

# **STUDY OF DYNAMIC DIELECTRIC AND THERMAL PROPERTIES OF SUNDARI WOOD UNDER DIFFERENT SALINITY AND HUMIDITY**

**M. Phil. THESIS**

**By**

**KHAN ALALUDDIN**

**Roll No. 0055504**

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CERTIFICATION OF THESIS WORK  
A THESIS ON

**Study of dynamic dielectric and thermal properties of Sundari Wood  
under different salinity and humidity**

By

**KHAN ALAL UDDIN**

has been accepted as satisfactory in partial fulfillment for the degree of Master of Philosophy in Physics and certify that the student demonstrated a satisfactory knowledge on the field covered by this thesis in an oral examination held on 23 August, 2005.

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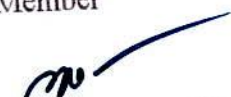
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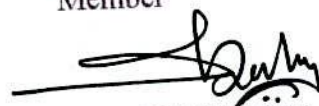
4. **Professor Dr. Md. Mahbub Alam**  
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Khulna University of Engineering and Technology

  
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Khulna University of Engineering and Technology

  
.....  
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Principal Scientific Officer, Magnetic Materials Division, AEC,  
4, Kazi Nazrul Islam Avenue, Ramna, Dhaka-1000

  
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**DEDICATED TO MY MORSHED HAZRATH  
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## List of Symbols and abbreviations used

MC	- Moisture Content
RH	- Relative Humidity
MCM	- Moisture Content Meter
SHM	- Selling Hygrometer
FSP	- Fiber Saturation Point
DC	- Dielectric Constant
K	- Thermal Conductivity
T	- Temperature
L	- Thickness of identical specimens
T <sub>h</sub>	- Temperature of the hot plate
T <sub>c</sub>	- Temperature of the heat Sink
C	- Capacitance
ε	- Dielectric permittivity
Q	- Electric charge
V	- Potential difference
E	- Electric field strength
D	- Density
ψ	- Flux lines
A	- Area of the specimen
m	- Mass of the disc
S	- Specific heat of material
∞	- Air gap thickness
d <sub>1</sub>	- Thickness of specimen
d <sub>2</sub>	- Thickness of specimen
d	- Thickness of air film
G	- Conductance
ω	- Angular frequency
ε''	- Dielectric loss factor
n	- Complex number
σ̄(ω)	- AC Conductivity

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## ABSTRACT

Sundari wood is very useful as a construction material. Its physical properties were not well studied. Thermal conductivity and dynamic dielectric properties of Sundari wood have been studied for their dependence on salinity and thickness. Drying quality of most wood products is mainly depends on the distribution of moisture content of different slices, such as the humidity of environment, the temperature effect from the cutting slices, dielectric constant and dielectric loss, etc. The error associated with sensors when used to estimate relative humidity does not exceed  $\pm 12\%$  except when relative humidity increases with increasing salinity at the rate in excess of  $\pm 2\%$  per hour. The moisture content of the samples, in the form of small disc, has been varied by immersing the specimens in to water and the moisture content of the Sundari wood slice has been determined from the difference of weight of the treated samples and the dry samples. The same procedure has been applied to induce salinity in the specimen, where saline solution of different strengths was used. The dielectric constant was found to increase with increasing moisture content and also increases with increasing saline concentration. The introduction of solutions into the wood matrix increases with increasing dielectric constant by a factor of two. This increase is quite expected due to the presence of additional ions in Sundari wood and its composite nature.

Dynamic dielectric permittivity, loss factor and a.c conductivity have been measured as a function of frequency in the range from 1 kHz to 13 MHz at room temperature. The dielectric permittivity, loss factor and real part of the conductivity of the Sundari wood were found to be about 5.8 to 0.68, 5.28 to 0.04 and  $12.64 \times 10^{-9}$  to  $24135.23 \times 10^{-9}$  mho/cm, respectively, over the frequency range from 1 kHz to 13 MHz. These results also varied with thickness of the specimen and its saline content. From the conductivity results it is important to note that the conductivity in the high frequency is very sensitive and precisely .The conductivity varies appreciably with a small variation of parameters.

The thermal conductivity of Sundari wood has been determined using a technique which is a modification of Lee's method in order to avoid the error due to the air gap between the specimen and the conducting disc used as heat source and heat sink. The effective temperature of Sundari wood samples at which thermal conductivity has been measured, was altered by changing the temperature of the heat source. Thermal conductivity of these samples increases with increasing salinity. The thermal conductivity has also been observed to increase with the increasing in the applied voltage heat the sample to the same temperature.

Results are explained interms of the additional contribution from the water molecules and ions and also interms of the transfer of few electrons from the valence band to the conduction band which acts as the thermal energy carrier.

## **Chapter-I          INTRODUCTION**

- 1.1    Introduction
- 1.2    Review of the Past Work on Dielectric Properties of Wood
- 1.3    Review of the Past Work on Thermal Conductivity of Wood
- 1.4    Objective of This Research Work

# Chapter-I

## 1.1 Introduction

Wood is the dominant pre-industrial thermal energy source for western European and North American societies and remains a dominant fuel in many African and Asian societies today<sup>(1)</sup>. The dominant means for generating energy from wood involves direct combustion; gasification being the primary alternative, wood is an extremely heterogeneous material and is not surprising that its chemical composition, anatomy and physical properties vary within wide limits. Its macrostructure is evident in its grain. Its microstructure is biological origin and its atomic coordination are molecular chemically, wood is a partially oxygenated solid composed of cellulose, the hemicelluloses, lignin and extractives. It is highly volatile, with modest amounts of aromatic structures.

