ABSTRACT

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Measurements of dielectric constant, dissipation factor, and density were made on 220 samples of aviation fuels of grades 91/98, 100/130, 115/145, JP-1, JP-3, and JP-4 and certain experimental and foreign fuels received from various suppliers.

This report summarizes this work as well as other investigations such as effect of evaporation, and effect of moisture content.

The capacity index, a criterion of gage response to a given mass of fuel, determined at the reference condition of 32°F and 400 cps, was found to vary as much as 4% or 5% among the specimens of any of the grades 91/98, 115/145, and JP-1, and as much as 5.6% in grades 100/130 and JP-3.

The change in mean values of capacity index due to evaporation of 10% by volume was under .3% for all grades of aviation fuel.

PUBLICATION REVIEW

Manuscript Copy of this report has been reviewed and found satisfactory for publication.

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STUDIES TO DETERMINE THE ELECTRICAL AND PHYSICAL PROPERTIES OF AVIATION FUEL

G. C. Petersen
Armour Research Foundation

September 1952

Materials Laboratory
Contract No. AF 33(038)-3793
RDO No. 601-301

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio
FOREWORD

This report was prepared by the Armour Research Foundation on Contract Number AF33(618)-3793, Research and Development Order Number 601-301, "Aircraft Fuels and Lubricating Oils". Work was initiated in October, 1950, and was administered under the direction of the Petroleum Products Branch of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. R. W. Altman acting as Project Engineer. In June, 1951, Mrs. E. J. Bartholomew assumed the duties of Project Engineer. Mr. J. W. Briscoe of the Instrument and Navigation Branch, Equipment Laboratory, Directorate of Laboratories, Wright Air Development Center, also worked closely with this project.

Personnel of the Armour Research Foundation who participated in this project are Harvey J. Finison, Chairman, Electrical Engineering Research, Raymond E. Zener, Asst. Chairman, Clifford C. Petersen, Supervisor, Professor L. W. Matsch, Joseph L. Badnik, Paul E. Bowers, and George Slad of the Electrical Engineering Department; Maurice Kayner, Research Analytical Chemist, Ralph Hinch Jr., Donald Laskowski, Donald O. Landon, and Ilse M. Wolfson of the Chemistry and Chemical Engineering Department.

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W. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Directorate of Research

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</tr>
<tr>
<td>22.</td>
<td>Grade 91/98 Fuel Characteristics at -65°F(-54°C), 32°F(0°C), and 130°F(54°C), 100 cycles</td>
<td>176</td>
</tr>
<tr>
<td>23.</td>
<td>Grade 100/130 Fuel Characteristics at -65°F(-54°C), 32°F(0°C), and 130°F(54°C), 100 cycles</td>
<td>177</td>
</tr>
<tr>
<td>24.</td>
<td>Grade 115/145 Fuel Characteristics at -65°F(-54°C), 32°F(0°C), and 130°F(54°C), 100 cycles</td>
<td>178</td>
</tr>
<tr>
<td>25.</td>
<td>Grade JP-1 Fuel Characteristics at -65°F(-54°C), 32°F(0°C), and 130°F(54°C), 100 cycles</td>
<td>179</td>
</tr>
<tr>
<td>26.</td>
<td>Grade JP-3 Fuel Characteristics at -65°F(-54°C), 32°F(0°C), and 130°F(54°C), 100 cycles</td>
<td>179</td>
</tr>
<tr>
<td>27.</td>
<td>Chemical Properties - Grade 91/98 Fuel</td>
<td>180</td>
</tr>
<tr>
<td>28.</td>
<td>Chemical Properties - Grade 91/98 Fuel</td>
<td>181</td>
</tr>
<tr>
<td>29.</td>
<td>Chemical Characteristics - Grade 91/98 Fuel</td>
<td>182</td>
</tr>
<tr>
<td>30.</td>
<td>Chemical Characteristics - Grade 100/130 Fuel</td>
<td>183</td>
</tr>
<tr>
<td>31.</td>
<td>Chemical Characteristics - Grade 115/145 Fuel</td>
<td>184</td>
</tr>
</tbody>
</table>
INTRODUCTION

The capacitance-type fuel quantity gage for aircraft is comprised essentially of a capacitor of concentric cylindrical plates standing vertically in the fuel tank. This arrangement has a certain value of capacitance when the medium between the plates is air. As fuel is added to the tank and the level rises and displaces the air, the value of capacitance increases until, when full, the capacitance is about twice the value measured while empty. The factor two is approximately the dielectric constant of aviation fuels.

In addition to simplifying the sensing element by eliminating moving parts, such as floats which are part of the old type gages, the capacitance-type gage partially compensates for volume changes of the fuel which result from temperature changes. The volumetric expansion of gasoline due to an increase in temperature is accompanied by a decrease in dielectric constant tending partially to maintain a constant value of capacitance for a given mass of fuel, regardless of temperature changes. Further compensation which also corrects for differences between fuels is usually achieved in a simple manner by built-in compensators. Since the energy available in a quantity of fuel is dependent on the mass rather than the volume of the fuel, the advantage of this type gage is self evident.

To utilize the capacitance-type fuel quantity gage it is necessary to know the value of dielectric constant for all fuels used. The purpose of this investigation has been to determine the dielectric constant of
various fuel specimens obtained from various sources throughout the United States along with a few fuels from foreign sources, and to investigate the behavior of this electrical characteristic under the influence of changing temperature, and after ten per cent by volume has been evaporated. Density measurements of these specimens were also needed for the purpose of correlation with the dielectric measurements. Dissipation factor measurements were obtained to determine the presence of conductive constituents. A special investigation was also made to determine the effect of moisture.

In addition, work was carried out with a study group composed of representatives of interested users and suppliers of aircraft fuels and fuel gages and a standard test method was developed and proposed.

