The study of silicon carbide filled adiprene.

Nazar Hussain Malik
University of Windsor

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LA THÈSE A ÉTÉ MICROFILMÉE TELLE QUE NOUS L'AVONS REÇUE
THE STUDY OF SILICON
CARBIDE FILLED ADIPRENE

by

Nazar Hussain Malik

A Thesis
submitted to the Faculty of Graduate Studies
Through the Department of
Electrical Engineering in Partial Fulfillment
of the requirements for the Degree
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Windsor, Ontario, Canada
1976
ABSTRACT

Insulator flashover under polluted environments has emerged as a very serious problem in the past decade. Today it is the major factor which determines the line insulation level of a modern power transmission network. Various solutions have been proposed towards the reduction of flashovers due to contamination. They include measures such as washing and cleaning of the insulator surface, treatment of insulator surface with grease or oil, improvement in the insulator design, increase in the number of insulator units at heavily polluted sites and development of semiconducting glazed insulators. All such solutions except the last one are either temporary and partial or uneconomical and inconvenient. Modern semiconducting glazed insulators, though expensive, offer a better solution. However they have a negative temperature co-efficient of resistance which sometimes leads to thermal instability and hence a breakdown of the insulator.

This thesis describes an experimental study which was carried out to determine various properties of silicon carbide filled adiprene. The need for such a study was to determine whether a silicon carbide filled adiprene layer can be used on an insulator having a function similar to that of a semiconducting glaze on an anti pollution insulator. The study describes the voltage current characteristics of this new material. A brief outline of
various parameters effecting the voltage current characteristics is provided. Temperature dependence of the electrical properties of this material has been investigated in the subzero as well as higher temperature ranges. The possibility of thermal aging of this material has been investigated using elevated temperature aging tests. Experiments used to simulate natural sunlight and outdoor environments have been described.

On the basis of short term evaluation, it has been concluded that this material shows promise to be utilized in the manufacture of outdoor anti pollution insulators.
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Chapter I
Introduction

1.1 Introduction

The reliable and uninterrupted operation of a modern Power System depends on its insulation. Besides normal operating voltages, insulation of an electric power system is subjected to three basic types of abnormal conditions that can cause flashover and outage;

(i) over voltage caused by lightning strokes
(ii) over voltage caused by line switching operations
(iii) abnormal voltage gradients in the insulation system caused by contamination of solid insulator surfaces.

(1)

The relative severity of these conditions varies with system operating voltages; with surges and contamination dominating above 500KV as shown in figure 1. With the improved design of lightning arresters and techniques to reduce the switching surges to 2 to 2.5 times the system operating voltage and at the same time with continous increase in the air pollution, contamination has emerged as a very prominent problem. (2). The seriousness of the problem can be evaluated from the fact that contamination is the second major cause of line outages in the United States of America as reported by the IEEE-EEI joint committee. (3).
1 - Lightning surges
2 - Switching surges with resistors
3 - Switching surges without resistors
4 - 60 Hz Contamination scatter

Figure 1 - Line insulation level against various kinds of over-voltages
1.2 Nature of the Problem

Basically, the insulator contamination problem arises due to the deposition of wind born natural and man made pollutants on the insulator surface. The formation of pollution layers is influenced by wind, gravity and electrical forces on suspended particles in air, the adhesion conditions, and the direction of incidence and thus also the insulator shape and the position in the service. (4). There is a great variety of possible types of contaminants on the insulator surface depending on the location of the line. A survey conducted by an IEEE working group describes the possible contaminants found on insulator surface in various locations in the North American continent. (3).

Various types of pollution can broadly be classified into two categories i.e industrial pollution and coastal pollution. Industrial pollution normally consists of conducting as well as non-conducting ingredients and usually contains soot and dirt carried from coke ovens, chemical, brick, steel and cement works, and smoke from power stations and locomotives. (5). On the contrary, the coastal pollution occurs when a transmission line is located on the seaside and in river districts and contamination is due to the deposition of the salt on the insulator surface. The salt is borne by spray carried by a strong wind blowing off the sea. The exact amount of contaminants
deposited on the surface of insulators depends largely on location of the line, height of towers, operating voltage of the line, direction and speed of winds, frequency of the rains and general weather conditions.

The contaminants form a non-uniform layer on the surface of the insulator. This layer exhibits a high resistance in the absence of moisture. Problems arise when contaminants are moistened by fog, dew, mist, drizzle or rain. Even the moisture in the air is enough for the deposition of the contaminants because a water molecule has a large dipole moment of 1.85 debye. The moisture layer on the contaminants results in the formation of a low resistance film on the insulator surface which causes relatively large leakage currents, of the order of milliamperes, to flow over the surface of the insulator. (6). Because of the non-uniformity of the contamination layer, the surface resistivity across the insulator is significantly non-uniform. The resulting leakage current causes the moisture on the insulator surface to evaporate faster in the regions of higher current density. (7) This leads to the formation of dry zones which have relatively very high resistance and hence, a surging behaviour of the leakage current commences. At a certain critical stress, surface breakdown occurs and discharge takes place across the dry zone. The essential result is that when one or more discharges occur across a dry zone, the markedly in-
creased current causes increased heating at the location of a discharge entering the adjacent wet contaminants. This in turn causes an increase in the width of the dry zone due to further evaporation of the moisture. Depending on the geometry, particularly the distance between the electrodes, and on the level of the surface resistivity of the wet contaminants, the dry zone either becomes too wide for the discharge to continue to exist or it attains a critical length beyond which the discharge rapidly crosses the remaining portion of the wet contaminated surface and a flashover occurs: \((8, 9, 10)\). Essentially, therefore the failure of insulation occurs because of the effect of contaminants on the insulator surface in the presence of wetting agent as fog, dew or rain.

1.3 **Scope of the previous work**

Since the beginning of the present century when contamination started to become a problem by causing line outages, extensive amounts of work have been done both in the laboratory as well as in the field along with the theoretical work in order to understand the nature of the problem and to predict the behaviour of insulators in polluted environments. \((11)\) Efforts had been directed to find ways and means to combat flashover problems in polluted environments. The following preventive measures against flashover due to pollution have been tried

(i) over insulation \((3, 4, 11, 12)\)

(ii) design of anti-fog types of insulators \((4, 11, 12, 13)\)
(iii) Arrangements of insulator strings to get increased effective length (11)
(iv) Cleaning of insulator surfaces (3, 4, 6, 11, 12, 14)
(v) Surface treatment to increase resistivity (3, 4, 6, 11, 12, 14)
(vi) Control of voltage distribution over insulator surfaces (4, 11, 12, 13)

Increase of insulation is one of the earliest methods used to prevent insulator flashover and it is still a common preventive measure adopted by various utilities. It has been reported that in up to 9.3% of the cases of flashover increase of insulation is the preventive measure adopted by various North-American utilities. But over-insulation has not solved the problem. It has been reported that a 140% increase in insulation over the normal clean condition insulation at 230KV (24 suspension units instead of 10 units in the insulator string) is not adequate to completely eliminate the contamination problem. (3)

Several methods have been tried, amongst them

(i) increase in leakage length and particularly increase in the leakage distance exposed to direct rainfall so as to use the washing effect of rain on contaminants (5)

(ii) Design of insulators having good aerodynamic properties.

As a result anti-pollution design of insulators efficiently improves their performance. However, it is impractical to rely only on anti-pollution design of an insulator because
pollution sometimes assumes very severe dimensions. (14)

Some improvements in the performance of insulators have been obtained by increasing the effective length of insulator strings by using them in various configurations. For example, the effective length of the insulator string can be increased by approximately 15 to 40% if instead of using one vertical string, two are used in a V-configuration. Other configurations such as Y, inverted T or X have also been tried in England with limited success. (11)

Insulators can be prevented from flashing over if the surfaces are kept clean. This can be achieved by hand cleaning, by washing while the insulators are energized or by live washing which is commonly known as hot line washing. Unenergized cleaning of salty deposits is most effectively done by washing but hard industrial deposits can be removed by proprietary compounds, hot caustic soda solution or grit blasting without damaging the insulators surface. The effectiveness of this method is increased if cleaned insulators are wiped with an oily cloth before putting them back into service. This makes the insulator surface water repellent which usually remains effective for several weeks. (6) To avoid frequent outages for cleaning operation, live washing is preferred. Live washing is accomplished by spraying the insulators either with a jet of water from portable washing units or by means of nozzles fixed at suitable locations around the insulator. (2) In the former case, precautions have to be taken to
ensure the safety of the operator while in the later case the disposition of the nozzles is important so that the surrounding electrical equipment is not damaged. Hot line washing is quite a positive counter measure against pollution, especially in substations and is quite popular in Japan. (14) Generally washing and cleaning represents the second most frequent counter measure adopted by utilities in North America in 16.9% of the cases (3). However, it is costly, inconvenient and a temporary solution as in certain cases cleaning as often as twice every week is required in bad weather conditions. (15) The other drawback is that flashover can be initiated by hot line washing itself, so it really does not represent a suitable solution to the contamination problem.