Wood is a composite material consisting of three major polymers namely cellulose, hemicelluloses, and lignin in wood, the changes in them and degradation of products formed under different conditions are discussed by Hills W.E.<sup>(2)</sup>. He also discussed the changes in the nature of hemicelluloses, which appear to play an important role in conveying stability. wood, as a composite insulating material, has many interesting physical characteristics. In explaining the mechanism of electrical conduction, the general assumption is that the electrical charge is carried by ions in wood and cellulose rather than by electrons<sup>(3-6)</sup>.

These ions arise from metallic residues or impurities. In addition cellulose and wood exhibit polarization phenomena that are typical characteristics of ionic conduction in direct electric fields as reported by Brown J.H.<sup>(7)</sup> and O'Sullivan J.B.<sup>(8)</sup>. The migration of ions through wood under the influence of an applied field by using ions, was observed by Lin

R.T<sup>(9)</sup>. Therefore ions play an important role in electrical conduction. But there have been no quantitative measurements of the extent to which charge transport is electrolytic.

Reduction in drying time and energy consumption offers the wood industries a great potential for economic benefit. But the reduction in drying time often results in an increase in drying related defects such as checks, splits and warp. Most of these defects are caused by drying stresses which are developed from moisture gradients and restrained shrinkage within the wood. So the key to improving drying quality and reducing time lies in understanding and controlling moisture movement in wood during drying.

Historically the measurement of moisture gradient in wood during the drying period by the slicing method. The theory of this slicing method is reasonable, but the results are not ideally accurate because slices for measuring the moisture gradient are thin and sensitive to the environment. Moisture gradient is not easy to measure by nondestructive method because moisture in wood is associated with many other properties of wood, such as density and temperature. The relative humidity (RH) is a measure of the degree saturation of the air and of wood material in contact with that air, assuming that the air and wood material are in moisture equilibrium<sup>(10-13)</sup>. The RH is changing all the time, especially between night and day. Floorboard and furniture tend to follow the humidity change and this is the reason for the ghostly noises one hears in the house at nights. The standard perturbation theory analysis to develop a new microwave technique for simultaneously and independently measuring the size and dielectric constant of wood samples with increasing moisture content, the amount of water within the wood matrix increases, which itself is characterized by high dielectric values<sup>(14-16)</sup>.

All timbers tend to come to equilibrium with the relative humidity of the surrounding air. The most important effect of this is that the wood shrinks or swells. The movement in the direction along the grain of the wood is negligible as one would expect from the molecular structure. The cross grain swelling and shrinkage is however, very large. Every one percent change of moisture content may cause about a half percent shrinkage or swelling over the range of moisture contents likely to be reached in air. The lateral dimensions of wood can thus change between five and ten percent i. e up to an inch on a ten inch wide plank. The most important effect of moisture on wood is to cause it to swell. A rather less important effect, from the practical point of view, is to change the mechanical properties. Thoroughly wet wood has something like to third of the strength and stiffness of completely dry wood.

Wood consists of closed tubes which in the living tree are partly full of water or rather sap. In freshly felled wood the moisture content varies but may be over 100 percent of the weight of the dry wood substance. About 25 percent of this water is absorbed on the hydroxyl is of the Sibarina wall, the remainder is liquid water inside the cell. Seasoning consists in removing most of the water in a controlled way; essentially it is a drying operation and nothing more. The cells are closed spindle-shaped tubes, the liquid water inside them is not very easy to get out. It can only be dried out by diffusing it slowly through the tube walls. This would present no great difficulty if one were dealing with a single cell but real wood contains many thousands and it is necessary to diffuse the water from the inner cells through the wall of most of the other cells, which lie between them and the outer world. This is why one cannot season too fast without ruining the timber. At about 25 percent moisture content, however these hydroxyls become saturated and the cell walls can absorb no more water this is known as the fiber saturation point. Up to the fiber saturation point the lumen or hollow part of the cell is empty of water. Above the fiber

saturation point virtually the whole of the additional moisture exists as loose liquid water within lumen. All the dimensional and mechanical changes in wood which are due to moisture occur below the fiber saturation point, that is 0 to 25% moisture content.

Constructions of wet wood during freezing is observed by Kubler<sup>(17)</sup> as well as Schirp<sup>(18)</sup> and on several wood species. In thermal expansion tests with wood samples starrier paid no attention to possible varieties in moisture content. Glatzel<sup>(19)</sup> noticed some drying of his samples but disregarded the corresponding shrinkage and Villari<sup>(20)</sup> used oil-soaked samples apparently assuming that the oil prevented or at least reduced change in moisture content. The bond between atoms of a molecule are much stronger than bonds between molecules. Consequently intermolecular bond may be assumed to be more stiff and to permit less thermal vibration than bonds between adjoining molecules. Wood consists mainly of chainlike cellulose molecules most of which are arranged parallel to each other approximately in fiber direction. In such a structure exists many variable intermolecular joints per unit of specimen length in the transverse direction than longitudinally.

Thermal conductivity is one of the physical properties of wood essential to drying. The phenomena of heat transfer in wood depend on the geometry of the wood, as well as porosity. Thermal conductivity is different in solids, gases and liquids. As wood is a heterogeneous medium containing the three phases, its thermal conductivity is only an apparent conductivity because it results from complex exchange concerning simultaneously: conduction in gases, conduction in the liquids and conduction in the solids. A solid phase of thermal conductivity occupying a fraction of volume, a gas phase occupying the voluminal fraction and a liquid phase occupying the voluminal fraction<sup>(21)</sup>.