The investigations reported here were carried out over a period of one year. Measurements were made on a total of 220 specimens of the following types:

- **Grade 91/98**: 55 specimens
- **Grade 100/130**: 51 specimens
- **Grade 115/145**: 44 specimens
- **Grade JP-1**: 24 specimens
- **Grade JP-3**: 35 specimens
- **Grade JP-4**: 6 specimens
- **Experimental**: 5 specimens

**SECTION I**  
**APPARATUS AND EQUIPMENT**

A. **Electrical Measuring Equipment**

1. **Cell**

A Balsbaugh type 3TN 25 three terminal liquid dielectric measuring cell was used in the dielectric measurements. It is a guarded cell made of glass and nickel, has an empty capacitance of about 25 micro-microfarads, and holds about 85 cc of liquid. Being small in mass, it is well suited for applications where temperature is to be changed often. This
cell used with the present bridge circuit yields measurements of dielectric constant which are accurate to within ± 1.0 per cent. Sufficient sensitivity is available to distinguish between values of dielectric constant which differ by 0.2 per cent. Figure 1 shows the Balsbaugh cell disassembled.

2. Bridge Circuit

The General Radio Type 716C Capacitance Bridge, used in conjunction with a Wagner ground coupling circuit to balance the guard circuit to ground potential, was selected for these measurements. This bridge is usable up to 300 kHz with an accuracy of ± 0.2 micro-microfarads in capacitance and ± 0.0002 or ± 2 per cent, whichever is greater, in dissipation factor. A General Radio Type 722D Precision Condenser was used as a balancing capacitor in the bridge circuit. Figure 2 shows the circuit and Figure 3 is a photograph of the entire bridge circuit.

Equations applicable to the 716C Capacitance Bridge, when used in the substitution method, and when the dissipation factor of the specimen is less than 0.1 are:

\[
\text{Capacitance: } \quad C_x = \Delta C \\
\text{Dissipation Factor: } \quad D_x = \left(\frac{C'}{\Delta C}\right)
\]

where

\[
\Delta C = C' - C \\
\Delta D = D - D'
\]

\[f = \text{oscillator frequency} \quad f_0 = \text{frequency step set on bridge.}\]

Initial readings with the unknown out of the circuit are indicated by primes, and Δ stands for "change in." D and D' include the 0.01 multiplier which should be applied to the scale readings.

With this type of bridge circuit, the generator and detector connections to the bridge should be interchanged at the higher frequencies.
3. Oscillator

A Hewlett-Packard Model 200C oscillator having a frequency range of 20 cycles to 200 KC was used as the source. The oscillator gives a voltage of about six volts across the measuring cell at frequencies up to twenty kilocycles. At higher frequencies the voltage decreases to about one volt.

4. Null Detector

As a null detector a General Electric Type CRO-3A Cathode Ray Oscilloscope, with a sensitivity of 0.30 volt per inch, was used in conjunction with an amplifier having a gain of 100.

5. Shielding

Guard shields were used as shown in Figure 2; in addition, grounded exterior shields were used to eliminate 60 cycle pickup. The lining of the temperature chamber was also grounded.

B. Temperature Equipment

1. Chamber

An American Instrument Company, sub-zero, constant temperature test cabinet, using dry ice and providing control accurate within ± 0.5°F, was used to obtain the required temperatures. Thermostatic equipment operates a blower which forces the cold carbon dioxide atmosphere of the dry ice chamber into the test chamber. Close control of temperature is achieved by heating coils which operate alternately with the cold blower. Chamber temperatures from -100 to +220°F can be maintained.
The measuring cells were suspended in an air bath within the test chamber, as shown in Figure 4. The air bath was constantly circulated by an auxiliary blower.

2. Temperature Measuring Equipment

The temperature was measured by means of a glass stem thermometer placed near the measuring cells and readable through the chamber window. The chamber was held at the desired temperature for 30 minutes before making electrical measurements.

The accuracy of these temperature measurements is considered adequate in view of the small changes of dielectric constant caused by temperature change. An inaccuracy of 3°F will cause a small change in the dielectric constant about equal to the sensitivity of the measuring circuit.

C. Experimental Cell

While the Balstaugh cell gave adequate results for this investigation, and appeared to be the best of existing cell designs, it was necessary to design a new cell for special investigation, such as moisture content where very small changes in dielectric constant were measured, for the following reasons:

The measurement of dielectric constant and dissipation factor of aviation fuels over a temperature range of -65°F to 130°F imposes a special problem in that existing cells do not provide a closed system for sealing in the vapors and for sealing out condensation. Further characteristics objectionable in existing cells are lack of provision for filling without disturbing the electrodes, too small a capacitance, and difficulty in cleaning if the cell should become contaminated.
The revised experimental cell, as is shown in Figure 5, is constructed essentially of a standard taper ground joint of Pyrex, two lengths of Pyrex tubing, and two lengths of Nickel tubing. Contacts are carried through the glass by means of platinum wire sealed in the Pyrex and formed into a contact bead. The Nickel tubes slip over these beads by means of grooves in their inner surfaces, and are placed, after slight rotation, so that they wedge tightly over the contact beads. Small wedge shaped grooves in the cylinders insure good contact and fix their positions. All parts can be removed for thorough cleaning.

The cell was further equipped with a reservoir and filling and draining cocks to permit filling without disturbing the electrodes and to facilitate testing of successive samples, in which case the cell is flushed with an excess portion of the sample to be tested.

This type of construction results in a high capacitance, low liquid volume cell which presents a large external surface area to the temperature bath in which the cell is placed. Because of its higher capacitance, this cell increases the accuracy of the capacitance measurements and also increases the sensitivity of the dissipation factor measurements.