Treatment of the insulator surface with oil or grease to make it water repellent and thus keeping the surface resistivity high is one of the most common anti-pollution measures in use. Satisfactory insulators had been designed with an oil bath using various types of constructions to combat the pollution flashover. (5) The oil surface presents a nearly infinite resistance to the flow of the leakage current over the insulator surface. After some time the oil creeps over the rest of the surface impregnating any solid pollution and rendering it water repellent. However the oil bath needs shielding from rain and wind and as it becomes polluted with water and dirt, it has to be replaced. Moreover these insulators have a
very complex profile making their manufacturing extremely difficult. Oil leak insulators in which oil is continuously allowed to leak over the surface have also been reported but with a limited success. (12)

The greasing of insulators is accomplished by hand application of a thin film of silicon grease or petroleum jelly to the insulator surface. An alternate method is to dip the insulator in molten grease. In doing so, a thin layer of grease is applied on the insulator surface. As a result, water settling on the insulator surface forms separate beads which run off thus preventing the formation of a continuous conducting film on the insulator surface. However, as dirt accumulates, the usefulness of the grease layer decreases. As a result, the old coating is removed and a new one is applied. The problem with this method is that the grease coating has to be removed and a fresh one has to be applied at 3 weeks to 3 years intervals depending on the thickness of the grease coating, the amount of pollution and the weather conditions. In the regreasing operation, the insulator must be cleaned properly or else failure due to current discharges under the grease coating could result. (7). Also the silicon greases generally giving better performance are quite expensive whereas hydrocarbon greases including petroleum jelly, though relatively inexpensive are inferior in the performance.

If a fairly uniform voltage distribution can be maintained over an insulator surface under all conditions,
flashover can be prevented. It was demonstrated at Croyden in 1940 that a stable voltage distribution on a string of insulators can be achieved if the resistance of each unit is such that it permits a current of about one milliampere to flow through the insulator. Not only would this leakage current keep a stable voltage distribution but also the power loss would keep the insulator surface at a temperature higher than the ambient to prevent the formation of water film on the insulator surface. (16)

English manufactures used a ceramic semiconducting glaze to produce antipollution insulators with very good performance but the glaze of the insulators deteriorated in about one year. (12). Further research in this field led to modern semiconducting glazed insulators offering a better solution to the contamination problem.

In such insulators a fine coating of semiconducting glaze is applied to the insulator surface. This allows the resistive part of the leakage current higher than the capacitive part, keeping the surface dry and maintaining a fair voltage distribution. (15) However certain problems are associated with this method. The main drawback is that the negative temperature co-efficient of resistance of the semiconducting glaze occasionally leads to thermal breakdown of the glaze and thus a permanent failure of the insulator. Problems are also encountered in providing reliable electrical contact between the glaze and the metal electrodes. This contact often deteriorates in a short period
because of electrolysis. The application of semiconducting glaze to complex geometries is quite difficult and expensive. Therefore it is necessary to simplify the insulator profile. Thus as semiconducting glazed insulators offer a partial solution to the contamination problem, further research in this field is necessary in order that a long term solution to the problem may be found.

In the search for improved insulators, new materials have constantly been reviewed and those showing a possibility of outdoor insulation have been subject of special investigations. The rapid development of organic insulating materials during World War II prompted researchers to explore the possibilities of using such materials for outdoor insulation. The reason for much interest in these materials as outdoor insulation is the fact that for many applications, organic materials offer certain advantages over porcelain or glass. (17) One advantage in using organic materials is that it is possible to manufacture thinner sheds than are possible with porcelain or glass and as a result, a more complex profile with greater creepage path can be obtained with organic/insulating materials than is possible with porcelain or glass. Also they are more easily fabricated in combination with other materials such as glass fibre and in this composite form insulators of very high tensile strength can be obtained. (11)

Initial attempts to use such materials for outdoor insulation proved unsuccessful because of tracking and
erosion of the surface of the insulator when operated in polluted environments. (12) However, further research led to the development of track-resistant casting elastomers and plastics which made the use of such materials possible in the outdoor insulation. An example of one of the early outdoor low voltage insulators is GEOPAL. GEOPAL is a General Electric trade mark for a cast track resistant epoxy resin around a glass fibre tension core. It is suggested for use on circuits upto 15 KV in a horizontal position. It has been reported that in this position, the performance of GEOPAL polymer insulator is superior to the porcelain suspension units. (13)

Studies on synthetic polymer systems have shown that it is more difficult to start dry band formation and hence arcing on these materials. This is related to their lower initial surface energy properties and the non wetting behaviour of such materials. (19) Outdoor insulators from synthetic materials can be cast with longer creepage paths. This has resulted in improved flashover voltages for such insulators. However on highly polluted sites, the discharges which occur along the surface cause a general erosion or roughening of the surface of non tracking materials. To a lesser degree, natural weathering also produces similar effects. Erosion results in a surface which is more readily wetted, has a lower resistivity in pollution and therefore, is more susceptible to flashover. The extent to which the pollution flashover voltage of an insulator is reduced by
erosion is a function of the material, the electric stress, general weather conditions and the exposure time. (20)

In order to overcome such problems in 1974 Cicotelli tried various fillers in the polyurethanes and epoxies to get a reasonable value of volume resistivity. (7) His aim was to find a suitable combination of semiconducting and insulating materials possessing desirable volume resistivity. The purpose of the semiconducting filler was to get a leakage current sufficient enough to keep the surface of the insulator at a temperature higher than the ambient to keep it dry. As a result of his investigations he reported that Silicon Carbide filled Adiprene, a polyurethane manufactured by Du Pont De Nemours and Co. possesses desirable properties in terms of voltage current characteristics. He also reported a positive temperature co-efficient of resistance for such a material (7). His interesting work led to further investigations by Sangha who reported very encouraging results such as a very good performance of the cylindrical sample insulators in the presence of fog. (16)

1.4 Objective of the present study

Based on the investigations carried out by Cicotelli and Sangha, it was anticipated that this new material, Silicon carbide filled Adiprene, might be used in a new type of antipollution insulator. The new insulator will have a layer of this material on the surface of a fibre glass reinforced epoxy insulator. As a result a sufficient amount of leakage current will flow through this layer. The
power dissipated in this way will keep the surface temperature of the insulator higher than the ambient. Thus in the presence of moisture, the surface of the insulator will remain dry. This will, in turn avoid the pollution flashover.

The aim of the present study is to collect more information on the behaviour of this new material. To fulfill this aim, the behaviour of this material under extreme, high as well as low, temperatures is studied. Furthermore, the possible aging effect of this material is also investigated using elevated temperature aging tests. As this material is expected to be used in outdoor insulation, the possible effects of ultraviolet radiations on the electrical properties of this material are studied. Polymer and plastic insulation can be attacked by various chemicals. Therefore this material is tested to find the effects of various possible contaminants present in the atmosphere. Beside this information, other important data like voltage current characteristics, dielectric constant of the material and reproducibility of the characteristics of this new material is also collected.
Chapter II

Materials

2.1 Introduction

The sample insulators used for this study were cast from Adiprene LD-955 filled with silicon carbide. Adiprene LD-955 is a polyurethane elastomer rubber and is a product of Du Pont De Nemours and Co. Silicon carbide is a semiconducting material and it is added to the adiprene to obtain a required volume resistivity. It is important to study these materials in some detail in order to understand the behaviour of the new insulating material.

2.2 Polyurethanes

2.2.1 Introduction

The polyurethanes are among the most recent addition to the many commercially important classes of polymers. Originally developed in Germany during World War II, the polyurethanes include those polymers which contain a significant number of urethane groups, regardless of what the rest of the molecules may be. (21) Usually these polymers are obtained by the combination of a polyisocyanate with reactants which have at least some hydroxyl groups, for example, polyethers, polyesters, castor oil or simple glycols. Other active groups may also be present, such as the amino and carboxyl groups. Thus a typical polyurethane may contain, in addition to urethane groups, aliphatic and aromatic hydrocarbons, ester, ether, amide and urea groups. The interunit linkage in polyurethanes is
and they are formed typically through the reaction of a diisocyanate and a glycol (22).

\[ \text{OCNRCNO} + n \text{HOR'OH} \rightarrow \left( \text{OCNHRNHCOOR'} \right)^n \]

The polyurethanes formed in this way are useful in four major types of products: foams, fibres, elastomers and coatings. Of primary electrical interest are the casting compounds, which feature light weight and resiliency and are commonly known as urethane elastomers or urethane rubbers.

Several chemical steps are usually involved in preparing urethane elastomers. These steps may be isolated or combined in several ways so that a number of different commercial processes have been developed. These chemical steps include the preparation of a low molecular weight (1000-2000) prepolymer, chain extension to a higher molecular weight soluble polymer, and cross linking. Each step is explained in (23).

2.2.2 Casting Urethane rubbers

The chemical steps generally characteristic of all urethane preparations may be combined in several ways. Commercial systems most frequently employed generally fall into categories classified as "casting", "millable gums", and "thermoplastic".

The casting system of preparing elastomers utilizes a technique whereby the reactants are mixed in the liquid state, poured into a mould, and permitted to cure at least to a solid rubbery state in the mould. Most fre-
quently the casting process utilizes the following steps; prepolymer formation, mixing of prepolymer with chain extender in the liquid state, chain extension to a higher molecular weight while in the mould (often with some cross-linking occurring almost simultaneously) and final cure to a crosslinked state by continued heating.

2.2.3 Types of casting urethane rubbers (elastomers)

Basically there has been three types of urethane elastomers which have been developed over the years:

(a) Polyester based elastomers= A typical example of this type of urethane rubber is obtained by mixing the polyester and di-isocyanate at 130°C and maintaining the reaction mixture at that temperature for several minutes. The glycol in amounts slightly less than equivalent to the isocyanate content is then stirred at 130°C and the mixture is poured into a waxed or silicon treated mould at 100-120°C. The polymer is left in the mould at 100-120°C until it develops sufficient mechanical strength to be dimensionally stable at the same temperature (about 20 minutes). It is then removed from the mould and heated 10 to 15 hours at 100°C to complete the crosslinking reaction. This technique is normally used in preparing the commercial "Vulkollan" elastomers in Europe.