The co-efficient of thermal conductivity should apply only to homogeneous materials in which the heat transfer is by conduction as in metals. Heat is transferred across an air space by radiation, conduction or convection. The rate of heat transfer across an air space is affected materially by the orientation of the space. The equipment for the determination of conductance value must be so designed that the air space can be rotated to various positions Wilkins and Peterson designed an equipment and it has been in almost constant use, since that time with some refinements added. If the structure of an insulating material is sufficiently open to permit convection currents, the rate of heat flow is affected by orientation. Air spaces of sufficient width for convection to occur transfer heat at different rates, depending upon whether the direction of heat flow is horizontal, vertically upward or vertically downward. This transference is much more pronounced in air spaces formed by reflection insulation. Stamm, A.J. et. al. <sup>(22)</sup> reported that when wood is heated under temperature and time condition that cause a loss of water of constitution, together with other broken down product, the less in weight is accompanied by dimensional stabilization. Stamm A.J. showed that the rate of the thermal change occurs in wood and paper prior to give them dimensional stabilization can be greatly increased by introducing salts into the wood or paper prior to heating. These catalysts do not change the nature of the reactions as indicated by the constancy of the activation energy and they do not affect various losses that accompany the attainment of any definite level of dimensional stabilization.

For wood products the dielectric properties have already been studied on a large scale at lower frequencies <sup>(23-25)</sup>. The practical applications of the dielectric properties are that the density and moisture content of wood can be determined nondestructively. It has also been reported that knots, spiral, grain and other defects can be detected by measuring dielectric properties <sup>(25)</sup>. The utilization of high frequency and



microwave technique are also of growing importance for heating, gluing drying as well as improving the quality of wood and wood based products. In the high frequencies like MHz range, however, a lot of work has still to be performed. The loss factor of wood also depends strongly on the properties of the free water, which can vary significantly with frequency. However, water in vegetation is not pure, and the salt content results in finite static current (dc) conductivity. The loss factor increasing with waters content depending on the salt content.

The present research work includes the development of technique for more accurate measurements of thermal conductivity and dynamic dielectric constants of Sundari wood in their normal states and under conditions of humidity and salinity. Sundari wood is an important material with complex properties, which have variety applications as a construction material. Its composite structure and physical properties vary from one kind of Sundari wood to another depending on the plant source, seasonings, moisture contents, relative humidity and specially the content of salts as absorbed chemicals. The basic physical characteristics underlying electrical conductivity and dynamic dielectric properties depend of frequencies.

## **1.2 Review of the Past Work on Dielectric Properties of Wood**

Scientific interest in the dielectric properties of wood as a result of the use of high power radio frequency and microwave energy for wood processing tasks such as heating, drying and gluing. A more recent application to make use of the dielectric properties of wood is the use of low-power microwave signals to rapidly and automatically measures such properties as moisture content and density <sup>(26)</sup>. In many cases, it becomes very difficult to locate the exact data on when and how the phenomena are first established. This may also be applied in the case of dielectric

materials like wood and study of their properties. The dielectric properties are important not only for understanding the structure of wood and cellulose at the molecular level, but also for practical application in Industrial heating and in measuring density and moisture content of cellulosic materials. However, according to many people who worked with the dielectric properties of materials. Faraday was the man who first pointed out the increase of the capacity of condenser with the presence of the dielectric material by neutralizing charges at the electrode surfaces which otherwise would contribute to the external field. Drude was also one of the pioneers in the systematic study of the dielectric properties.

In 1931 Stoops measured the dielectric constant of a few vegetable oils over the wide range of temperature and calculated their polarization and electrical moments. He discussed the results from the stand point of molecular structures. The interpretation of dielectric polarizations from the stand point of molecular structure depends upon a representative molecule of a specimen of the dielectric substance under the influence of a microscopic electric field. The dielectric measurement by Cole and Drude gave evidence of anomalous dielectric dispersion i. e. the decrease in the dielectric constants at high frequencies. For wood products the dielectric properties have already been studied on a large scale at lower frequencies <sup>(27-33)</sup>. In the microwave range, however a lot of work has still to be performed. Interesting studies in this respect were done by James and Harmil and Tinga <sup>(34)</sup>. In the case of microwave heating the rise in vibrational motion is attributed to the mechanism of ionic (the electrolytic) conduction and mainly dipole rotation. It is likely that microwave sensing will also be extended to measuring a wide range of other wood features such as sweep, microfibril angle and internal defects such as voids, checks and cracks. In order to achieve this goal detailed mechanical models are required relating the dielectric properties, at both the microscopic and macroscopic levels, to the physical properties of wood <sup>(35)</sup>. Hill N.E. <sup>(36)</sup>

showed that the application of on Sagar's theory of dielectric dispersion contained an incorrect assumption about the behavior of reaction field when the applied field is varied.

Ionic conduction is practically independent of temperature in the microwave region but is only effective for wood at high moisture contents. The electric field applied at microwave frequencies causes a dissociation of molecules and a migration of ion and delivering kinetic energy. The ordered kinetic energy is then converted into disordered kinetic energy which may be regarded as heat by collision of the migrating ions with an ionized molecules. This transfer of energy leads to an increase in temperature. In order to increase the energy of magnitude of vibrations of the individual molecules. In the case of microwave heating the rise in vibrational motion is attributed to the mechanisms of ionic conduction and mainly dipole rotation. Dipole rotation on the other hand is characterized by both temperature and frequency dependency. However, it may also takes place in wood at low moisture contents, because of the presence of polar groups. The vibrations that are induced in the interior of the dielectric material are based on a rotation of the polar molecules under the influence of the external electric field. When an electric field is applied the randomly oriented dipoles align themselves in a direction apposite to that of the external field.