The revised cell has the following characteristics:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Height in Stand</td>
<td>18 7/8&quot;</td>
</tr>
<tr>
<td>Projected Floor Space</td>
<td>8&quot; x 10&quot;</td>
</tr>
<tr>
<td>I.D. of Outer Electrode</td>
<td>3-3/64&quot;</td>
</tr>
<tr>
<td>O.D. of Inner and Guard Electrodes</td>
<td>2-15/16&quot;</td>
</tr>
<tr>
<td>Average Gap</td>
<td>.070&quot;</td>
</tr>
<tr>
<td>Length of Electrodes, Outer</td>
<td>6-3/4&quot;</td>
</tr>
<tr>
<td>Inner</td>
<td>5&quot;</td>
</tr>
<tr>
<td>Guards</td>
<td>1&quot;</td>
</tr>
<tr>
<td>Wall Thickness of Electrodes</td>
<td>.030&quot;</td>
</tr>
<tr>
<td>Capacitance, Empty</td>
<td>150 mfd</td>
</tr>
<tr>
<td>Liquid Capacity</td>
<td>175 ml</td>
</tr>
</tbody>
</table>
Oscillator -------------- Hewlett-Packard Model 200C
Amplifier -------------- Ballantine Model 220
Cathode Ray Oscilloscope -- General Electric, Type CRO-3A
Cp ---------------------- General Radio Type 722D Precision Condenser
                        with worm correction
Rg and Rt -------------- General Radio Type 602 Decade Resistance Boxes
Cs and Ct --------------- General Radio Type 722D Precision Condensers
Ra, Rb, Ca, Cb, and Cn -- General Radio Type 716C Capacitance Bridge

FIG. 2 - BRIDGE CIRCUIT
Figure 4. ARRANGEMENT OF CELLS IN TEMPERATURE CABINET

WADC TR 52-53 10

Approved for Public Release
A. Measurement of Dielectric Constant and Dissipation Factor

1. Procedure

Six measuring cells of the guarded type are disassembled and cleaned by shaking with clean dry acetone. After drying, the cells are assembled and placed in the test chamber. The capacitance while empty is measured, using the substitution method wherein the high lead to the cell (k Figure 2) is connected for one measurement and then disconnected for another measurement. This procedure effectively eliminates the capacitance and losses of the leads. It has been found that the value of capacitance while empty does not vary significantly with temperature; however, due to reassembly, a slight change in value may occur so that it is necessary to determine the empty capacitance after each reassembly.

The cells are then filled with the fuels to be measured and the temperature is adjusted until a glass stem thermometer placed near the cells indicates the desired temperature. After holding the temperature constant for 30 minutes, the capacitance of the filled cells is measured by the substitution method. Two measurements are made at 32°F (0°C) to make sure cooling to -5°F (-20°C) has not changed the fuel characteristics.

During the test run it is necessary to open the top of the test chamber. The top is equipped with an automatic switch so that when opened the fans are cut off. No change in cell temperature is detected due to this brief opening.

Periodic calibration of the measuring cells is made with chemically pure benzene. Corrections of the guarded Halsbaugh cell have been negligible. The dielectric constant of the fuel, therefore, is
simply the ratio of the capacitance while full to the capacitance while empty.

2. Operation of Coupling Circuit

Referring to Figure 2, the resistors $R_a$ and $R_t$ and the capacitors $C_s$ and $C_t$ comprise the Wagner ground coupling circuit. The values of $R_s$ and $R_t$ should roughly conform to the values of the bridge ratio arms $R_a$ and $R_b$, respectively. The function of the coupling circuit is to adjust the potential of the guard circuit, including the shields and the guard ring of the measuring cell, to ground potential. When this condition is achieved there can be no charging current through the terminal capacitance, guard ring to ground plate of the measuring cell, and therefore no bridge current shunting the direct capacitance of the cell.

In practice, successive balances are made with the switch $S$ alternately opened and closed. With $S$ open, $C_b$ and $C_n$ are adjusted until the oscilloscope indicates a null. Switch $S$ is closed, usually upsetting the null indication; $R_s$ and $C_s$ are adjusted until a null is again indicated. This process is continued until no change occurs when $S$ is opened or closed.

B. Density Measurement

Determination of fuel density was made with special pycnometers calibrated to indicate true volume. This method, described in A. S. T. M. Specification D-241-57T, gives results which are accurate to within .05 per cent. Constant temperature liquid baths were constructed using transparent Dewar flasks so the pycnometer graduations may be read without
lifting the pycnometer out of the bath. Density in grams per cc is converted to density in pounds per gallon by multiplying by 8.3454.

C. Capacity Index

The capacity index is defined in OSRD Report No. 4016, June 30, 1944, "Some Characteristics of Aircraft Engine Fuels: Their Influence on Capacitor Type Tank Gages." It is the ratio

\[
\frac{K - 1}{D}
\]

where \( K \) is the fuel dielectric constant and \( D \) the fuel density.

The OSRD report shows that the indication of a capacitance type fuel gage is proportional to the product of the mass and the capacity index provided the liquid in the tank has a constant surface area.

D. Effect of Moisture Content

1) Electrical Measurements

Because of the small effects of moisture content indicated in previous investigations, it was necessary to use a larger, more accurate cell in the determination of dielectric constant and dissipation factor.

Three specimens of each of grades 91/98, 100/130, 115/145 and JP-3 and one specimen of grade JP-4 were measured at 77°F and 400 cps as received and after saturation with distilled water, synthetic hard water, and synthetic sea water. Electrical measurements were made after all specimens had settled 24 hours, and the specimen used was drawn off the upper portion of the saturated fuel to eliminate excess water.

2) Moisture Content Measurements

The amount of water present in the fuels as received and after saturation was determined by the Karl Fischer method. This method is
accurate to within approximately 3 parts per million (milligrams of H₂O per liter of fuel).

E. Handling of Specimens

Specimens were stored in their original containers in an outdoor enclosure protected from the weather. Before measurements one quart of each specimen was processed to distill off 10 per cent by volume. This portion was designated with the suffix "E" and was treated as a distinctly different specimen. All specimens were handled in brown glass bottles to prevent possible formation of precipitate due to sunlight. One pint of each specimen was retained after electrical measurements.