(b) Polyether based Elastomers= Cast elastomers based on polyethers have been reported in the literature since 1956 and include polytetra methylene ether glycols used in "Adiprene B" and Adiprene C". These also include "Adiprene
I", an isocyanate terminated prepolymer based on poly
(1,4- oxybutylene) glycols. Another form of elastomer
in this category, that derived from polypropylene glycols
and tolylene diisocyanate are now commercially available.
(c) Castor oil based Elastomers= Cast elastomers based on
castor oil and castor oil polyols are described by Patton
and by Heiss. (23). In this case prepolymer are obtained
from castor oil and castor polyols. Elastomers are pre-
pared from these prepolymer by reacting the degassed
prepolymer with curing castor polyols and degassing the
resulting mixture before pouring them into heated moulds
for curing (130°C) for two hours. These elastomers have
excellent water resistance. However, they possess lower
dielectric strength and volume resistivity as compared
to polyether based elastomers.

2.2.4 Selection of casting urethane rubbers for outdoor
Insulation

While selecting urethane rubbers for outdoor
insulation, it is very important to consider the "hydro-
lytic stability" of these materials. A detailed study by
R. Athey has led to the following important conclusions. (21)

(i) Polyether based urethanes are inherently more
resistant to hydrolysis than polyester based urethanes,
by a factor of 5 to 10. These figures have been obtained
by observing long term aging and exposure of these urethanes
to high humidity.

(ii) In the polyester based urethanes, the ester group is
the major point of attack. In the polyether based urethanes, the urea and the urethane groups are the major point of attack. As these groups are more resistant than the ester groups, urethanes based on polyether are more suitable for outdoor insulation.

2.2.5 "Adiprene L" series of urethane rubbers

Adiprene LD-955 used in this study is a member of the Adiprene L series of Du Pont De Nemours and Co. and is a polyether based urethane rubber. General properties of this product are listed by Sangha. (16). These cast elastomers are isocyanate terminated tetramethylene ether glycols with an approximate molecular weight of 2000. Since this polymer possesses terminated — NC0 groups, it can be reacted further with active hydrogen containing materials to transform the liquid into a solid rubber. In order to obtain good mechanical properties, chain extension is necessary to change the low molecular weight liquid into a high molecular weight tough polymer. In addition, crosslinking of the high molecular weight polymer is needed to obtain the desirable elastic properties. By varying the ratio of the chain extension to the crosslinking, the physical properties of the cured elastomer can be varied over a wide range. Both the chain extension and crosslinking can be controlled by the type and concentration of the curing agent as well as curing temperature and time.

2.2.6 Curing agents for "Adiprene L" series

The most important curing agents for "Adiprene L"
type casting urethane rubbers are:

(i) Diamines= when diamines are used as curing agents for adiprene, chain extension takes place with the formation of substituted urea linkages. Crosslinking is effected through the reaction of excess isocyanate groups with the urea group to form biuret linkages. The degree of biuret crosslinking is controlled by the amount of diamine used as well as the curing temperature. Most aliphatic diamines react too fast, therefore aromatic diamines are the most common curing agents. A favoured curing agent of this type is 4, 4'-methylene-bis (2-chloroaniline) which is commercially known as MOCA. The presence of chlorine atoms in the position ortho to the reactive amino groups slows down the curing rate and yields elastomers exhibiting a good balance of desirable physical properties.

(ii) Polyols= This type of curing agent produces elastomers with moderate hardness and strength, having long pot life and a fairly slow curing. A triol or a combination of triol and diol can be used. Typical examples are trimethylol propane, 1, 2, 6-hexanetriol, castor oil or combination of these materials with 1,4-butanediol.

(iii) Water= The presence of moisture from the air causes a cure which is similar to a diamine cure, forming urea linkages. Required exposure time varies from 3 to 14 days, depending upon the humidity and temperature. This curing technique is frequently used for adiprene L type compounds in coating and sealing applications.
(iv) Miscellaneous catalysts= Metal Salts such as cobalt naphthenate and potassium acetate as well as certain titanate esters are capable of curing liquid urethanes. These catalysts appear to promote merely crosslinking rather than chain extension.

We can sum up present section by saying that, although diamine curing agents offer a very short pot life, they need relatively a short curing time while yielding a polymer having good mechanical properties. On the contrary, other curing agents such as polyols, water or miscellaneous catalysts offer a longer pot life, longer curing time and inferior mechanical properties. Thus if the pot life is not a problem diamine curing agents are preferred because they produce stronger polymer on curing than the other curing agents. However, polyol cured ether based urethane possesses more resistance to hydrolytic degradation than MOCA cured urethane.

2.3 Silicon Carbide

Silicon carbide is a very useful semiconducting material. It is refractory, abrasion resistant, corrosion resistant. In its crystal structure, silicon carbide can be represented as an almost infinite series of polytypes (24). However, it can be represented by two main types, i.e. alpha silicon carbide and beta silicon carbide. The alpha silicon carbide has a hexagonal unit cell while beta silicon carbide has a cubic unit cell. In the chemical bonding, silicon carbide occupies an intermediate position
between silicon and diamond. The bonds between atoms are basically covalent, with only small amounts having ionic character. It has been determined that the forbidden gap in silicon carbide crystals is relatively large as compared to technically more common semiconductors. A minimum energy gap of 2.9 eV has been suggested for alpha silicon carbide while the value suggested for beta silicon carbide is 2.35 eV. (25)

Silicon carbide crystals are heat resistant and retain their strength at high temperatures. Mono lithic silicon carbide is notable for its chemical stability. It is stable in oxidizing media at temperatures up to 1500°C. It is stable up to 1300°C in steam. Sulphur and sulphur dioxide exert an appreciable effect on silicon carbide only at temperatures above 1000°C. Up to 1100°C, silicon carbide does not react at all with nitrogen. It is also inert in hydrogen and carbon dioxide atmospheres. Silicon carbide reacts very weakly with mineral acids of any concentration, including hydrofluoric acid. However, it becomes unstable in a mixture of nitric and hydrofluoric acid, and in orthophosphoric acid of specific gravity 1.75, only at 200°C. Silicon carbide is stable when exposed to radiations from an atomic reactor, which makes it a promising material for covering reactor fuel elements and for fabrication of heat exchange pumping equipment.

Commercial silicon carbide commonly known as carborundum is made from sand and coke in an electric furnace
at temperatures between 1780 and 2000°C. The various types of commercial silicon carbide do not differ very much in chemical analysis. The most obvious difference is in the aluminum content. Crystals are colourless or exist in black, gray and green colours. The colourless material is purer but still far short of the purity required for basic research on electrical conduction. Table 2.1 shows typical analysis for samples of silicon carbide that have undergone a severe acid treatment to remove surface contamination. (27). The studies have shown that purer silicon carbide is relatively colourless and has a very high resistivity. The green colour of the silicon carbide crystal is due to the presence of nitrogen as the donor impurity. On the contrary, a black, blue or gray colour has been attributed to the presence of aluminum as acceptor impurity. Actually aluminum is present in all the four types i.e. colourless, green, black and gray but it is much higher in black and gray than in the green or colourless. (26).

It has been found that the ohmic resistivity of the interior of silicon carbide crystal is of the order of 1 to 10 ohm-cm. This value does not include the contact resistivity. However, the contact resistance between silicon carbide crystal surface and the electrodes is non ohmic with resistivities ranging from $10^6$ or more ohm-cm for small current densities (1 microampere/cm$^2$) to 10 ohm-cm for large current densities ($10^3$A/cm$^2$). It is believed that the crystal surface is completely covered with
Table 2.1

Chemical Analysis of Commercial Silicon Carbide
(in percent)

<table>
<thead>
<tr>
<th></th>
<th>colourless</th>
<th>green</th>
<th>gray</th>
<th>black</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC</td>
<td>99.7</td>
<td>99</td>
<td>98.7</td>
<td>98.7</td>
</tr>
<tr>
<td>Free C</td>
<td>0.11</td>
<td>0.3</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Free SiO₂</td>
<td>0.02</td>
<td>0.00</td>
<td>0.75</td>
<td>0.71</td>
</tr>
<tr>
<td>Al</td>
<td>&lt;0.05</td>
<td>0.05</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>Fe</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Ca</td>
<td>&lt;0.03</td>
<td>&lt;0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Mg</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>
a thin (10 cm) insulating film. This amorphous film is assumed to consist of silica and is considered to be responsible for non-linear electrical behaviour of silicon carbide crystals. (28) However, Jones points out that the presence of such film is not essential to the exhibition of the special electrical properties of the contact. (29)

Silicon carbide is a very useful material and finds extensive applications in technology. It is used as a semiconductor material. It is used in non-linear resistors, in lightning arresters, in varistors, in electric heating elements, ignition firers and thermocouple components. Carborundum used in this study had an electrical grade grit of one hundred. The crystals were black in colour (making it a p-type semiconductor). Other specifications of this material have been listed by Sangha. (16)
Chapter III

Experimental Procedures

3.1 Introduction

As mentioned in the first chapter, the main objective of the present study is to gain more information about the behaviour of silicon carbide filled adiprene. Early investigations by Cicotelli (7) and Sangha (16) have shown promising characteristics in terms of voltage - current characteristics, high value of comparative tracking index of the material, satisfactory performance of cylindrical sample insulators under fog and a positive temperature co-efficient of resistance. In spite of these characteristics, the material can not be used as an outdoor insulation if it becomes unstable in the temperature range of its applications. Furthermore, possible environmental effects on the material must be studied to make sure that the use of this material under such conditions is feasible.