The cellulose in wood has amorphous regions and contains ionic impurities soluble in water. With ions present the dielectric behavior of moist wood could be similar to that of weak electrolytes. Brown and Skaar<sup>(37)</sup> suggested that when an external alternating electric field is applied and the frequency is not too high, each time the field is reversed the polar molecules reverse their position too a continuous dipole rotation is the result .The total stored energy consists of the sum of the potential and kinetic energies of the rotating molecules. Although, during each cycle a

certain fraction of the total energy is dissipated due to friction, the energy levels of the adjoining molecules are raised owing to collisions and transfer of energy and this result in a temperature rise. Sarker M.R.<sup>(38)</sup> studied the dielectric properties of some local varieties of wood at 3cm wavelength in the electronic Research laboratory department of physics; University of Rajshahi; Courtry W.E.<sup>(39)</sup> presented the theory and experimental result to show possibility of using a resonant post technique for characterizing dielectric and magnetic materials at microwave frequencies.

For radio frequencies the dielectric constant of dry vegetation is very low and virtually independent of frequency. However, living vegetation contains a high proportion of water, which has a high dielectric constant. The high dielectric constant is representative of the fact that water consists of polar molecules that are free to align themselves with the applied field. This is a vastly simplified view of the dielectric properties of vegetation. However it gives a feeling for the observed variations of dielectric properties with moisture content and frequency. In practice the permittivity depends on many different factors and varies significantly from one part of a tree to another and with tree age and species. The permittivity is also quite anisotropic for wood, and can vary significantly depending on whether it is measured parallel or perpendicular to the grain of the wood. Norimoto et al<sup>(42)</sup> studied the dielectric behaviors of pines densiflonsids at face, the anisotropy in longitudinal and transverse direction is described to a difference in the arrangement of cell wall and Lumen Physical properties of Sundari wood such as dielectric constant have been studied in the past but existing information is not exhaustive and demands further study especially for wood of local origin.

### 1.3 Review of the Past Work on Thermal Conductivity of Wood

The need for conservation of energy resources necessitates a more careful look at the thermal properties of building materials. Unfortunately, the failure to include the framing members of an insulated stud wall in the heat load calculations has resulted in the overrating of the insulation value of a frame house. Engineers usually speak of the insulation of building materials as conductivity or conductance. Conductivity compares the heat flow through a one inch thickness of homogenous material such as wood, fiberglass, concrete etc.<sup>(43)</sup>. According to Finnish Sauna experts, the insulation value of wood varies with its moisture content, density and temperature. The thermal conductivity of wood is nearly linearly proportional to its density.

Wood is a complex material because of its complex and hygroscopic structure. Wood consists of small crystal like regions dispersed in a matrix of amorphous material which is hygroscopic. So wood contains moisture in proportion to the humidity of its environment. Conductivity is a material property that determines the current density resulting from a given voltage gradient in the material. Its reciprocal is resistivity. The conductivity of wood varies enormously with its moisture content. Chemically wood is a partially oxygenated solid composed of cellulose, the hemicellulose, lignin and extractives.

Cellulosic materials are most hygroscopic substance and its thermal conductivity depends upon its moisture content, temperature and applied the voltage. In oven dry wood, resistivity is of the order of  $10^{17}$  to  $10^{18}$  Ohm-centimeters at room temperature<sup>(44-46)</sup>. Moisture content has the predominant effect upon electrical conductivity of wood and cellulosic materials but conductivity is also affected by temperature<sup>(47-48)</sup>. At moisture content above fiber saturation Lin R.T. <sup>(49)</sup> observed a discontinuity in the curve near 0°C. This may have been related to the

change in moisture content of the cell wall due to freezing associated with the phenomenon known as "Coldness Shrinkage" observed by Kubler. H. <sup>(50)</sup> and Lin R.T. <sup>(49)</sup>. In explaining the mechanism of electrical conduction it has been generally assumed that the electrical charges are carried by ions in wood and cellulose rather than by electron <sup>(51-54)</sup>. These ions arise from metallic residues or impurities. In addition, cellulose and wood exhibit polarization phenomena that are typical characteristics of ionic conduction in direct current electric fields.

The conductivity of cellulose may be governed both by the number of free ions and by their mobility <sup>(52)</sup>. The number of free ions, on the other hand, is influenced by the presence of water in moist wood that has a large dielectric constant. Therefore, Hearle <sup>(54)</sup> postulated that the conductivity of hygroscopic materials increases with increasing moisture content because of the increase in its dielectric constant. The theory of electrical conduction for ionic crystals to cellulose and proposed that its conductivity be represented by the sum of the intrinsic conduction <sup>(55)</sup>. The theory was further extended by Lin <sup>(49)</sup>, who considered that the formation of charge carries in wood is statistical and that equilibrium exists with temperature.