SECTION III
RESULTS

A. Dielectric Constant, Density, and Capacity Index versus Temperature

Dielectric constant at 400 cps and density were measured and capacity index was calculated for about one of every five test specimens through a temperature range of -65°F (-54°C) to 130°F (54°C) with results given in Tables 1 to 7 inclusive and plotted on Figures 6 to 28 inclusive. The group consisted of the following number of specimens of each grade of fuel:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>91/98</td>
<td>10</td>
</tr>
<tr>
<td>100/130</td>
<td>9</td>
</tr>
<tr>
<td>115/145</td>
<td>9</td>
</tr>
<tr>
<td>JP-1</td>
<td>6</td>
</tr>
<tr>
<td>JP-3</td>
<td>6</td>
</tr>
<tr>
<td>JP-4</td>
<td>6</td>
</tr>
<tr>
<td>Experimental</td>
<td>4.</td>
</tr>
</tbody>
</table>

In these and all following results, the suffix "E" designates a specimen after evaporation of 10% by volume.
The mean slopes of the dielectric constant versus temperature curves listed above were calculated for each grade of fuel to be used in determining the mean temperature coefficient and are presented in Table 20. The density of all specimens was practically a linear function of temperature. Data has been compiled to show this relation and is presented in a subsequent section.

Two specimens exhibited peculiar behavior due to temperature change. Initially the dielectric constant of specimen No. 248 measured 2.127 at 32°F (0°C). After cooling to -65°F (-54°C) and then reheating to 32°F (0°C) the fuel measured 2.149. A fresh sample was used for the high temperatures, giving a measurement of 2.052 at 130°F (54°C). The sample which had been subjected to the low temperatures measured 2.092 at 130°F (54°C). Sample No. 365E also exhibited a behavior similar to that of No. 248. Initially at 32°F (0°C), its dielectric constant measured 1.994. After cooling to -65°F (-54°C) and then reheating to 32°F (0°C), the fuel measured 1.984. After further heating to 130°F (54°C) and then recooling to 32°F (0°C), the dielectric constant measured 1.972. These effects were demonstrated by several repetitions of the experiment.

B. Dielectric Constant, Density, and Capacity Index at 32°F (0°C): All Specimens.

The dielectric constant at 400 cps and the density were measured, and capacity index calculated for all specimens at 32°F (0°C). These results are presented in Tables 8 to 14 inclusive, and are shown graphically in Figures 29 to 33. Figures 34 to 36 present plots of dielectric constant versus density at 32°F (0°C) and a line of regression, determined by statistical means. ("Methods of Correlation Analysis", WADC TR 52-53)
M. Ezekiel, Wiley and Sons, 1941, Chapter 8). This line is the best straight line which can be drawn to depict the correlation between the two variables. The figures also give the per unit correlation, 1.0 being perfect correlation.

Figures 39 to 43 present plots of capacity index versus dielectric constant at 32°F (0°C) and lines of regression for these two variables.

Figures 44 and 45 show lines of regression of dielectric constant versus density and capacity index versus dielectric constant for all grades plotted on one chart. Also included on these charts are lines of regression for a combination of 51 specimens of grade 100/130 and 44 specimens of grade 115/145 fuels; and a combination of 51 specimens of grade 100/130, 44 samples of grade 115/145, and 35 samples of grade JP-3 fuels.

Tables 15 and 16 present the mean, maximum, and minimum values of dielectric constant, density, and capacity index of both the unevaporated and evaporated samples at 32°F (0°C) for each grade and for combinations of grades 100/130 and 115/145, and grades 100/130, 115/145, and JP-3. From these tables the effect of evaporation of 10% by volume was determined and is presented in Table 17.

C. Dissipation Factor

The electrical measuring circuit, using the Balsbaugh cell, is sensitive only to values of dissipation factor greater than about 0.0007 at 400 cps. Therefore, only dissipation factors exceeding this value are reported in Table 18.
D. Slope of Density versus Temperature Curves as a Function of Density

The density versus temperature curves of 36 fuel specimens were analyzed and equations were derived which predict density values at various temperatures.

Table 19 gives the slope of the density versus temperature characteristic for each specimen considered in this determination. The slope appears to be approximately a linear function of density at 32°F (0°C) as shown in Figure 46. The per unit correlation of the line of regression was determined to be 0.888, unity being perfect correlation.

Based on these calculations, the general equation for determining density of temperature T when the density at 32°F is known becomes

\[
D_T = D_{32} (.983822 + .00050556T) \\
- .009302T + .221766
\]

where \(D\) is the density in pounds per gallon, and \(T\) is the temperature in degrees F.

Specific equations which apply to the end points of the temperature range are:

\[
D_{-65} = D_{32} (.95096) + .67223
\]
\[
D_{130} = D_{32} (1.04954) - .67916
\]

E. Dielectric Constant, Density, and Capacity Index at -65°F (-54°C), 32°F (0°C), and 130°F (54°C)

Using the mean slope of the dielectric constant versus temperature curves and the mean value of dielectric constant, the mean temperature coefficient of dielectric constant was determined for each grade of fuel and is presented in Table 20. The temperature coefficient is defined by the following equations:
where \( K \) is the dielectric constant
\( t \) is the temperature in degrees F
\( t' \) is the temperature in degrees C
\( \alpha \) is the temperature coefficient of dielectric constant per degree F
\( \alpha' \) is the temperature coefficient of dielectric constant per degree C.

Using this equation, the dielectric constants of all specimens not tested at temperatures other than 32°F (0°C) were calculated at -65°F (-54°C) and 130°F (54°C). Density was determined at these same two temperatures by means of the equations of the preceding section, thereby permitting calculation of the capacity index.

Tables 21 to 26 present the dielectric constant and density and Tables 27 to 32 the capacity index of all specimens at -65°F (-54°C), 32°F (0°C), and 130°F (54°C) for each grade of fuel.