With these points in view, a series of experiments were conducted. The experimental procedures are outlined in the following sections.

3.2 Test Equipment Used

Most of the experimental work carried out in connection with the present study was done using the voltage source represented in figure 2. It consists of a 3KVA, 220V/120KV X Ray High Voltage Unit modified to function as a biphasic half wave rectifier of 220V/60 KV yielding a direct output voltage of positive polarity. (2). A wire
1. CURRENT LIMITING RESISTOR (25 K-OHM)
2. CAPACITOR-BANK (0.5 MICROFARADS)
3. RESISTOR FOR DISCHARGE CIRCUIT (6 K-OHM)
4. 600 M-OHM RESISTOR FOR VOLTAGE DIVIDER CIRCUIT
5. 100 K-OHM POTENTIOMETER CALIBRATED TO 60 K-OHM
6. PAPER GAP (APPROXIMATELY 700 VOLTS)
7. NEON LAMP (90 VOLTS)
8. D. C. V.T.V.M. MODEL 412 A
9. HIGH VOLTAGE SUPPLY TO TEST CHAMBER

FIGURE 2—HIGH VOLTAGE SUPPLY AND VOLTAGE MEASURING CIRCUIT
wound resistor of 25 KV is used to limit the maximum current through the diodes in the high voltage unit to a recommended safe level. A capacitor bank with a total capacitance of 0.5 microfarad (two, 0.25 microfarad, 50 KV capacitors connected in parallel) was used to obtain a smooth direct output voltage. In order to limit the short circuit currents during the breakdown of a test specimen, a 6 kilohm resistor was placed in series with the test samples in the measuring circuit.

Most of the tests were carried out in an asbestos chamber. The high voltage supply to the chamber was fed through a porcelain bushing from one side of the chamber while the low voltage connections were made on the opposite side. Arrangements were made in the test chamber to have facilities for simultaneous testing of six test specimens (figure 3).

The measurement of high voltage was accomplished by using a potential divider as shown in figure 2. The potential divider consists of a 500 megohm resistor and a 100 kilohm potentiometer connected in series. The potentiometer was calibrated to 60 kohms thus the potentiometer gives a reading of one volt on the voltmeter corresponding to 10 KV across the test specimen. For voltage measurements, a Hewlett Packard d.c. V.T.V.M. model 412 A was used. A circuit consisting of a parallel combination of a 90 volt neon lamp and a paper gap of approximately 700 volts was used for the protection of the voltmeter.
FIGURE 3  A VIEW OF THE TEST CHAMBER
Current measurements were accomplished by measuring voltage drops across known resistors. Test specimens (six or less) were connected to the same high voltage supply whereas the low voltage side of each test specimen was connected in series with a 470 kilohm resistor with 5% tolerance. The other ends of the six resistors were joined together and the common point was grounded through a 100 ohm potentiometer used in the trip circuit. These connections are shown in figure 4. As the resistors used for the current measurements (470 kilohm) are very small compared to the resistance of the test specimen (which is of the order of several hundred megohms at room temperature and the test voltages), they do not effect to any appreciable degree the values of the currents measured by this method. The voltage drop across each resistor was measured using a separate Hewlett Packard d.c. V.T.V.M. model 412 A. Protection for this voltmeter was provided using a 200 volt surge arrester and a paper gap connected in parallel.

3.3 Preparation of the test specimen.

The test specimen were cast in a cylindrical shape having a diameter of 2.54 cm. (one inch) and a length of 12.7 cm. (5 inches) with embedded brass electrodes of hemispherical geometry as shown in figure 5. This geometry was chosen because it offers ease in casting the test samples under laboratory conditions. The reason for embedding the electrodes was to ensure a good electrical contact between the electrodes and the test material. This parti-
A. HIGH VOLTAGE SUPPLY
B-G. TEST SPECIMENS
R. 470 OHM RESISTOR USED TO MEASURE SPECIMEN CURRENT
P. 100 OHM POTentiOMETER USED FOR TRIP CIRCUIT
V. D.C. V.T.V.M. MODEL 412 A
K. 200 VOLTS SURGE ARRESTER
L. PAPER GAP (700 VOLTS APPROXIMATELY)

FIGURE 4-CIRCUIT USED FOR CURRENT MEASUREMENTS.
1.2. BRASS ELECTRODES

3. SILICON CARBIDE FILLED ADIPRENE

FIGURE 5-GEOMETRY OF THE TEST SPECIMEN USED IN THE STUDY
cular electrode geometry was chosen to minimize the localized electrical stresses at the electrodes surfaces for a better performance of the sample insulators.

As already mentioned, the samples used were cast from adiprene LD 955 and silicon carbide. MOCA was used as a curing agent for adiprene. For most of the study, the ratio by volume of the silicon carbide to the polymer (polymer plus its curing agent) was 40:60. However, samples of the ratio 42:58 were also used in this study. The amount of various ingredients required for the preparation of one such sample with varying contents of silicon carbide is shown in Table 3.1. The test specimens were cast in the laboratory according to procedure outlined in this section.

Desired quantities of silicon carbide of 100 GGE as supplied by S White Abrasive Grains Niagra Falls, and adiprene urethane rubber LD 955 as supplied by Du Pont De Nemours and Co. were placed in two separate containers and heated in a dry air furnace for 3 hours at 95°C. The aim of this heating was to ensure that both compounds attain a fairly uniform temperature and any moisture present in silicon carbide or adiprene is evaporated. This heating also reduces the viscosity of the adiprene making thorough mixing of adiprene and silicon carbide easy. After this heating, silicon carbide and adiprene were mixed thoroughly. This mixing was done with a teflon rod having a diameter of 1.27 cm. After mixing, the mixture was left in the oven for about one hour. During this period, the mixture was
Table 3.1
Quantity of SiC, Adiprene and Moca required for one sample

<table>
<thead>
<tr>
<th>Composition of the sample</th>
<th>Quantity required</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SiC (g)</td>
</tr>
<tr>
<td>40:60</td>
<td>111</td>
</tr>
<tr>
<td>42:58</td>
<td>116.5</td>
</tr>
</tbody>
</table>
stirred thoroughly at least twice to ensure that the silicon carbide is fairly uniformly distributed throughout the mixture. It was observed that a temperature of 95°C gives longer pot life than a temperature of 73°C. Parallel to the later heat treatment, MOCA, the curing agent, was taken in a separate container and heated in a muffle furnace at 120°C for one hour, till it attained a liquid state. Molten MOCA was then poured into the mixture of adiprene and silicon carbide and mixed thoroughly to attain chain extension and the initiation of the crosslinking reaction. This well-stirred and fairly homogenous mixture was then poured in a copper tube mould of 2.54 cm (one inch) internal diameter and 0.635 cm (½ inch) wall thickness which was already coated with a fine layer of 5% silicon mould release (IDI Electric Canada Ltd.). A view of the molding apparatus is shown in figure 6. This molding apparatus provides provisions for the embedding of the electrodes. Furthermore it was possible to apply a fairly uniform pressure while casting more than one test specimen.

The material was left in the mould for approximately 5 hours to complete chain extension of the polymer. Subsequently the samples were cured in the oven while they were in the mould. Curing of the test specimens is necessary for the completion of crosslinking of the polymer. It was carried out roughly for six hours at 100°C and for sixteen hours at 75°C in the dry air oven. This curing time and temperature has been recommended by the manufacturers'
FIGURE 6 A VIEW OF THE MOLDING APPARATUS
for casting pure adiprene samples. (30) After this curing period, samples were taken out of mould and the surface of the insulators was then cleaned using a fine sand paper. These samples were then stored at room temperature for 3 days before testing them.

3.4 Experimental Procedures

Following is a brief description of the experimental procedures.

(a) Voltage-current characteristics were obtained using two different techniques. In the first method, a voltage was applied which was increased in 2 KV steps every 15 seconds. The resulting current was recorded at the end of 15 second interval and immediately after the current measurement, change in the voltage was accomplished. In the second method, a voltage in steps of 2 KV was applied and the resulting current was recorded ten minutes after the change in voltage was accomplished. Again after the current measurement, the voltage was adjusted to the next higher step as was done in the first method. The ten minutes interval between the application of the test voltage and the measurement of resulting leakage current was allowed in order to enable the sample to attain a fairly uniform temperature throughout its entire volume. The voltage was increased successively in 2 KV steps until a breakdown occurred. However, the samples intended to be used for other tests such as aging and ultraviolet exposure, were subjected to test voltages somewhat below the breakdown voltage of the speci-
mens.

(b) In order to check the thermal stability of this material at higher temperatures, the test chamber was fitted with eight reflector lamps each having a power rating of 250 watts. The supply voltage to the reflector lamps was controlled by two ten amperes, 110 volt varics. Using this arrangement, a fairly uniform temperature could be achieved over a wide range (up to 145°C) in the region of interest. A thermocouple, Alumel-Chromel, was used to measure the temperature. A constant voltage was applied and the resulting leakage current was recorded when the temperature had attained its steady state value. Normally the temperature attained its steady state value in about one hour after the change in applied voltage to lamps. Using this method, leakage current was recorded corresponding to various temperatures between 25°C and 145°C.

(c) The above test arrangement was also used to study the influence of aging on the behaviour of this material. Six test specimens were kept at 94 ± 2°C for a period of 603 hours under constant voltage and the resulting leakage current was monitored during this period. At the end of this period the temperature in the chamber was gradually increased to 145°C during the following week. Subsequently the temperature was brought back to room temperature and the voltage current characteristics of the test samples were measured.

