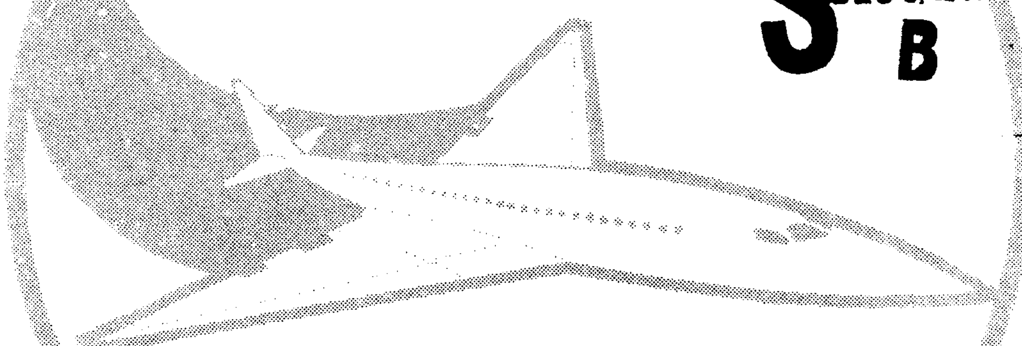

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16. Abstract

A laboratory study on the effects of adding ethanol to motor fuel was performed. This technical note presents the results of Reid vapor pressure and vapor to liquid ratio tests performed on the blended fuels. Increased volatility problems with ethanol blends were uncovered, particularly at 10 to 15 percent ethanol. The investigation also showed how vapor to liquid ratio tests can be useful in areas where Reid vapor pressure data are inconclusive.

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EXECUTIVE SUMMARY

The use of ethanol as an additive to motor fuel in order to reduce emissions from aircraft engines was studied in a laboratory at the Federal Aviation Administration Technical Center. Vapor to liquid ratio and Reid vapor pressure tests were conducted on various motor fuel blends. The blends ranged from as little as 5 percent ethanol to as much as 100 percent ethanol on a volume/volume basis. The most important observations made are as follows:

1. The addition of ethanol to motor fuel causes a flattening of the vapor to liquid ratio curve, which is lowest for the 10 to 15 percent blends and increases steadily with increasing percentages of ethanol.

2. The Reid vapor pressure of the ethanol blends decreases parabolically with increasing concentrations of ethanol.

3. The change in volatility of the ethanol blends at 10 to 15 percent with respect to pure motor fuel is more noticeable in the vapor to liquid ratio curves than in the Reid vapor pressure data.

4. The vapor to liquid ratio automatic tester is an effective tool for measuring vapor lock tendencies.

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INTRODUCTION

PURPOSE.

The Federal Aviation Administration (FAA) evaluated the use of ethanol as an additive to motor fuel in order to reduce emissions in aircraft engines. The FAA Technical Center was then assigned to identify the effects of ethanol blends on motor fuel volatility.

Laboratory tests were performed to uncover any adverse effects that might result when ethanol is mixed with motor fuel. The tests were performed as a followup study to a project investigating the vapor lock tendencies of ethanol blends. The tests were also conducted to compare the Reid Vapor Pressure (RVP) test to the automatic Vapor to Liquid Ratio (VLR) test as indicators of volatility.

BACKGROUND.

Ethanol was tested in the FAA Technical Center's laboratory for its effects upon the volatility of motor fuel. Ethanol (an alcohol) is widely recognized because it causes intoxication when ingested by animals and humans. It has been manufactured most commonly by two methods. The first method is the fermentation of carbohydrates and the second is the hydration of ethylene. Ethylene is obtained when crude oil is cracked to produce gasoline.

TEST APPARATUS

REID VAPOR PRESSURE TESTS.

A semi-automatic Reid vapor pressure apparatus was used in accordance with the American Society for Testing and Materials (ASTM) Standard D 323. For more information regarding the setup and equipment of this test, refer to Procedure B in the Annex A2 of ASTM Standard D 323.

VAPOR TO LIQUID RATIO TESTS.