Plots of dielectric constant versus density and capacity index versus dielectric constant at the three temperatures are shown in Figures 47 to 56, inclusive.

F. **Effect of Moisture Content**

The results of the effect of moisture content investigation using the revised cell are presented in Tables 33, 34 and 35.

G. **Chemical Properties versus Dielectric Constant**

Attempts to correlate initial boiling point, and lead, sulfur, and aromatic content with dielectric constant showed insignificant correlation. These quantities are presented in Tables 36 to 40, inclusive, and are shown graphically in Figures 57 and 58 for grade 91/98 fuel.

The aniline-gravity constant, however, exhibited a definite relationship to the dielectric constant. This relationship is shown
graphically in Figures 59 to 61 inclusive.

H. Evaluation of New Cell

A calibration at room temperature was performed using chemically pure benzene as a standard liquid. The dielectric constant of the benzene measured 2.277. The accepted value at 77°F is 2.274.

Two gage lines are inscribed on the glass cell at the ground joint so the cell may be assembled the same way each time it is cleaned. Only a slight change in empty capacitance is noted after repeated disassemblies and assemblies.

An investigation was made to determine the changes of the cell capacitance, while empty, during a temperature run. The results of this investigation showed that the changes in empty cell capacitance over the temperature range of −65°F (−54°C) to 130°F (54°C) are insignificant considering the sensitivity of the bridge circuit.

I. Effect of Storage and Handling

Three samples of fuel, one from the fueling truck, one from a B-36 aircraft before flight, and one from the same B-36 after flight, were tested at 77°F (25°C) and 400 cps to determine the effect of storage and handling upon the electrical and physical properties of the fuel. To obtain greater sensitivity and accuracy, the experimental cell was used in the measurement of dielectric properties. The results of these tests are presented in Table 41.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Temperature, Degrees F</th>
<th>Density in Air (Lb/Gallon), and Capacity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-65 (-54°C)</td>
<td>-40 (-40°C)</td>
</tr>
<tr>
<td></td>
<td>32 (0°C)</td>
<td>77 (25°C)</td>
</tr>
<tr>
<td></td>
<td>130 (51°C)</td>
<td></td>
</tr>
<tr>
<td>219 (DC)</td>
<td>2.083</td>
<td>2.068</td>
</tr>
<tr>
<td>(D)</td>
<td>6.594</td>
<td>6.491</td>
</tr>
<tr>
<td>(CI)</td>
<td>0.1642</td>
<td>0.1645</td>
</tr>
<tr>
<td>219E (DC)</td>
<td>2.089</td>
<td>2.077</td>
</tr>
<tr>
<td>(D)</td>
<td>6.644</td>
<td>6.510</td>
</tr>
<tr>
<td>(CI)</td>
<td>0.1639</td>
<td>0.1647</td>
</tr>
<tr>
<td>223 (DC)</td>
<td>2.050</td>
<td>2.033</td>
</tr>
<tr>
<td>(D)</td>
<td>6.376</td>
<td>6.270</td>
</tr>
<tr>
<td>(CI)</td>
<td>0.1647</td>
<td>0.1648</td>
</tr>
<tr>
<td>223E (DC)</td>
<td>2.062</td>
<td>2.042</td>
</tr>
<tr>
<td>(D)</td>
<td>6.411</td>
<td>6.302</td>
</tr>
<tr>
<td>(CI)</td>
<td>0.1657</td>
<td>0.1654</td>
</tr>
<tr>
<td>256 (DC)</td>
<td>2.037</td>
<td>2.024</td>
</tr>
<tr>
<td>(D)</td>
<td>6.339</td>
<td>6.240</td>
</tr>
<tr>
<td>(CI)</td>
<td>0.1636</td>
<td>0.1644</td>
</tr>
<tr>
<td>256E (DC)</td>
<td>2.062</td>
<td>2.040</td>
</tr>
<tr>
<td>(D)</td>
<td>6.393</td>
<td>6.295</td>
</tr>
<tr>
<td>(CI)</td>
<td>0.1661</td>
<td>0.1652</td>
</tr>
<tr>
<td>273 (DC)</td>
<td>2.046</td>
<td>2.034</td>
</tr>
<tr>
<td>(D)</td>
<td>6.309</td>
<td>6.210</td>
</tr>
<tr>
<td>(CI)</td>
<td>0.1644</td>
<td>0.1665</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>-65(-54°F)</th>
<th>-40(-40°F)</th>
<th>-1(-20°F)</th>
<th>32(0°F)</th>
<th>77(25°C)</th>
<th>130(54°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>273E (DC)</td>
<td>2.055</td>
<td>2.033</td>
<td>2.009</td>
<td>1.986</td>
<td>1.951</td>
<td>1.909</td>
</tr>
<tr>
<td>(D)</td>
<td>6.349</td>
<td>6.251</td>
<td>6.111</td>
<td>5.970</td>
<td>5.796</td>
<td>5.587</td>
</tr>
<tr>
<td>(CI)</td>
<td>1.1652</td>
<td>1.1653</td>
<td>1.1651</td>
<td>1.1652</td>
<td>1.1641</td>
<td>1.1627</td>
</tr>
<tr>
<td>307 (DC)</td>
<td>2.095</td>
<td>2.079</td>
<td>2.066</td>
<td>2.008</td>
<td>1.976</td>
<td>1.944</td>
</tr>
<tr>
<td>(D)</td>
<td>6.144</td>
<td>6.346</td>
<td>6.209</td>
<td>6.070</td>
<td>5.895</td>
<td>5.690</td>
</tr>
<tr>
<td>(CI)</td>
<td>1.1699</td>
<td>1.1700</td>
<td>1.1685</td>
<td>1.1661</td>
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## Table 5

**Dielectric Constant at 1000 Cycles per Second**

**Density in Air (Lb/Gallon), and Capacity Index**

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## TABLE 6

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Density in Air (lb/Gallon), and Capacity Index