(d) To check the effects of temperature cycling, voltage-
current characteristics of a set of test specimen were obtained. These specimens were then subjected to five heating cycles. Each heating cycle consisted of maintaining the test specimen at 107°C for about twenty four hours and then allowing them to cool down and remain at room temperature for the next twenty four hours. Conduction was noted at the elevated temperature as well as at the room temperature during each cycle. After five heating cycles, the voltage current characteristics were measured again.

(e) Low temperature stability tests were performed using an oil bath cooled down to -25°C with the help of dry ice. Transformer oil was taken in a plastic container and cooled to -25°C by mixing dry ice in it. Samples were suspended in the oil bath and the temperature of oil was measured using an Alumel-Chromel thermocouple. The junction of the thermocouple was placed about an inch from the centre of the insulator. A direct voltage of positive polarity was applied. The oil was allowed to gradually attain room temperature. Values of the leakage current were recorded for various temperatures between -25°C and +20°C.

In order to understand the performance of this material at the most critical temperature zone, near 0°C, a study was carried out using an ordinary home freezer with a removable top. High voltage connections were provided through the insulating top of the freezer. Test specimens
used for this study were cast without embedded electrodes. Electrical connections to the samples were provided with two flat electrodes at both ends. The specimens were held tight in between the brass electrodes with the help of a plexiglass frame. High voltage supply consisted of a 150 KV, 60 HZ transformer having a current limiting resistor of 53.6 Kohm. The temperature in the freezer was controlled to within ± 2 degree fluctuations using a thermostat control. Using this arrangement, a controlled temperature in the range of -19°C to room temperature was obtained. Eight test samples were selected and the following data was obtained.

(i) cold switch on characteristics at a voltage (r.m.s.) level of 0.393 KV/cm. (1KV/inch), .98 KV/cm. (2.5 KV/inch) and 0.787KV/cm. (2KV/inch). The temperature setting used for these readings were -19°C, -10°C, +10°C, +20°C and 0°C.

(ii) Steady state value of leakage current in the temperature range of -19°C to room temperature using voltages mentioned in part i.

(f) In order to find the possible effects caused by ultraviolet radiations on this material, following exploratory experiments were conducted.

(i) Two test specimens, one of pure adiprene and the other filled with silicon carbide of known voltage current characteristics were exposed to U.V. radiations emitted by two 4 watt, short wave lamps facing each other. The intensity of the U.V. radiations was measured at the surfaces of the
specimens using a black ray U.V. meter model J225 as supplied by Ultra-Violet Products, Inc. After an exposure period of about one month, their voltage-current characteristics were obtained and their surfaces were examined.

(ii) One of the test specimen was exposed to U.V. radiations having an average intensity of about $3000 \mu W/cm^2$. A constant direct operating voltage of $0.787 \text{ KV/cm}$ was selected and the resulting leakage current was recorded during the exposure.

(g) A set of about ten samples were selected to check the possible effects of the contaminants on this material. They were placed in the following solutions for about one month.

(i) Sodium Chloride Solution (0.1g /ml)
(ii) Calcium Chloride Solution (0.1g /ml)
(iii) Ammonium chloride solution (0.1g /ml)
(iv) Sodium carbonate solution (0.1g /ml)
(v) Sulfuric acid of 0.01 mole strength
(vi) tap water

After this period, test samples were examined carefully and their electrical characteristics were measured again.

(h) A set of test samples with varying surface conditions (ranging from a fairly smooth surface to a rough one) were exposed in the open atmosphere from June 10, 1976 to Oct. 20, 1976 after measuring their electrical behaviour. After the exposure period, their electrical behaviour was remeasured for the purpose of comparison with the unexposed samples.
Besides the above mentioned study, attention was directed to see the relation between d.c. and a.c. conductivity. Moreover dielectric constant of adiprene and silicon carbide filled adiprene was measured using a capacitance bridge.

In our opinion the above test program encompassed a majority of the desired tests required to establish the applicability of this material as an outdoor insulation in the polluted atmosphere. The results of all these tests are discussed in the following chapter.
Chapter IV
Results and Discussions

4.1 Introduction

Silicon carbide filled adiprene, the material under study is expected to be used as outdoor insulation. It is very important to consider the possible environmental effects on the behaviour of this material. While discussing the environmental effects, one has to consider a variety of contributing factors. These factors are most likely to effect the long term performance of the synthetic insulating materials. Most important of them are the effects of weather, climate conditions, pollution and thermal effects due to ambient temperature changes as well as temperature cycling. The possible effects of these factors can be studied only after making a long term evaluation of the material. In view of the relatively short time available for this study, a set of experiments were carried out to find the answers to some of these questions besides obtaining more general information about the behaviour of this material. This chapter is devoted to the experimental results of this study. The results are accompanied by brief discussions wherever possible.

4.2 Voltage Current Characteristics

A systematic study of the voltage current characteristics of silicon carbide filled adiprene was carried out. It was verified that this material shows a non-linear
behaviour in that it exhibits very high resistivities for lower test voltages which decrease with increasing test voltages over a certain range and then increase with increasing test voltages until breakdown occurs. It was noted that the non-linear behaviour of this material is highly dependent on the nature of the applied field, the ambient temperature and the method used for making such measurements. For example, the v-i characteristics obtained by allowing approximately 15 seconds between the application of the test voltage, in steps of 2 KV/15 seconds, and the measurement of the resulting current differs from those obtained by allowing about 10 minutes between the application of the test voltage, in steps of 2 KV/10 minutes, and the measurement of the resulting current. Figure 7 shows this difference very clearly. It is obvious that for this particular sample both of these methods result in the same values for current up to about 18 KV. Above this voltage, the resulting current shows a marked saturation tendency in the second case, curve #2, where we allow sufficient time for the test specimen to heat up and attain a roughly uniform temperature throughout its volume. This heating caused by the leakage current is responsible for the saturation tendency, which is absent in curve #1 where we do not allow sufficient time for the test specimen to heat up.

As we are dealing with neither a pure semiconductor, nor a pure dielectric, we have to consider the be-
Figure 7 - Voltage Current Characteristics of Silicon Carbide Filled Adiprene

Curve #1. 2 KV/15 Seconds
Curve #2. 2 KV/10 Minutes
Specimen. 4258
Temperature. 22°C
haviour of the silicon carbide and adiprene seperately
in order to understand the characteristics of the composite
material. It has been observed that a granular aggregate
of silicon carbide displays a non linear v-i characteristics
which is frequently described by the following empirical
equation: (31)

\[ i = k v^n \]  \hspace{1cm} (4.1)

where \( i \) is the current flowing through the aggregate,
\( v \) is the applied voltage and \( k \) and \( n \) are constants.
For a given type of silicon carbide, the value of \( k \) depends
on the dimensions of the cell containing the aggregate,
the average particle diameter and the applied pressure,
whereas the constant \( n \) appears to be independent of these
parameters. Adiprene being a polymer is a dielectric or
insulating material having few free electrons available
for charge transport. (32)

When the two components are mixed, the number of
contacts among silicon carbide particles is reduced and
will be a function of particle shape, diameter and concen-
tration. For electric conduction to take place, the elec-
trons have no trouble in travelling within the silicon
 carbide particles but have to jump or hop across the gaps
through the adiprene. Thus the gap size between the par-
ticles of silicon carbide will greatly affect the values of
the leakage current which will increase with decreasing gap
size. The gap size depends on the ratio of silicon carbide
to adiprene, the uniformity of the mixture, the degree
of curing achieved and the ambient temperature.
Figure 7 explains the effect of interparticle spacing. Curve #1 shows the $v-i$ characteristics measured immediately after the application of the voltage while curve #2 shows the $v-i$ characteristics when a ten minute interval existed between the application of voltage and recording of the resulting current. In the later case, the test specimen had enough time to warm up due to the $V^2/R$ loss in it, causing an increase in the average gap distance and hence an increase in the resistivity of the test specimen.

The nature of the applied field greatly affects the $v-i$ characteristics. Great variations in the current values were observed for the same test voltage using direct as well as alternating applied voltages. The difference which was observed in all the tested specimens decreased with increasing values of the test voltage. For example, in eight 42.58 samples, with a stress of 0.557 KV/cm (peak value in case of alternating voltage), the peak value of the resulting current was between 5.35 and 13.9 times the current obtained when direct applied voltage was used. However, when the test voltage was doubled, this difference dropped to between 1.45 and 3.65 times.

Based on the difference between the a.c. and d.c. conductivity, it can be anticipated that the current of the test specimen is frequency dependent. The frequency dependence of the current was further verified when the specimen current was measured as a function of the supply
frequency. Figure 8 shows the results obtained for a rectangular test specimen having dimensions of 2.0 x 2.5 x 0.3 cm. A peak test voltage of 1.11 KV/cm was used in this case.