The automatic vapor to liquid ratio tester was used to perform this test. The apparatus consists of a 15-milliliter (ml) measuring cell, an automatic temperature control and measurement, and a keyboard with display. A vacuum pump, a 5-ml syringe, and a printer were also used in coordination with this apparatus. The apparatus had the capability to test eleven different vapor to liquid ratios from 4 to 100. For more information regarding this equipment, refer to Grabner Instruments CCA-VLR operation manual.

TEST PROCEDURES

Mixing was conducted on a volume/volume basis at room temperature. The Reid vapor pressure tests were performed as outlined by ASTM. However, the vapor to liquid ratio tests were performed as described below.

VAPOR TO LIQUID RATIO TESTS.

The fuel was prepared for the tests in accordance to the Reid vapor pressure method. A 4-ml fuel sample was extracted with a 5-ml syringe that had been chilled to 0 °C with the fuel. Any water condensation was inhibited by keeping the syringe closed while it was in the refrigerator. The outside of the syringe was also wiped before sampling. This sample was connected to the luer bore of the CCA-VLR machine, and the machine extracted fuel as required. The test volume inside the machine was heated to 80 °C before each test and sampling.

The machine measured the temperature for vapor to liquid ratios of 4, 5 10, 15, 20, 25, 30, 40, 60, 80, and 100 at 1.000 atmospheres, achieving each point within 3 minutes of the previous one. The results were printed out simultaneously with the performance of the test. The equipment was cleaned using standard laboratory procedure. The test volume was rinsed each morning and after several tests throughout the day.

RESULTS

The ethanol readily combined with the 14 psi motor fuel. In this technical note, a 5 percent ethanol blend means that 95 percent of the volume of the fuel was 14 psi motor fuel and 5 percent of the volume was dry ethanol.

VAPOR TO LIQUID RATIO TESTS.

These tests were performed in order to determine the usefulness of the automatic vapor to liquid ratio tester in predicting vapor lock tendencies. The vapor to liquid ratios of all the ethanol blends were determined, and the results are presented in figures 1, 2, and 3. Figure 1 shows a plot of the pure motor fuel and the lower concentrations of ethanol. The low ethanol concentrations tended to have a constant slope which was less than the pure motor fuel. All of the ethanol blends in figure 1 achieved vapor to liquid ratios at lower temperatures than the pure motor fuel, with the 10 and 12.5 percent blends having the lowest temperatures. This general trend coincided with the vapor lock behavior of the fuels tested at the FAA Technical Center.

Table 1 shows the average sediment bowl temperature and time to vapor lock as a function of ethanol concentration. These data were extracted from reference 1. Table 1 also shows the temperature for the vapor to liquid ratios of 40 and 60. Despite the different base fuels used, the shapes of the two curves are similar, indicating a correlation between ethanol concentration, the vapor lock behavior, and the results from the vapor to liquid ratio tests. It is interesting to note that the temperatures where vapor lock occurred are similar to the vapor/liquid ratio of 60 temperatures.

TABLE 1. VAPOR LOCK INDICATORS AND VAPOR TO LIQUID RATIO TEMPERATURES AS A FUNCTION OF ETHANOL CONCENTRATION

Ethanol Conc. (%)	Sediment Bowl Temp. (°C)	Time to Vapor Lock (min.)	Temp. (°C) for Vapor/Liquid Ratio 40	60
0	47.58	3.40	48.4	54.3
5	45.33	3.17	42.5	45.8
10	45.17	2.83	42.3	45.4
15	44.67	2.50	43.3	46.7
20	45.67	3.08	43.9	47.0

In figure 2, the 30 to 60 percent ethanol blends were plotted, again yielding a flatter slope which was curved downward at the lower vapor to liquid ratio points. These ethanol blends achieved the same range of temperatures as the pure motor fuel for the vapor to liquid ratios. It should be noted that at 40 percent ethanol, the vapor to liquid ratio of 40 was the same as the motor fuel. This vapor to liquid ratio is used by industry to determine overall tendency to vapor lock.

In figure 3, the higher concentrations of ethanol all required greater temperatures to achieve the same vapor to liquid ratios as the pure motor fuel. The plots increased in curvature slightly due to the effects of the remaining motor fuel before flattening out completely at approximately 78 °C for pure ethanol, which is its boiling point.