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WADC TR 52-53

Approved for Public Release
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### TABLE 9

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**Grade 100/130 Fuels**

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Approved for Public Release
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# Table 13

**Dielectric Constant, Density and Capacity Index at 32°F(0°C)**

**Grade JP-4 Fuels**

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# TABLE 15

Mean, Maximum, and Minimum Values at 32°F (0°C)

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## TABLE 16

Mean, Maximum, and Minimum Values at 32°F(0°C)

Evaporated Specimens

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TABLE 19

Slope of Density vs. Temperature Curves
As a Function of Density

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### TABLE 19
(Continued)

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<td>Mean Temperature Coefficient of Dielectric Constant Per Degree F</td>
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# Contrails

**TABLE 21**

Dielectric Constant and Density

at $-65^\circ F (-54^\circ C)$, $32^\circ F (0^\circ C)$, and $130^\circ F (54^\circ C)$

Grade 91/98 Fuels

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<th>Density - Pounds per Gallon</th>
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Approved for Public Release
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**TABLE 21**

(Continued)

**TABLE 21**

(Continued)
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WADC TR 52-53
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### TABLE 25

**Dielectric Constant and Density**

at \(-65^\circ F(-54^\circ C)\), \(32^\circ F(0^\circ C)\), and \(130^\circ F(54^\circ C)\)

**Grade JP-3 Fuels**

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Approved for Public Release
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### TABLE 26

Dielectric Constant and Density

at \(-65^\circ F (-54^\circ C)\), \(32^\circ F (0^\circ C)\), and \(130^\circ F (54^\circ C)\)

**Grade JP-4 Fuels**

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### TABLE 28

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-65°F(-54°C), 32°F(0°C), and 130°F(54°C)

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-65°F(-54°C), 32°F(0°C), and 130°F(54°C)

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### TABLE 30

**Capacity Index at**

$-65^\circ F(-54^\circ C)$, $32^\circ F(0^\circ C)$, and $130^\circ F(54^\circ C)$

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## CONTRAILS

### TABLE 31

Capacity Index at

-65°F(-54°C), 32°F(0°C), and 130°F(54°C)

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WADC TR 52-53  112
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TABLE 32

Capacity Index at
-65°F(-54°C), 32°F(0°C), and 130°F(54°C)

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### Table 33

**Effect of Moisture Content**

(Saturation with Distilled Water)

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# TABLE 34

**EFFECT OF MOISTURE CONTENT**

(Saturated with Synthetic Hard Water)

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### Table 35

**Effect of Moisture Content**

(Saturated with Synthetic Sea Water)

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## Table 36

### Chemical Properties

**Grade 91/98 Fuels**

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### TABLE 37

**CHEMICAL PROPERTIES**

**Grade 100/130 Fuels**

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WADC TR 52-53  122
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### TABLE 38

#### CHEMICAL PROPERTIES

**Grade 115/115 Fuels**

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<th>Aniline Gravity Constant</th>
<th>Tetaethyl Lead-cc/gal</th>
<th>Sulfur %</th>
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WADC TR 52-53

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### TABLE 39

**CHEMICAL PROPERTIES**

**Grade JP-1 Fuel**

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TABLE 39

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Figure 7
Dielectric Constant vs. Temperature at 1000 Cycles, Grade 91/98 Fuels
FIG. 8
Dielectric Constant vs. Temperature at 100 Cycles, Grade 91/98 Fuels

Temperature - Deg F
-62 -40 -18 40 80 120

Temperature - Deg C
4 27 49
FIG. 9

Dielectric Constant vs. Temperature at 400 Cycles, Grade 91/98 Fuels
Contrails

Dielectric Constant vs. Temperature at 600 Cycles, Grade 100/130 Fluids

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Contraills

Dielectric Constant vs. Temperature at 1000 Cycles, Grade 100/130 Fuels

WADC TR 52-53

135

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Contrails

![Graph showing the relationship between dielectric constant and temperature for different materials.](image)

**FIG. 12**

Dielectric Constant vs. Temperature at 400 Cycles, Grade 100/130 Fuels
FIG. 13

Dielectric Constant vs. Temperature at 600 Cycles, Grades 100/130 Fuels
Contrails

Dielectric Constant

Temperature - Deg F

Temperature - Deg C

FIG. 14
Dielectric Constant vs. Temperature at 400 Cycles, Grade 115/145 Fluids

WADC TR 52-53

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Dielectric Constant vs. Temperature at 400 Cycles, Grade 115/145 Fuels

FIG. 15

Temperature - Deg F

Temperature - Deg C

-80 -62 -40 0 40 80 120
-62 -40 -18 4 27 49

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FIG. 16
Dielectric Constant vs. Temperature at 400 Cycles, Grade 115/115 Fuels
FIG. 17

Dielectric Constant vs. Temperature at 400 Cycles, Grade 115/145 Fuels
Dielectric Constant vs. Temperature at 600 Cycles, Grade JP-1 Fuels
Dielectric Constant vs. Temperature at 400 Cycles, Grade JP-1 Fuels

Temperature - Deg F

-80 -40 0 40 80 120

Temperature - Deg C

-62 -40 -18 4 27 49

FIG. 19

Contrails

WADC TR 52-53
Contrails

Dielectric Constant vs. Temperature at 400 Cycles, Grade JP-1 Fuels

Temperature - Deg F

-62  -40  -18  4  27  49

Temperature - Deg C

Figu...
Contrails

Temperature - Deg F

-62 -40 -18 4 27 69

Temperature - Deg C

Dielectric Constant vs. Temperature at 1000 Cycles, Grade JP-3 Fuels

FIG. 21

WADD TR 52-53 145
FIG. 22
Dielectric Constant vs. Temperature at 400 Cycles, Grade JP-3 Fuels
Dielectric Constant vs. Temperature at 4000 Cycles, Grade JP-3 Fuels
FIG. 24