Since wood lacks free electrons, which so rapidly transfer heat and electricity in metals, it conducts heat by the relatively inefficient transfer of vibration energy from one particle to the next. For this reason, and because hollow cells of wood trap air, wood and wood based Fanel products are low in thermal conductivity. In the longitudinal fiber direction, which is lengthwise in most pieces wood conducts heat 1.5 to 1.8 time faster than in the transverse direction, perpendicular to the fibers. This is due to the orientation of fibers and of cellulose - chain molecules. The higher ratios apply more to dry wood and the lower ratios more to - wet wood in which water equalizes the difference between longitudinal and transverse conductivity. In dry wood the ratio averages 2.5. The

thermal conductivity of water is more than 20 times higher than that of air and also exceeds the conductivity of cell-wall substance. The thermal conductivity increases with increasing moisture content. Moisture also contributes to heat conduction by diffusion of vapor from the warm to the cold side.

Skaar <sup>(56)</sup> reported that when current passes through conducting media, it is always accompanied by Joule's heating, which will increase the temperature of the conducting body. With cellulose and wood, resistivity is initially reduced. Such initial decrease in resistance is opposed by the effects of electrode reaction and polarization, which increases the resistance. Temperature has the strongest influence on thermal conductivity at a given moisture content, which is lower for dense wood than for light wood. Dense wood, after all, has relatively little cell cavity space for water and for diffusing vapor.

Wood-based panel products, fibers are usually oriented in the plane of the panel, so that heat flows across the panel perpendicular to the fibers, as in its flow across solid wood. In solid wood, however all fibers lie parallel to each other and are grown together, whereas in the panels a number of fibers lie at angles and touch each other only over a part of their length. The thermal conductivity of wood has been determined by clamping an externally insulated heating plate with a heated edge guard ring to prevent lateral heat losses on one surface of a board and measuring the electrical energy input per unit of time required to maintain the surface of the board at a fixed temperature above the opposite face, the temperature of which is thermostatically controlled <sup>(57-59)</sup>. After a linear steady state temperature gradient is set up across the board, the amount of heat required to maintain the gradient per unit of time becomes constant. Clarke, L. N and Kingston <sup>(60)</sup> reported a more recent method for

measuring heat conductivity makes it possible to measure heat conductivity and specific heat simultaneously as the temperature is raised.

Ward, R.J. and Skaar C. <sup>(61)</sup> reported that two identical specimens to be tested are clamped on opposite faces of a heat sink with a guard ring. Around it that is heated electrically at a rate to keep its temperature equal to that of the heat sink thus avoiding lateral heat losses. Electric hot plates are clamped on the outer faces of the two test specimens and adjusted to give equal heating and a rise in temperature of a rate about equal to the rate of rise in temperature of the heat sink. Part of the heat entering the test specimens is used in raising their temperature and the remainder is conducted across the specimens to raise the temperature of the heat sink. Thus both the specific heat of the test specimens, C and their thermal conductivity, K are involved through the following relationship,

$$K = \frac{dT_c}{dt} \left[ \frac{L(PCL + P_1C_1L_1)}{2(T_h - T_c)} \right], \quad (1.1)$$

where  $\frac{dT_c}{dt}$  is the rate of temperature rise of the heat sink in ° C/sec.

L is the thickness of the identical specimens and L<sub>1</sub>, is the thickness of the heat sink in cm, P is the specific gravity of the specimen, P<sub>1</sub> is the specific gravity of the heat sink metal and C<sub>1</sub> its specific heat, T<sub>h</sub> is the temperature of the hot plate and T<sub>c</sub> is the temperature of the heat sink in °C.

The thermal conductivity of oven-dry wood is 2.25 to 2.75 times greater in the fiber direction than in the transverse direction. Variations between the radial and the tangential directions are practically negligible <sup>(62)</sup>. The direction of heat flow through most heat insulators has little effect on the thermal conductivity, but there are some important exceptions to



this statement. It is reported that the K values are 60 to 80% greater when the heat flow was parallel instead of perpendicular to the grain in light weight woods <sup>(63)</sup>. Frinck <sup>(64)</sup> made thermal conductivity determinations on various fibrous materials and showed the effect produced on the K value by different arrangement of the fibers. The rate of heat transfer across an air space is affected materially by the orientation of the space equipment. For the determination of conductance values must be so designed that the air space can be related to various positions.

The electrical resistivity of cellulose material is also affected by the presence of water-soluble electrolytes. This is reflected in the fact that hardwood in general not only shows higher conductivity but also requires less activation energy <sup>(65)</sup>. The conductivity of wood and cellulose is increased by the introduction of ionic salts into the structure. The electrical conductivity of wood and cellulose does not follow Ohm's law. Apparent resistance of cellulose materials depends upon the applied voltage, known as the Evershed effect, which was observed by Davidson R.W <sup>(66)</sup>. The direct current resistance decreases rapidly with increase in applied voltage from 0 to 150 Volts per cm. though temperature, moisture content and type of material affect the result slightly. When conductivity is measured with ac current of 60 Hz. The Evershed effect is not observed. Therefore appears to be a characteristic of ionic conduction for polar dielectric and may be attributed to the dependence of the degree of polarization of polar substances on field strength.

The thermal properties of wood are closely to the mechanical properties and quite possibly to the thermodynamics of wood. The electrical and thermal properties can be measured quickly with simple device and can be useful in nondestructive testing of wood and cellulose to measure moisture content, humidity, static dynamic dielectric constant, etc.

#### 1.4 Objective of This Research Work

Sundari wood is an important material with complex properties, which have variety of applications as a construction material. Some physical properties of Sundari wood such as thermal conductivity and dielectric properties (real dielectric permittivity, loss factor, etc) have been studied in the past but the existing information is not exhaustive and demands more investigation. The composite structure and physical properties of Sundari wood vary from one kind to another depending on the plant source, seasoning, moisture content and the content of salts.