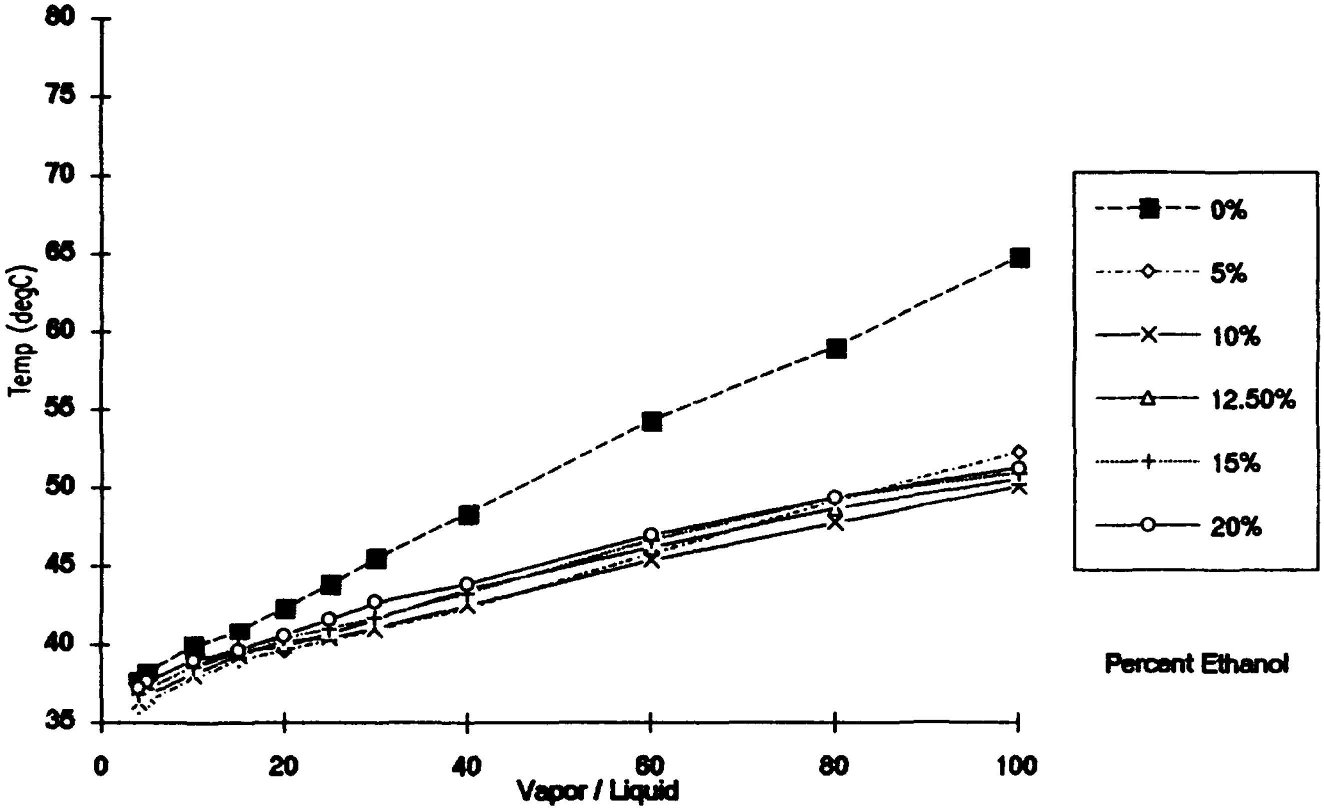

Figure 1: Vapor to Liquid Ratios for Ethanol Blends with 14 psi Motor Fuel (5-20%)