Dielectric Constant vs. Temperature at 400 Cycles, Grade JP-3 Fuels

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FIG. 25
Dielectric Constant vs. Temperature at 400 Cycles, Grade JP-4 Fuels
FIG. 26

Dielectric Constant vs. Temperature at 400 Cycles, Grade JP-4 Fuels
FIG. 27
Dielectric Constant vs. Temperature at 400 Cycles, Experimental Fuels

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FIG. 28

Dielectric Constant vs. Temperature at 400 Cycles, Experimental Fuels
Specimen Number - In Order of Decreasing Dielectric Constant
Figure 30
Grade 100/130 Fuel Characteristics at 32°F (0°C), 400 cycles
Figure 11

Specimen Number — In Order of Decreasing Dielectric Constant

Grade 115/145 Fluid Characteristics at 32°F(-0°C), 1,000 cycles
Figure 32

Specimen Number - In order of Decreasing Dielectric Constant

Grade JP-1 Fuel Characteristics at 32°F (0°C) - 400 Cycles
Figure 32
Specimen Number - In Order of Decreasing Dielectric Constant

Grade JP-3 Fuel Characterization at 37°C (99°F), 400 cycles

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Contrails

\[ Y = \text{Standard Error of Estimate} = .0095 \]

\[ \text{Adjusted Coefficient of Correlation} = .872 \]

Equation of Line of Regression: \[ Y = .0330 + .1833X \]

Density - Lb/Gallon

Figure 34

Grade 91/98 Fuel Characteristics at 32°F(0°C), 600 cycles
Figure 35

Grade 100/130 Fuel Characteristics at 32°F (0°C), 1600 Barles

\[ y = \text{Standard Error of Estimate} = .0101 \]
\[ \text{Adjusted Coefficient of Correlation} = .92 \]

Equation of Line of Regression: \[ y = .506x + .2473D \]
Figure 36

S = Standard Error of Estimate = .0014
Adjusted Coefficient of Correlation = .5671
Equation of line of regression: K = .9435 + .1736D

Density = Lb/Hallon
Grade 115/145 Fuel Characteristics at 32°F(0°C), 400 cycles
Figure 37
Density - lb/gallon
Grade JP-1 Final Characteristics at 32°F (0°C), 400 cycles

\[ S = \text{Standard Error of Estimate} = .0111 \]
\[ \text{Adjusted Coefficient of Correlation} = .9958 \]
\[ \text{Equation of Line of Regression: } X = .6401 + .2217D \]
$S = \text{Standard Error of Estimate} = .0114$

Adjusted Coefficient of Correlation = .9620

Equation of Line of Regression $K = .6271 + .2204D$

Density - Lb/Gallon

Figure 38

Grade JP-5 Fuel Characteristics at 32°F(0°C), 1000 cycles
Figure 39

Dielectric Constant

Grade 52/58 Fuel Characteristics at 12°F (0°C), 400 cycles

\[ \text{Standard Error of Estimate} = 0.00125 \]

\[ \text{Adjusted Coefficient of Correlation} = 0.6079 \]

Equation of Line of Regression

\[ G = 0.06616 + 0.06915K \]
Figure 6.3

Discrete Constant

Grade 101/100 Stress Characteristics at 327°F (165°C), 1,000 cycles

\[ E = \text{Standard Error of Estimate} = 0.0095 \]

\[ \text{Adjusted Coefficient of Correlation} = 0.6117 \]

Equation of Line of Regression:
\[ a = 0.0230 + 0.071E \]
Contrails

$E = \text{Standard Error of Estimate} = .00122$

$R^2 = \text{Adjusted Coefficient of Correlation} = .731$

Equation of Line of Regression: $\hat{y} = 10632.7 + 11.651x$

Dielectric Constant

Figure 41

Grade 115/155 Fuel Characteristics at $32^\circ F(0^\circ C)$, 500 cycles
$\bar{y} = \text{Standard Error of Estimate} = 0.00132$

Adjusted Coefficient of Correlation $= 0.8303$

Equation of Line Regression: $y = 0.0728 + 0.00452x$

Dielectric Constant
Figure 13
Grade EP-3 Fuel Characterization at 32°F(0°C), 400 cycles
Contrails

Density - Lib/Gallon
Figure 14:
Fuel Characteristics at 32°F(0°C), 400 cycles

Adjusted Coefficient of Correlation = .982

\[ K = 0.7550 + 0.2055 \]
\[ b = 0.0166 \]

\( \gamma = 0.6022 + 0.2314 \mu \)
\( \beta = 0.0099 \)

Adjusted Coefficient of Correlation = .994
Figure 15

Dielectric Constant

Fuel Characteristics at 32°F(0°C), 400 cycles
\[ y = 0.069302 - 0.00969556 x \]

Adjusted Coefficient of Correlation = 0.888

Equation of Line of Regression =

\[ y = 0.069302 - 0.00969556 x \]

Density at 32 Degrees F = Pounds per Gallon
Density - Pounds Per Gallon

Figure 47

Grade 91/98 Fuel Characteristics at -65°F (-54°C), 32°F (0°C), and 130°F (54°C), 1000 cycles
Contrails

Grade 100/130 Fuel Characteristics at -60°F (-51°C), 32°F (0°C), and 130°F (54°C), 100 cycles

Minority - Lb/Gallon

Figure 48

130°F (54°C)
32°F (0°C)
-60°F (-51°C)
Grade JP-1 Fuel Characteristics at -65°F (-55°C), 32°F (0°C), and 130°F (54°C), 400 cycles.
Density - Lb/Gallon

Figure 51

Grade JP-3 Fuel Characteristics at -65°F(-54°C), 32°F(0°C), and 130°F(54°C), 4,000 cycles
Figure 53

Grade 100/130 Fuel Characteristics at −65°F (−54°C), 32°F (0°C), and 130°F (54°C), 1,000 cycles
Contrails

Figure 9:
Grade 115/130 Fuel Characteristics at -65°F (-54°C), 32°F (0°C), and 130°F (54°C), 400 cycles.
Contrails

Dielectric Constant

Figure 55.