The saturation phenomenon of the v-i characteristics with the 10 minute interval between the application of the voltage and recording of the resulting current was investigated carefully for both alternating and direct applied voltages. Figure 9 and figure 10 contain such results for two typical test specimen. It was observed that the higher the value of the sample current, the more pronounced the saturation tendency and the lower the value of the breakdown voltage. This suggests a relation between the breakdown voltage and the saturation tendency of the specimen current. For relatively higher values of the applied field, the specimen current is high enough to cause high localized temperatures of more than 100°C in the silicon carbide particles. Moreover, silicon carbon particles maybe having higher concentration in certain regions giving rise to higher temperatures in those regions. Also as some of the crystals of silicon carbide possess very sharp edges and corners, very high localized stresses might develop. These stresses combined with the softening of the adiprene caused by high localized temperatures result in a partial breakdown of the adiprene. As a result this will lead to the complete breakdown of the test specimen. Thus, in general, breakdown voltage will depend on the ratio of
FIGURE 8 - SPECIMEN CURRENT VS SUPPLY FREQUENCY

TEMPERATURE 22.5°C
TEST SPECIMEN: 42158
TEMPERATURE 22°C
BREAKDOWN VOLTAGE 26 KV (RMS)

FIGURE 9-V-I CHARACTERISTICS OF SILICON CARBIDE FILLED ADIPRENE
UNDER ALTERNATING APPLIED VOLTAGES
TEST SPECIMEN: 42.58
TEMPERATURE 22.4°C
BREAKDOWN VOLTAGE 26 KV

DIRECT APPLIED VOLTAGE KV

FIGURE 10-V-I CHARACTERISTICS OF SILICON CARBIDE FILLED ADIPRENE UNDER DIRECT APPLIED VOLTAGES
silicon carbide to adiprene in the specimen. The lower this ratio, the lower the probability of attaining higher leakage currents and the lesser the heating caused by the leakage current. Therefore higher breakdown voltages are expected for specimens with low silicon carbide to adiprene ratios.

4.3 Thermal Investigations

4.3.1 High temperature investigations

Cicotelli (7) was the first to associate a positive temperature co-efficient of resistance with silicon carbide filled adiprene and it was further verified by Sangha (16). However the results of the present investigations do not fully agree with the conclusions drawn by these authors about the nature of the temperature co-efficient of resistance of this material. Sample current recorded as a function of temperature while keeping the applied voltage constant revealed that an increase in the specimen temperature above room temperature results in a rapid decrease of current indicating a positive temperature co-efficient of resistance. The value of the co-efficient of resistance depends largely on the value of the current of the test specimen. It was observed that the higher the value of the specimen current, the greater the value of temperature co-efficient of resistance. With the increase in the specimen temperature, the decrease in the specimen current continues with a fairly constant value of
temperature co-efficient of resistance until the temperature becomes about 70°C (for 40:60 sample) where the specimen current drops to about 10 to 20% of its value at room temperature. Further increase in the specimen temperature causes a decrease in the specimen current, but with a relatively low rate. This behaviour is obvious in figure 11, where the current practically becomes negligible at about 90°C. However, if the increase in temperature is continued, conduction starts increasing at about 120°C giving rise to a negative temperature co-efficient of resistance (see figure 12). For six 40:60 ratio samples, this transition temperature was found to lie between 115 and 130°C.

The positive temperature co-efficient of resistance of silicon carbide filled adiprene can be attributed to its thermal expansion. Thermal cycling is liable to cause changes in the number of contact points as well as the distance between the silicon carbide particles. At the same time this cycling might cause stress changes in the polymer matrix which can cause changes in its resistivity. (32) However, the transition from positive to negative temperature co-efficient of resistance can be explained in terms of softening of the test specimen caused by the higher temperature. It has been observed that pure adiprene softens in the temperature range of 125-160°C depending on the degree of crosslinking or curing achieved. (30) In the case of silicon carbide filled adiprene, the softening temperature decreases with increasing amounts of silicon carbide.
SAMPLE 40:60
APPLIED VOLTAGE (DIRECT) 2.76 KV/CM

FIGURE 11—SPECIMEN CURRENT VS AMBIENT TEMPERATURE
SAMPLE 40:60
APPLIED VOLTAGE (DIRECT) 2.76 KV/CM

FIGURE 12—SPECIMEN CURRENT VS AMBIENT TEMPERATURE AT HIGHER TEMPERATURES
Thus the negative temperature co-efficient of resistance is probably the result of softening of the test specimens caused by the higher temperatures. Moreover the value of negative temperature co-efficient of resistance is quite small compared to the positive one indicating two different mechanisms for co-efficient of resistance. Inspite of the negative temperature co-efficient of resistance, the 40:60 ratio samples were found to be thermally stable up to about 145°C provided such temperature cycles were for short duration of time.

4.3.2 Low Temperature Investigations

Outdoor insulators have to be operated in extreme temperatures. Hence low temperature testing was a very important part of the present study. It was observed that the decrease in the ambient temperature is accompanied by an increase in the leakage current. However, the specimen current flowing immediately after the application of a particular test voltage drops gradually until it attains an almost steady value in 15 to 30 minutes. The initial value of the specimen current depends mainly on the ambient temperature, the relative humidity of the surroundings, the test voltage and the specimen composition. The time in which specimen current attains a steady value depends largely on the ambient temperature and specimen composition. The change of specimen current in the first 25 minutes after the application of a particular test voltage is obvious from figure 13. Here current is plotted
Figure 13 - Initial Current vs Time

Peak Voltage Applied 1.11 kV/cm

Peak Voltage Applied 1.39 kV/cm
as a function of time for one test specimen corresponding to various temperatures. Figure 13(a) corresponds to a test voltage of 1.11 KV/cm while in figure 13(b) a test voltage of 1.39 KV/cm has been used. It is obvious that the initial current does not follow a definite pattern. In some cases with the same test voltage, the initial current at a lower temperature was less than the initial current at a higher temperature. However, the steady state values of the current followed a definite pattern. Keeping this point in mind, steady values for the current were recorded using 1.11 KV/cm and 1.39 KV/cm as test voltages and -19°C, -10°C, 0°C, +10°C, +20°C as temperatures. Specimen current is plotted as a function of the ambient temperature in figure 14(a) for a typical test specimen. Test voltages corresponding to 1.11 KV/cm and 1.39 KV/cm were used while the specimens tested were of the ratio 42:58. Tests were carried out using eight test specimens of the same composition. In all the specimens, it was observed that a decrease in ambient temperature is accompanied by an increase in the specimen current and this increase was found to be a function of the test voltage. For example the specimen current at -19°C was found to be 3.4 to 7.0 times the specimen current recorded at +20°C. These figures correspond to a test voltage of 1.11 KV/cm. However, with a test voltage of 1.39 KV/cm, the above mentioned ratios were found to be between 2.41
FIGURE 14—(A) CURRENT VS AMBIENT TEMPERATURE
(B) CURRENT SCATTER VS AMBIENT TEMPERATURE
and 4.56. The scattering of the resulting current as a function of the ambient temperature is shown in figure 14(b). Again these values refer to eight test specimens tested using 1.11 KV/cm and 1.39 KV/cm as the test voltages.

Experiments were carried out in order to check the low temperature stability of this material. A 40:60 specimen was placed in transformer oil and cooled to -25°C by adding dry ice to the oil. In this case a much higher test voltage, i.e. 2.95 KV/cm was used. Five specimens were tested using this technique. All of the specimens survived without breakdown. Current at -25°C was found to be 9 to 12 times the current at +25°C. No physical changes were observed after subjecting these specimens to the lower temperatures. This may be attributed to the fact that unlike other polymers, adiprene can be subjected to -62°C without causing any brittleness, although stiffening gradually increases as temperature is reduced below -18°C. (34)

It is very important not to consider the low temperature results only in terms of stability but also in terms of power dissipation. The increase in the specimen current with decreasing temperatures is a very important property. This gives a higher amount of power dissipation at lower temperature and much lower power dissipation at higher temperatures. This property can help to attain an economical and technically better product.
4.4 Thermal Aging Test

Insulators are expected to stay in service over prolonged periods of time, 15 to 20 years. Therefore it is important to ascertain that the proposed material does not age appreciably with time when in operation. Any chemical or physical change during operation may make the material unsuitable for practical use. Synthetic insulating materials like cellulose, poly vinyl chloride, poly vinyl acetal and polyamides are attacked by oxygen while in service. The result is that such materials crack after aging and their dielectric properties decrease. Along with oxidation there are several other thermal aging mechanisms; polymerization, depolymerization, hydrolysis and evaporation. While these are active in some cases the major aging factor is oxidation (33).

It has been reported that adiprene cured with moca shows some softening after aging for seven days at 121°C but the tensile properties are unaffected. Even after seven days at 150°C, the material retains a high percentage of its original properties and shows no sign of embrittlement. (30)

No information was available about the thermal aging effects on the electrical properties of pureadiprene or adiprene filled with silicon carbide. Thus it was decided to carry out long term elevated temperature tests using the arrangement described in the previous chapter.
A set of six test specimens were kept at a temperature of $94\pm 2^\circ C$ with a direct voltage of 2.95 KV/cm across them. The resulting current recorded as a function of aging time in hours is shown in figure 15 for a typical test specimen. It can be seen that the resulting current keeps on increasing for the first 200 hours of aging. After this the leakage current fluctuates about a constant value. These fluctuation probably arise due to slight variations in the ambient temperatures. The continuous increase in the current during the first 200 hours of heating suggests that some chemical change takes place in the polymer structure. Most probably this change is further curing of the test specimen.

After the first 600 hours of aging at $94^\circ C$, the chamber temperature was gradually increased to $145^\circ C$ during the next 100 hours. All of the six test specimens were kept at this temperature for the next 20 hours. One of the test specimens failed at this point. The remaining test specimens were allowed to remain at room temperature for several days before their v-i characteristics were measured for comparison with the characteristics obtained before the commencement of the aging test. Figure 16 shows the comparison of the v-i characteristics obtained before and after the elevated temperature aging test for one of the test specimens. It is obvious that there is a permanent change in the v-i characteristics of the test specimen. The effect of long term aging, especially at
Figure 15: Specimen Current vs Hours of Aging

Specimen 40460
Voltage 2.95 kV/cm
Temperature 94°C
FIGURE 16—EFFECT OF THERMAL AGING ON V-I CHARACTERISTICS OF SILICON CARBIDE FILLED ADIPRENE
the higher temperatures, is a permanent increase in the length of the test specimen, causing a permanent change in the $v$-$i$ characteristics of this material. This permanent increase in length may be due to further curing of the test specimen. Furthermore it was observed that the colour of the test specimens had changed slightly. The specimens were found to have more of a sheen and the colour had gone brownish, after the termination of the long term aging test.