Moisture and salinity can have far reaching effects on electrical properties of wood and can alter the value of the dielectric breakdown voltage. Wood as a construction material, therefore, needs to be studied for its physical changes due to moisture and temperature variation. Wood is often used for building cold storage for its thermal insulating property. The study of thermal and electrical properties is important for their variation due to salinity and humidity.

The following are the objectives of this work:

- (i) To study the effect of moisture content, RH, dielectric constant for salinity and various thickness of the Sundari wood slice.
- (ii) Measurement of thermal conductivity and its variation due to salinity and various sample thicknesses of the wood slice.
- (iii) The dynamic dielectric permittivity, loss factor, complex number and their variation due to salinity and thickness of the wood slice in the frequency range of 1 kHz to 13 MHz.

The results will be analyzed using the existing theories of dielectrics and thermal conductivity. This will help to understand the dielectric and thermal behaviour of Sundari wood. This understanding of the property of Sundari wood will give a direction for different application.

## **Chapter II      STRUCTURE AND PROPERTIES OF WOOD**

- 2.1      Sundari Wood
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  - 2.7.3    Water seasoning
- 2.8      Uses of Timber

## **Chapter II**

### **Structure and Properties of Wood**

#### **2.1 Sundari wood**

Many varieties of wood are available in Bangladesh. But this research work is about wood, whose local name is Sundari and scientific name is *Heritiera fomes*.

Sundari tree is very strong and most abundant timber resource of the Sundarbans. It is believed that the word Sundarbans comes from Sundari Ban, which literally means, Sundari (Forest).

About 90% of Sundari timber and about in dbh or found in the Sundari timber production areas which exclude the wild life sanctuaries and compartment 41 and above. For Sundari 20 cm and above the SP as account for 92% of the growing stock. The structure and ray cells are made of any other wood is called grain. The grain of Sundari wood is so constructive. The color of this wood is brown and gray. It is difficult of work with and does not take good polish.

The ODA inventory of (1983-84) cites that Sundari 15<sup>+</sup> cm dbh was 7.52 million cubic meters and for Sundari 20<sup>+</sup> cm 4.93 million cubic meters. The inventory of 1995 cites that Sundari 15<sup>+</sup> cm dbh 6.99 million cubic meters and 20<sup>+</sup> cm dbh is 4.77 million cubic meters.

Assuming that the result of the two inventories are comparable, there appears to be a considerable decline in Sundari inventory especially at this 15<sup>+</sup> cm dbh classes. The immediate implication of these figures is that removals, both official and unofficial, over the 13 years span between inventories had been set much higher than the capacity of the forest to regenerate itself. However these rough figures are at best, an indication of

the magnitude of the Sundari timber resource problem. Without invoking volume discrepancies, a more valid comparison could be made on the number of trees at minimum diameters. A comparison was made among the 3 inventories Forestall, ODA, and FRMP, as shown in the following table:

<b>10 cm and up</b>		<b>15 cm and up</b>	
Forestall	1959	511	511
ODA	1983	296	125
FRMP	1996	295	102

For Sundari and above in dbh the reduction in the number of trees between the forestall and ODA inventories is 42%. Between the ODA and FRMP inventories, there is no further reduction. For Sundari trees 15 cm and above in dbh, the picture is more alarming. The annual reduction over the 37 years between the Forestall and FRMP inventories is 2.95 trees per hectare per year.

The moratorium on felling timber from the material reserved forests went into effect starting 1990. Since then, with the exception of Gewa, felling of timber from the sundarbans was limited to salvage felling of top-dying Sundari trees. The other major source of removals of Sundari is other use by fishermen as anchor posts for their boats. According to the 1995-97 records of FD, there were 28,500 boats registered in the Sundarbans, more than 25,000 of which consist of small country boats used by small fishermen and the rest are bigger boats used to load Gorman, Globate, hooey, and other heavier Congo. Salvaged Sundari poles are sold at auctions in timber depots all over the Sundarbans, but it is largely assumed that fishermen, for convenience, liberally obtain Sundari posts for their boat use. It is not possible to estimate with confidence the amount of Sundari used by fishermen, but rough estimates place this source of amount of depletion at not more than 20% of

increment. Timber smuggling is also a major source of drawn, confiscations of illegal timber regularly occur, but the exact extent of the problem is not known.

Die-back of Sundari is an environmental phenomenon that was observed as early as the thirties. There had been several hypothesis about the causation of top-dying but until now, there appears to be no final arrangement, therefore, no solution to the problem. For a while it was believe that water salinity encroachment is the major cause. These occur as India withdraws fresh water from the Ganges. However, previous studies have so far failed to establish the direct linkage. Other believe it is caused by disease causing organize and insects have been found infecting TDS trees. The hypothesis that it is the combination of several factors. Such as rapid increase in salinity and rapid deposition of sediment burying the pneumatophores (the "breathing organs of Sundari") seems to be the most plausible. It further aggravated by cyclone and tidal surges or synergistically cause top-dying of Sundari. It is known that Sundari tolerates a certain level of salinity (as its range includes both medium saltwater and salt-water area). As with other living organisms, this tolerance to environmental factors is usually built into the system. However, the fact that not more than 20% of Sundari in some of the worst areas tends to discredit even this theory.

## **2.2 Properties of Wood**

Wood is the hard substance under the trees and shrubs. The outer bark (protecting the tree) is the dead corky part that varies in thickness with the kind of tree and its age. The inner bark carries the food made in the leaves down to branches, trunk and roots.

Hardwoods differ greatly from softwoods in some of their uses and properties. In general hardwood species are not only harder but also heavier and tougher than softwoods, and have a tendency to shrink more.