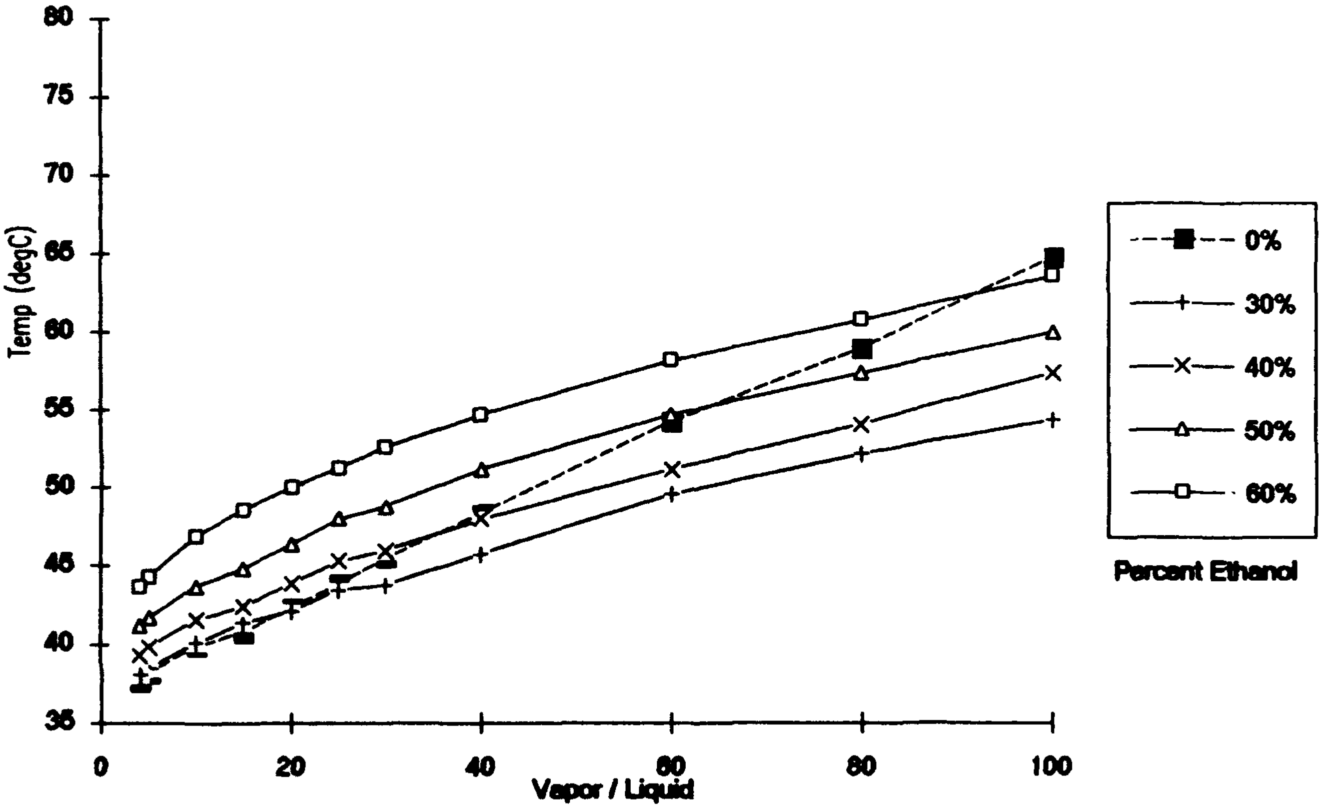

Figure 2 : Vapor to Liquid Ratios for Ethanol Blends with 14 psi Motor Fuel (30-60%)