4.5 Temperature Cycling Test

Temperature cycling tests are carried out in order to study the possible effects of changes in the ambient temperature on the behaviour of any material when subjected to operating voltages. In the temperature cycling test, attempts were made to study the effects of changes in the ambient temperature on the behaviour of this material.

During each temperature cycle, the temperature of the test chamber was kept at $107\pm2^\circ$C for 24 hours. The temperature was then lowered to room temperature and for another 24 hours, subjected to this new temperature. A direct operating voltage of 2.95 KV/cm was applied across the specimen during the entire test. Figure 17 shows the $v$-$i$ characteristics for one of the test specimens obtained before and after subjecting it to five temperature cycles.

These results indicate that a permanent change in the $v$-$i$ characteristics of this material has been caused
BEFORE TEMPERATURE CYCLING

AFTER TEMPERATURE CYCLING

AMBIENT TEMPERATURE 22.5°C
TEST SPECIMEN 40:60

DIRECT APPLIED VOLTAGE KV

CURRENT MICROAMPERES

FIGURE 17-EFFECT OF TEMPERATURE CYCLING ON V-I CHARACTERISTICS OF SILICON CARBIDE FILLED ADIPRENE
by the temperature cycles. However, there is a great deal of similarity in the results of figure 16 and figure 17 indicating the possibility of a common cause for change. The most likely reason for this change is the thermal expansion caused by temperature cycling. An increase in the length will change the gap as well as number of contact points between the neighbouring silicon carbide particles.

In the outdoor environment, temperature changes are less sudden and also maximum temperatures attainable in North America are much lower than that used in this test. Based on this fact we can assume that the $\gamma$-i characteristics of the material will change after it is in use for an appreciable time in the outdoor environment. This change however may not be too prominent. Furthermore one can always allow a factor of safety to account for the possible decrease in the conduction brought about by the use of this material in outdoor environments.

4.6 Exposure to Ultra-Violet Radiations

Synthetic insulation for outdoor use has to be evaluated for the possible effects of ultra-violet radiation. Ultra-violet radiation can cause a chemical change only if the energy of the individual photons is at least equal to the lowest bond energy found in the polymer molecules. The energy of a photon is related to its wave length by the equation

$$E = \frac{hc}{\lambda} \quad (4.2)$$
where \( c \) is speed of light in space, \( 3 \times 10^8 \text{m/sec} \)

\[ E = \frac{hc}{\lambda} \]

\( h \) is plank's constant, \( 6.626 \times 10^{-34} \text{Joule-sec} \) and \( \lambda \) is wave-length of the photon.

Figure 13 shows the energy of a photon as a function of its wave-length. Table 4.6 gives the energy values for various chemical bonds as given by Linus Pauling. \( (35) \)

These figures show that ultra-violet radiation of wave lengths from 200 to 400 nm has sufficient energy to break several different types of chemical bonds such as C-H, C-C, C-Cl, C-Si. Some of these bonds are present in all the common polymers. The breaking of the chemical bonds known as 'Scission' results in a reduction of the molecular weight and deterioration of the polymer which may be recognised as loss in both mechanical and electrical properties \( (36) \)

Approximately 5% of the total sunlight reaching the earth's surface falls within 200 and 300 nm wave length range. In order to simulate the effect of u-v light, germicidal lamps were used. They are electrically the same as fluorescent tubes of the corresponding size and wattages. However, these lamps differ physically from fluorescent lamps in that they contain no phosphor and are constructed with a special type of glass to maximize the emission of the 253.7 nm mercury spectral line. The glass used in ordinary fluorescent tubes filters out this particular emission which comprises more than 90% of the radiant energy. The special envelope used in germicidal lamps
FIGURE 18—ENERGY OF A PHOTON AS FUNCTION OF ITS WAVELENGTH
Table 4.6

Bond energies for some of the common chemical bonds

<table>
<thead>
<tr>
<th>Bond</th>
<th>Energy value ev</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-Si</td>
<td>2.99</td>
</tr>
<tr>
<td>C-N</td>
<td>3.03</td>
</tr>
<tr>
<td>C-Cl</td>
<td>3.38</td>
</tr>
<tr>
<td>C-C</td>
<td>3.60</td>
</tr>
<tr>
<td>C-O</td>
<td>3.64</td>
</tr>
<tr>
<td>Si-O</td>
<td>3.81</td>
</tr>
<tr>
<td>N-H</td>
<td>4.03</td>
</tr>
<tr>
<td>C-H</td>
<td>4.29</td>
</tr>
<tr>
<td>C-F</td>
<td>4.55</td>
</tr>
<tr>
<td>O-H</td>
<td>4.76</td>
</tr>
<tr>
<td>C=C</td>
<td>6.37</td>
</tr>
<tr>
<td>C=O</td>
<td>7.40</td>
</tr>
<tr>
<td>C=N</td>
<td>13.50</td>
</tr>
</tbody>
</table>
is of clear vycor or quartz. (37)

In the u.v. test, a test specimen was exposed to an average u.v. intensity of 3000 \( \mu W/cm^2 \). It has been reported that about 80% of the total radiation by the germicidal lamps used is at a wavelength of 253.7 nm. (38). The meter used for measuring this intensity has a peak sensitivity at 253.7 nm and an absolute accuracy of \( \pm 15\% \).

A test specimen was exposed to the u.v. radiation and at the same time a direct voltage of 0.78 KV/cm across the test specimen was applied. The specimen current was monitored. Figure 19 shows the plot of resulting current as a function of exposure time. It is clear from this figure that the specimen current shows a decreasing tendency. After the u.v. exposure was terminated, it was observed that the conduction level in the test specimen returned to about 85% of the original value under the same test voltage (0.78 KV/cm) and ambient temperature. This decrease in the resulting current may be attributed to long term heating caused by the u.v. radiation. After the u.v. exposure, whether a test voltage was applied to them or not, it was observed that all the test specimens including one of the adiprene had a shiny surface. Although no erosion was noticeable in any case, a slight change in colour from black to brown was detected. In fact to some extent, a similar change in colour was noticed in the long term elevated temperature aging test. Thus a certain optical change took place in both thermal
Figure 19: Specimen Current vs Time of Exposure to U.V. Radiation
aging and u.v. exposure. In both cases, the specimen conduction level dropped slightly.

Although this test was not long enough to enable us to make definite conclusions, it is very likely that long term exposure of this material to moderate sunlight would probably not result in any significant surface erosion. However, it is expected to affect the conductivity and the colour of the specimen. Change in colour might be accompanied by changes in some of the properties of this material which can only be estimated after long term exposure.

4.7 Effect of Atmospheric Pollutants

A great variety of contaminants are present in the atmosphere. These include solid contaminants such as coal dust, fly ash, general air borne dust, cement dust, salt and sand etc. and may be neutral, alkaline or acidic in nature. Besides solid contaminants, gaseous contaminants such as ozone; and oxides of sulfur and nitrogen also exist in the atmosphere. Some of the contaminants present in the atmosphere can react chemically with the surface of polymers and cause significant changes in their properties and performance. For example a ductile material may crack and a non tracking material may become tracking (36).

Among the gaseous pollutants the most important are ozone and the oxides of sulfur. Ozone is chemically very active and can attack any unsaturation present in a polymer causing chain scission. However, ozone normally
attacks polymers in the presence of u.v. radiation present in the sunlight. In our u.v. exposure tests, the germicidal lamps used also emit ozone producing radiations. So the slight change in the colour of the material in u.v. test might be partially due to the presence of ozone.

Oxides of sulfur present in the atmosphere can also attack polymers. The principal oxide of sulfur in the atmosphere is the dioxide. For example in 1968, the sulfur dioxide emission in England was estimated to be six million tons. (36) Sulfur dioxide reacts with the atmospheric oxygen in the presence of sunlight as follows.

\[
\begin{align*}
SO_2 & \xrightarrow{\text{u.v.}} SO^* \\
2SO^* + 2O_2 & \xrightarrow{\text{u.v.}} SO_3 + O_2 \\
SO_3 + H_2O & \rightarrow H_2SO_4
\end{align*}
\]

The sulfuric acid produced this way can damage highly filled polymer systems by reacting with the inorganic fillers. It can also damage polymer system by causing high leakage currents in humid conditions.

In order to study any possible effect of some of the contaminants present in outdoor environments, a set of test specimens were placed in the following solutions for a period of one month:

(a) (i) Sodium chloride \((0.1g/ml)\)
    (ii) Calcium chloride \((0.1g/ml)\)
    (iii) Ammonium chloride \((0.1g/ml)\)

(b) Sodium carbonate \((0.1g/ml)\)
Sulfuric acid of 0.01 mole strength tap water

After this treatment the electrical characteristics of the specimens were determined. No change was observed in the specimens treated in solutions of category a, b and d mentioned above. However the resistance of the sample placed in $\text{H}_2\text{SO}_4$ solution was found to be reduced to about one half of its original value at 2.36 KV/cm.