Hardwoods and softwoods are very similar in stiffness, which means that on a weight for weight basis the softwoods are stiffer. Hardness means that the wood is solid or firm and that the surface does not dent, scratch, or cut easily. The main disadvantage of hard woods is the difficulty of cutting them with tools. They are harder to nail and are much more likely to split.

Teak, which is a very fine furniture wood, is extremely hard and abrasive and requires machining by carbide - tipped tools. Hardness is of great value when selecting woods for flooring, fine furniture and tool handles. But the classification of woods by species into hardwoods and softwoods does not mean actual hardness. Many types of softwood cut from evergreen trees are actually harder than some hardwoods cut from broad-leaf trees.

The weight of wood is an important consideration in many types of construction. Weight is a good indicator of the relative strength of wood. A heavy piece of dry wood will be stronger than one of the same size that is light in weight like any other plant material. Wood tends to shrink as it dries and to swell as it take on moisture. Wood shrinks and swells almost twice as much in width if it is flat grained as it does if it is quarter sawed on edge grained.

Bending strength is the ability of lumber to be bent without breaking. A small increase in the height of the beam aids bending strength far more than does a similar increase in width. For example, an increase of one inch in the height of a 10 inch beam will increase its beading strength by 21 percent, whereas a similar increase in width will add only about 10 percent to the bending strength.

Stiffness is the quality that resists bending under loads. This is particularly important in house construction in selecting the correct kind and size of floor joints and standing. Height and length have great effect



on stiffness. All wood gain stiffness, when properly seasoned. Compression strength means the ability of a piece of lumber to resist being mashed or squeezed together by weight applied against its ends. A supporting post in an example of a structural member that must have good compression strength. The compressive strength of timber along the grain depends upon the structure and the moisture content of the timber.

Wood will last almost indefinitely if it is kept thoroughly dry. It will decay only when there is too much moisture present, particularly when it is in contact with the ground. Wood decays through the growth of certain fungi. A fungus however, requires warmth oxygen, food and moisture for survival unless wood has excess moisture; fungi die for lack of the water necessary for growth. The proper kiln drying of lumber kills any fungi that exist in wood. Wood can also be treated with certain preservatives to prevent from fungi developing.

Structural members of wood consist of in homogeneous material with anisotropy properties and a wide degree of variability. Anisotropy means that it should come as no surprise that dimensional changes that accompany variations in temperature, moisture and mechanical loading in wood are anisotropy. The features of wood that bring about its variable nature and its anisotropy properties can be explained by envisioning the cross- section of a tree. The basic structural element of wood, the fiber generally aligned longitudinally to the tree. In a material of this construction, the longitudinal compressive and tensile strength are expected to be high and the transverse values to be lower.

Warping is described as any variation from a true or plane surface. A warp may be a bow crook, cup or twist. Warping causes much waste of lumber in construction and manufacturing. Fasteners, including nails, are the weakest part of any construction. The resistance that wood offers to the

withdrawal of a nail is an important quality. Wood should never be nailed if the moisture content is to remain high since nails lose much of their holding power as wood dries. Wood splits as it is nailed, holding power is greatly reduced, even if the split is only a slight one.

Durability is the property of timber to remain in sound condition for a long time when exposed to the forces of nature in an exposed or underground condition. All timbers must be durable. For this the timber should be free from natural and artificial defects. The annual rings should be regular and uniform and lustrous. The timber should be well seasoned. Hardness, density, specific gravity and strength seem to have direct influence on the durability of timber.

## **2.3 Nature of Wood**

Two types Characteristics of wood :

- i) Growth characteristics
- ii) Structural characteristics

### **2.3.1 Growth characteristics**

Trees grow in all shapes and sizes and their timbers look very different. These variations are however, more or less superficial and the main differences between timbers lie in their density.

All trees are primarily divided into two groups according to their manner of growth. These are:

- (i) Exogenous trees or Exogenous.
- (ii) Endogenous trees or Endogenous.

### **2.3.1.1 Exogenous trees**

Exogenous trees increase in diameter by the annual formation between the old wood and the bark of a layer of new wood which envelops the entire living portion of the tree. They are mainly two types:

- (a) Conifers (needle leaved trees) and
- (b) Broad leaved trees

Conifers form a portion of important timber trees, comprising principally the pines, fir, kail, cedar, chir and deodar. They are usually light and soft, and hence, often called "soft woods". Timbers from conifers are used mainly for sport goods, furniture, interior finishing and cabinet works.

Broad leaved trees comprise many varieties of teak Sundari, (segun), sal, gorjan, shisam, Sundari, Jarul, mango, mahogany and many other species of lesser commercial importance. They are usually heavy and hard, strong, flexible and capable of resisting tensile, compressive and shear stresses quite well, hence often called "hardwoods". Most of the timber used by Engineers in engineering constructions is derived from deciduous trees.

### **2.3.1.2 Endogenous Trees**

This group is confined largely to tropical and semitropical regions like Bangladesh, India, Myanmar, etc. The main endogenous are palms, coconut, betel-nut, bamboo and cane. The palms, coconut, betel-nut and date trees are locally used for making piles, battens, posts etc. and also used as fuel but have practically no other commercial uses.