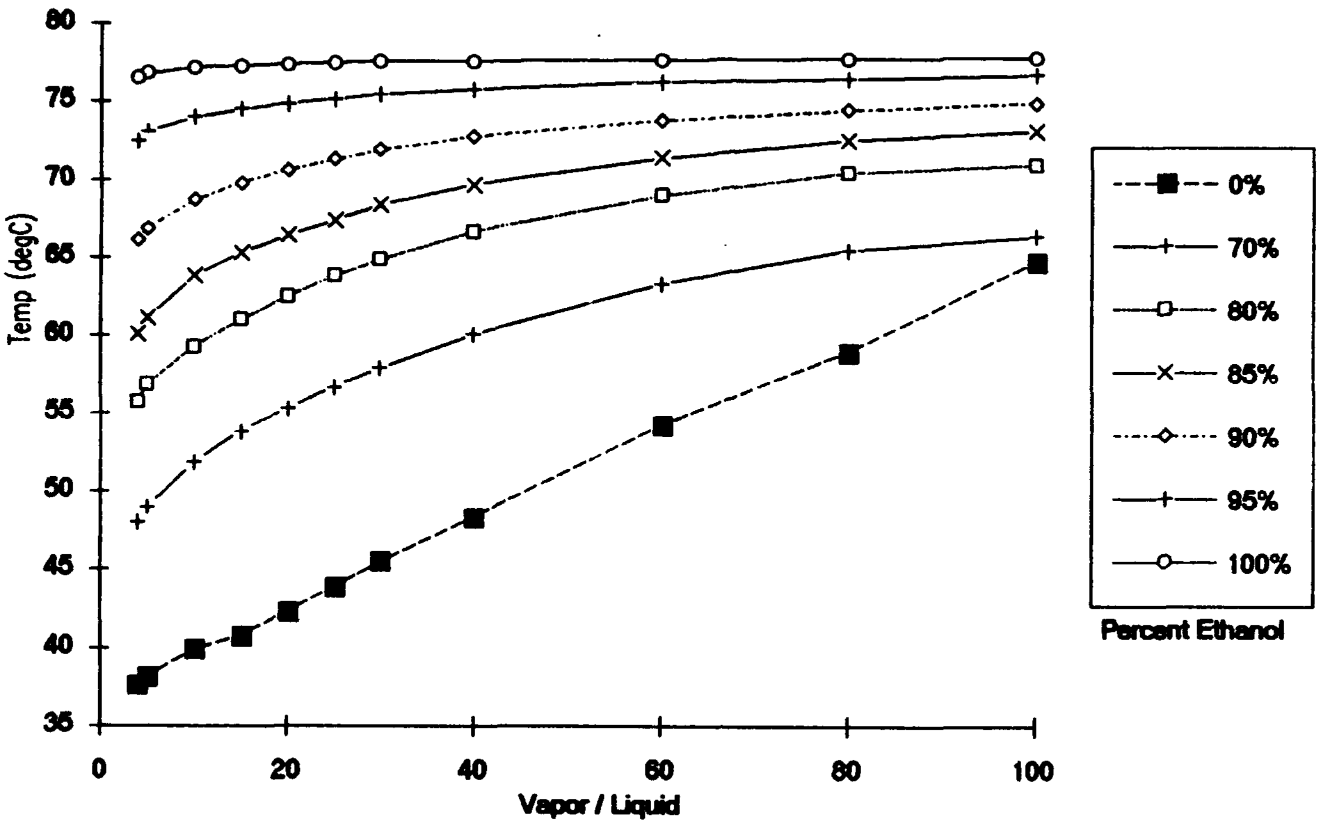

Figure 3: Vapor to Liquid Ratios of Ethanol Blends with 14 psi Motor Fuel (70-100%)

REID VAPOR PRESSURE TESTS.

These tests were conducted in order to serve as a basis for comparison with the vapor to liquid ratio tests. Figure 4 is a graph of the tests. As the percentage of ethanol increases, the RVP decreases parabolically until reaching 3.3 psi for 95 percent ethanol. The graph shows a slight increase in RVP for the 10 to 15 percent ethanol blends, but these values border the range of repeatability for the RVP procedure.

As shown in figure 5, which plots the same ethanol concentrations as found in figure 4, the vapor to liquid ratio temperature is roughly the same for pure motor fuel and the 10 to 15 percent ethanol blends at a vapor to liquid ratio of 4. The magnitude of the change is proportional to the change in RVP over this range of concentraion. However, the differing slopes of the lines in the vapor to liquid ratio test yield significantly lower temperatures for the vapor to liquid ratios of 30-50, which are encountered during the normal operation of an engine using pure motor fuel. (Typical sediment bowl temperatures ranged from 42 to 55 ^{o}C, reference 1. This is consistent with data generated for the automobile industry which indicate that fuels with a concentration of 40 to 50 percent ethanol have a vapor lock behavior similar to the base fuel).