Grade JP-1 Fiel Characteristics at -65°F (-54°C), 32°F (0°C), and 130°F (54°C), 600 cycles
FIG. 57
Chemical Properties - Grade 91/98 Fuel
FIG. 58

Chemical Properties - Grade 91/98 Fuel
FIG. 59

Chemical Characteristics - Grade 91/98 Fuel
Contrails

Chemical Characteristics, Grade 100/130 Fuels
Chemical Characteristics, Grade 115/115 Fuels

FIG. 61
SECTION IV
DISCUSSION

A. Dielectric Constant, Density, and Capacity Index versus Temperature

The effect of temperature variation upon dielectric constant was almost identical for all grades of fuel measured. Considering both unevaporated and evaporated specimens, the maximum variation in the mean slope of the dielectric constant versus temperature curves was only .00004 per degree F for all grades of fuel. In four of the five grades for which the mean slope was calculated, the mean slopes of the evaporated specimens were slightly less than the mean slopes of the unevaporated samples.

Particular curves of dielectric constant versus temperature show apparent variations of slope between successive temperatures, but no significance is attached because these variations correspond in magnitude to the limit of sensitivity of the measuring circuit.

The density of all fuel specimens was practically a linear function of temperature in the region of -65°F (-54°C) to 130°F (54°C).

In general an increase in temperature causes a decrease in capacity index although many exceptions were noted. In the 40 specimens of grade 91/98, 100/130, 115/145, JP-1, and JP-3 fuels tested, the average decrease in capacity index was .00414 as temperature was varied from -65°F (-54°C) to 130°F (54°C). Some of the irregularities in the variation of capacity index may be due to the fact that a small error in dielectric constant causes a relatively large error in capacity index.

B. Dielectric Constant, Density, and Capacity at 32°F (0°C): All Specimens

In Figures 29 to 33, inclusive, specimens were arbitrarily arranged in order of decreasing dielectric constant. The plots of density and capacity index do not decrease progressively with decreases in dielectric constant, but a definite decreasing trend is evident.
Correlations between dielectric constant and density, as shown in Figures 34 to 38 inclusive, are considered to be satisfactory, the highest per unit correlation being .962 for grade JP-3 fuel.

Correlations between capacity index and dielectric constant are also oonsidered to be good although they are not as high as the correlations between dielectric constant and density.

Figure 44 shows that the slopes of all lines of regression of dielectric constant and density are fairly similar while Figure 45 shows a relatively large variation in the slopes of the lines of regression of capacity index and dielectric constant.

The mean values of capacity index for the three grades of reciprocating engine fuels tested agree very closely, the variation being only .48 per cent.

The largest variation of capacity index at 32°F (0°C) among the specimens of any one grade was 5.6% (grades 100/130 and JP-3). The smallest variation was 3.9% in grade 91/98.

The effect of evaporation of 10% by volume on the mean value of capacity index was a maximum increase of .30 per cent in all grades with the exception of JP-1, which showed a .12 per cent decrease. The effects of evaporation on the mean values of dielectric constant and density were found to be increases of .09 to 1.10 per cent in dielectric constant and .25 to 1.82 per cent in density.

C. Dissipation Factor

The specimens having the largest dissipation factors at 400 cps,
as shown in Table 18, were all experimental fuels. However, none of these values is considered high enough to be detrimental to the operation of a capacitance type fuel quantity gage.

D. Slope of Density versus Temperature Curves as a Function of Density

The use of the density equations derived from the line of regression shown in Figure 46 for specimens whose plots are close to line of regression gives extremely accurate results. For the specimens farthest from the line of regression, use of the equations causes errors of not more than .7% at the extremes of temperature.

E. Dielectric Constant, Density, and Capacity Index at \(-65^\circ F (-54^\circ C), \ 32^\circ F (0^\circ C), \text{ and } 130^\circ F (54^\circ C)\)

The envelopes shown in Figures 47 to 56 were determined by drawing straight lines through the extreme points at each temperature. The edges of these envelopes are in most cases parallel to the line of regression determined at 32°F (0°C).

The extreme points at each temperature usually correspond to the same specimen.

F. Effect of Moisture Content

The effect on dielectric constant of saturating thirteen fuel specimens with distilled water, synthetic hard water, and synthetic sea water was very small as shown in Tables 33, 34, and 35. The largest change, .43%, occurred in specimen 378 when saturated with distilled water. In nine of the 39 samples the change in dielectric constant was negative.

The effect of moisture content on dissipation factor at 400 cps and 77°F (25°C) was found to be negligible.
The minor effects of water saturation are not surprising in view of the very small quantities of water which combined with the fuels.

G. **Chemical Properties versus Dielectric Constant**

Figures 59 to 61 show that as the dielectric constant increases the aniline gravity constant of the reciprocating engine grades of fuel decreases.

Lead, sulfur, and aromatic content and initial boiling point show no correlation with dielectric constant.

H. **Evaluation of New Cell**

Since the revised cell has practically no change in empty capacitance due to temperature changes, it is extremely well suited for work in which temperature variations are required.

The cell is equally well suited for successive testing of samples without measuring the empty capacitance for each sample. In this case the cell is flushed with an excess portion of the sample to be tested. The relatively large capacitance of the cell gives rise to more accurate measurements.

I. **Effect of Storage and Handling**

Figure 41 shows that the change in the electrical characteristics of the fuels taken from a B-36 aircraft before and after flight and from the loading truck from which the fuel was originally obtained, is small. It is considered that the change in characteristics due to storage and handling is insignificant. The dissipation factors of all three specimens were below 0.0007 at 77°F (25°C) and 400 cps.