Thus while solid contaminants such as sodium chloride, calcium chloride, ammonium chloride and sodium carbonate have no noticeable effect on this material, sulfuric acid has appreciable effect on the properties of this material. The extent to which this material is affected by sulfuric acid when used as insulation in polluted environments will depend on the amount of oxides of sulfur present in the atmosphere at that location. However it is quite likely that this material will not be affected by normal solid contaminants present in the atmosphere. Table 4.7 represents resistance of adiprene against some of the common chemicals. (34)
Table 4.7
Chemical resistance of pure adiprene

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Rating</th>
<th>Chemical</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium hydroxide solution</td>
<td>A</td>
<td>Chlorine gas wet</td>
<td>C</td>
</tr>
<tr>
<td>Calcium hydroxide solution</td>
<td>A</td>
<td>Fuel oil</td>
<td>B</td>
</tr>
<tr>
<td>Calcium bisulfite solution</td>
<td>A</td>
<td>Gasoline</td>
<td>B</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>A</td>
<td>Hydrochloric acid 20%</td>
<td>B</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>A</td>
<td>Hydrochloric acid 37%</td>
<td>C</td>
</tr>
<tr>
<td>Sea water</td>
<td>A</td>
<td>Kerosene</td>
<td>B</td>
</tr>
<tr>
<td>Sodium hydroxide 20%</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium hydroxide 46.5%</td>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water (50°C)</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water (100°C)</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfurous acid</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitric acid 10%</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium hydroxide solution</td>
<td>B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A = Little or no effect
B = Minor to moderate effect
C = Severe effect to complete destruction
4.8 Effect of exposure to atmosphere

We have already discussed that insulators operating in an outdoor environment are exposed to ambient temperature changes, u.v. radiation and various gaseous as well as solid pollutants. In addition to these factors, synthetic insulating materials can also be attacked by moisture. The moisture which can be present as rain, dew, condensation or high humidity can attack and degrade different polymers in a different way:

(a) chemical hydrolysis e.g. in polyesters, polyamides
(b) freezing of water in surface imperfections can cause cracks in which more water may lodge causing further cracking on freezing
(c) pollutants dissolved in a surface moisture film can cause loss of electrical properties e.g. by tracking or dielectric puncture.

In order to assess the environmental effects of all the contributing factors when acting simultaneously, a set of test specimens were placed in the open atmosphere for 18 weeks, from June 10, 1976 to Oct. 20, 1976. A small portion of the surface of each sample, carrying its identity number, was covered with an insulating tape. At the end of this period, it was observed that the uncovered portion of the surface had changed in colour from dark black to brownish black. No sign of erosion or cracking was observed. Moreover the portion of the surface which was not
facing towards sunshine did not change colour. A decrease in the electrical conduction was observed. Except in one sample which had low conduction before it was exposed to atmosphere, the conduction level had dropped to about 50% of their original value. The sample with low conductivity before it was exposed to atmosphere had a 20% decrease in the conductivity.

The possible reason for this decrease in conduction is a chemical change taking place in the polymer structure. This chemical change is most probably the result of u.v. radiations present in the sunlight and the changes in the ambient temperature. The question as to whether or not such a change can be prevented cannot be answered for the time being. An improvement in this respect might possibly be accomplished by using an appropriate glaze or coating.

4.9 Measurement of Dielectric Constant

Experiments were carried out to determine the dielectric constant of adiprene and silicon carbide filled adiprene using a General Radio bridge type 716-c. Due to restrictions on the voltage that could be applied to the bridge rectangular test specimens (2.0 cm X 2.5 cm) having a thickness of 3 mm were cast from pure adiprene and silicon carbide filled adiprene of the formulation 42:58. The voltage supply to the bridge consisted of a sinusoidal function generator, a power amplifier and a transformer.
In order to provide electrodes, both faces of each test specimen were painted carefully with Du Pont conductive silver paint of composition #817. The layers of silver paint applied to the test specimens were kept reasonably thick in order to minimize the voltage drop across various points on each electrode.

Using a peak voltage of 1.11 KV/cm across the test specimen, the dielectric constant of adiprene and silicon carbide filled adiprene was measured. Figure 20 shows the results as a function of frequency. The value of the dielectric constant for silicon carbide filled adiprene is roughly 5 times the corresponding value for pure adiprene. For example the value of dielectric constant for pure adiprene at 100 hz is 4.32 which agrees with the value of 4.80 given for this material by the suppliers. But the value of dielectric constant for silicon carbide filled adiprene at 100 hz is 22.59 which is 4.68 times that of pure adiprene.

It is very important to consider this relatively high value of dielectric constant for silicon carbide filled adiprene. Furthermore, it is very important to note that whereas the dielectric constant of pure adiprene remains roughly constant, the dielectric constant of silicon carbide filled adiprene decreases with increasing frequencies.

Forster (32) made similar measurements using carbon filled polymer systems. The composition of his test
samples is shown in table 4.91 where as results of his measurements are reproduced in table 4.92. It is seen that the values reported by Forster differ from those obtained by us. This difference is perhaps because of different materials used by Forster. However it is very interesting to note that the value of dielectric constant for carbon filled polymer systems is very high and depends on frequency, concentration of filler and the type of polymer used. The decrease in the dielectric constant with increasing values of the test frequencies is similar to the trend obvious in figure 20. The relatively higher drop in dielectric constant with increasing frequencies as compared to our results may be due to higher frequencies used by Forster.

Zeszmer et al (39) have reported about semiconducting non-linear resistors with silicon carbide as a major constituent. They describe that the value of the dielectric constant of such resistors lies generally between 50 and 200. This value depends on the composition of a particular resistor. They have attributed such high values of dielectric constant to relatively small thickness of intergranular films present in the non-linear resistors.

Thus the dielectric constant for pure adiprene is 4.84. This value for pure silicon carbide has been reported as 7. (40). However the dielectric constant of silicon carbide filled adiprene having 42.58 formulation was found to be 22.59 at 100 hz and it dropped to 18.44
### Table 4.9.1
Composition of samples used

<table>
<thead>
<tr>
<th>Sample I.D.</th>
<th>Polymer type</th>
<th>% weight of carbon black</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>XLPE</td>
<td>39</td>
</tr>
<tr>
<td>2</td>
<td>EPM</td>
<td>39</td>
</tr>
<tr>
<td>3</td>
<td>EPM</td>
<td>32</td>
</tr>
</tbody>
</table>

### Table 4.9.2
Results of dielectric measurements

<table>
<thead>
<tr>
<th>Sample I.D.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric constant at $2 \times 10^6 \text{Hz}$</td>
<td>20000</td>
<td>325</td>
<td>130</td>
</tr>
<tr>
<td>Dielectric constant at $2 \times 10^8 \text{Hz}$</td>
<td>10000</td>
<td>54</td>
<td>75</td>
</tr>
</tbody>
</table>
at 10,000 hz. Large variations in the value of dielectric constant of silicon carbide filled adiprene are expected with varying quantities of silicon carbide. In particular it is expected that a much higher value of dielectric constant will be obtained by increasing the percentage ratio of silicon carbide.
Chapter V
Conclusions

The main aim of this study was to assess the usefulness of silicon carbide filled adiprene in the development of a new type of anti pollution insulator. To meet this end, an experimental evaluation of this material was carried out. The results of this evaluation can be summarized as follows.

(i) Silicon carbide filled adiprene has a very useful set of v.i. characteristics. These characteristics are non-linear with current exhibiting a saturation tendency. If sufficient time is allowed between application of voltage and the measurement of resulting current, this saturation tendency is obvious under the application of both alternating as well as direct applied fields. Moreover, this tendency is a function of the conduction level of the test specimen. It is more pronounced in samples having higher conduction level. This tendency is very useful for the stability of the insulator and to avoid breakdown which can otherwise occur.

(ii) Conduction under the application of alternating voltages is much higher as compared to values observed under direct applied voltages. This difference in the conduction decreases with increasing test voltages.

(iii) The conduction in silicon carbide filled adiprene is highly frequency dependent.
(iv) This material possesses a positive temperature coefficient of resistance and hence is thermally stable over a wide range of temperatures. However, temperature coefficient of resistance becomes negative if temperature is raised above approximately 120°C at which adiprene becomes soft making it unsuitable for use above 120°C.

(v) The material does not age appreciably with heat provided the aging temperature is below 100°C. Aging temperature above 110°C in general and 120°C in particular can damage the material to a great extent. Long term aging also results in some reduction in the conduction level of this material.

(vi) The material is not attacked by most of the solid pollutants found in open atmosphere. It is neutral to water and humidity at normal temperatures. However, it is readily attacked by sulfuric and other acids which can act as life diminishing agents.

(vii) Prolonged exposures to u.v. radiation results in a change in the colour of this material which may be accompanied by a change in the physical properties. Such exposures are also responsible for a drop in the conduction level of this material.

From the practical viewpoint, the above results are quite encouraging and satisfactory. Hopefully one can find a suitable glaze or coating which can protect the material from ill effects of u.v. radiation. It is reported
that compounds such as chlorinated rubber (neoprene), can provide such a protective coating. Thus this material shows promise to be utilized in the manufacture of outdoor anti-pollution insulators.
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VITA AUCTORIS

1949  Born in District Sheikhpura, Pakistan on January 17.


1968  Completed Intermediate Education from Islamia College Lahore, Pakistan.

1973  Graduated from the West Pakistan University of Engineering and Technology Lahore with BSc. degree in Electrical Engineering.

1973-1975 Worked as Lecturer in the Electrical Engineering Department, University of Engineering and Technology Lahore.

1976  Candidate for Master of Applied Science Degree in Electrical Engineering at The University of Windsor, Windsor, Ontario.