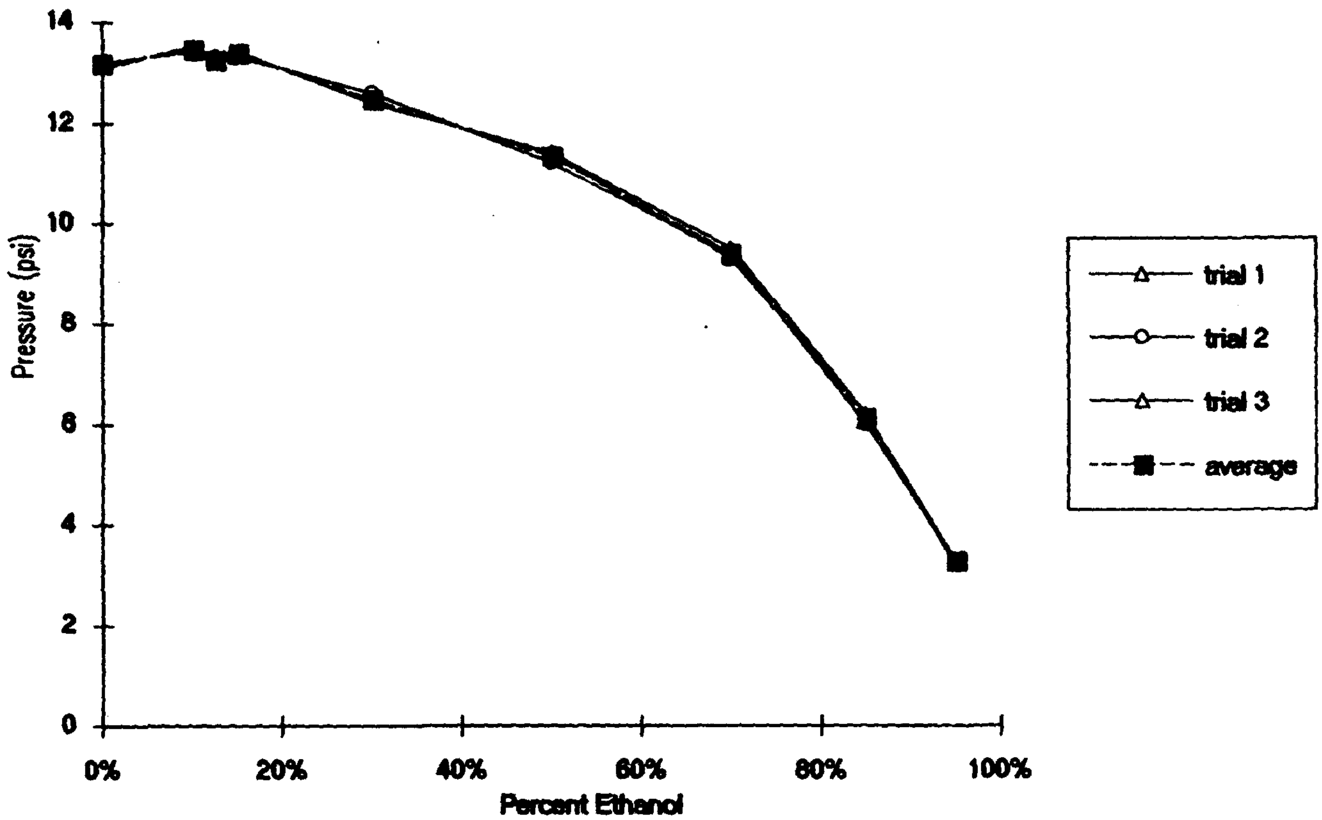

Figure 4: Reid Vapor Pressure for Ethanol Blends with 14 psi Motor Fuel

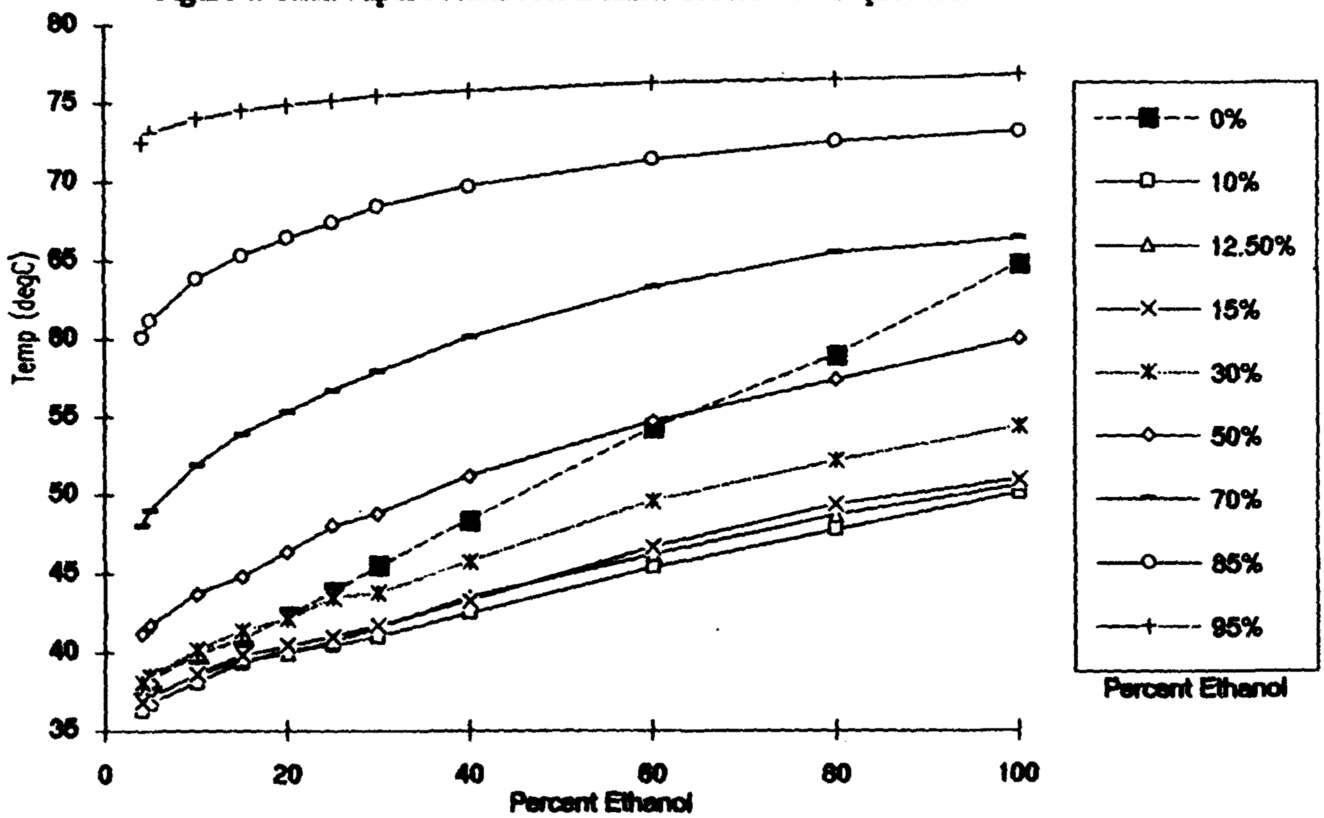

Figure 5: Vapor to Liquid Ratio Comparison to Reid Vapor Pressure

CONCLUSIONS

1. The addition of ethanol to motor fuel causes a flattening of the vapor to liquid ratio curve, which is lowest for the 10 to 15 percent blends and increases steadily with increasing percentages of ethanol.

2. The Reid vapor pressure of the ethanol blends decreases parabolically with increasing concentrations of ethanol.

3. The change in volatility of the ethanol blends at 10 to 15 percent with respect to pure motor fuel is more noticeable in the vapor to liquid ratio curves than in the Reid vapor pressure data.

4. The vapor to liquid ratio automatic tester is an effective tool for measuring vapor lock tendencies.

REFERENCES

1. Alternate Fuels for General Aviation Aircraft, DOT/FAA/CT-88/05, June 1988, Augusto M. Ferrara, FAA Technical Center, Atlantic City International Airport, New Jersey 08405.