### 2.3.2. Structural Characteristics of Wood

Wood may be considered to be made up of two chief structural elements, cells and vessels. The elemental cells are technically subdivided as tracheas, wood fibers, modularly rays and parenchyma. Although there is considerable difference in form and functions between these various sub-divisions, such distinctions are beyond the scope of this discussion and all these elements will be here referred to simply as cells. In cross-section these cells- are roughly polygonal and most commonly appear to be rectangular with rounded corners. The cells are formed of organic tissues with a cavity and a nucleus in it. The nucleus forms the living part of cell and constitutes what is termed as protoplasm.

In most timber, a very large proportion of these cells will be formed with the longitudinal axes approximately parallel to the trunk of the tree. These are termed as vertical cells or fiber cells. These vertical cells are crossed in a radial direction by a different class of cells called radial cells or medullar rays, extending from the centre of the trunk to the outside. The modularly rays maintain communication between the interior and the outside in transmission and storage of food and other materials. There are other types of cells also which act as storages for gums and resins. In a combination they act as inter-cellular canals and ducts in which these substances are deposited. They run both vertically and radially.

Cell walls consist essentially of cellulose in the form of fibrils which are long spiral strands; some lignin is also present. The walls are anisotropic but are cemented together by a layer of isotropic substance, essentially lignin, called the middle lamina.

From the engineering point of view, however all woods may be considered as bundles of parallel tubes, rather like bundles of drinking

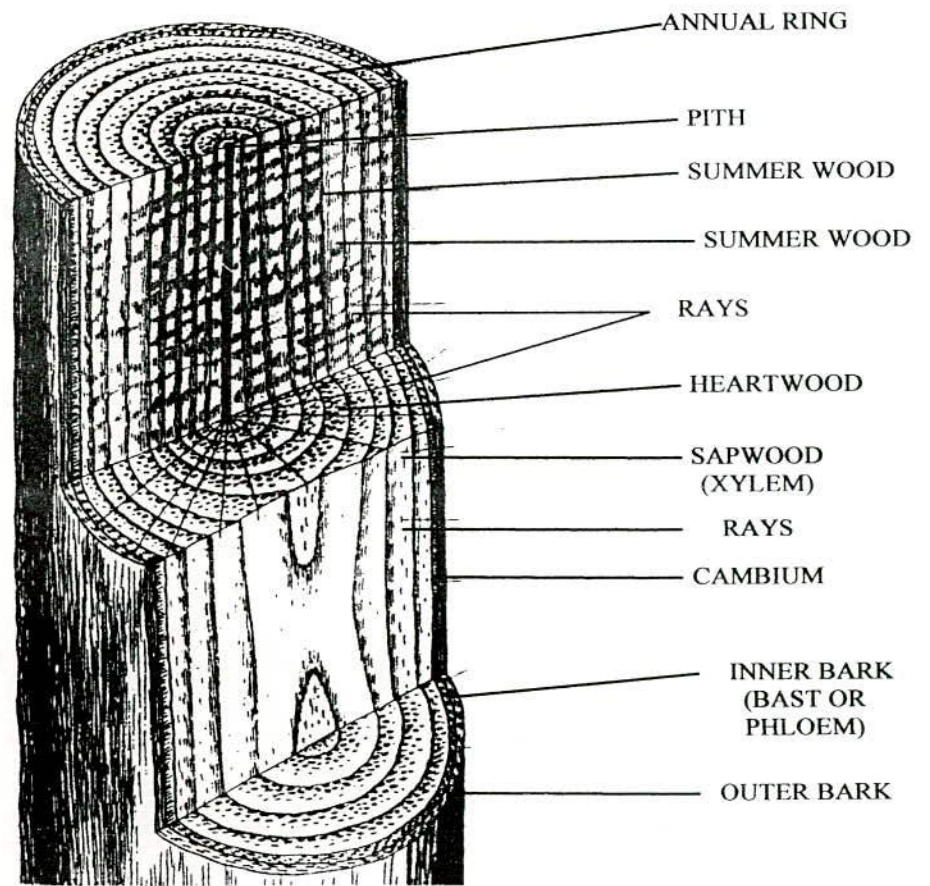
straws. Since the tubes are made of substantially the same materials the large range of density is caused by the various thicknesses of the cell walls.

Structural members of wood consist of a non homogeneous material with anisotropic properties and a wide degree of variability. The features of wood that bring about its variable nature and its anisotropic properties can be explained by envisioning the cross section of a tree. Starting at the center, the tree grows outward, adding a growth-ring each year. The growing is usually component of two types of cells, spring wood formed in period of fast growth and summer wood formed during the period of slow growth.

#### **2.4. Annual Growth Rings**

Cross section of a tree shown in fig-2.1. The cause of shrinking is the contraction of the cell walls due to the drying. More will be said about this in the unit on seasoning woods.

Between the bark and the wood itself is a layer of thin, living cells called cambium, in which the growth in thickness of the bark and wood develops by cell division. Wood that is already formed does not grow either in diameter or in length. New growth always takes place by the addition of new cells, mostly in the spring and summer months. It is this growth that produces well marked annual growth rings. As a matter of fact, the age of a tree can be determined by counting the number of these rings. As the tree grows larger diameter, the bark is pushed outward. This causes the bark layers to stretch, crack and become rigid. In some kinds of trees, there is a great difference in the wood formed early and that formed later in the growing season; the result is very pronounced annual growth ring shown in fig 2.2.



**Fig-2.1:** Cross section of a tree.



**Fig- 2.2:** Cross Section of a log showing the annual growth rings. Each light ring is spring wood each dark ring summer wood.

### **2.4.1 Spring and Summer Wood**

Growth rings in trees are made up of spring wood and summer wood. The portion formed easily in the growing season is called spring wood and that which is formed later is called summer wood. Spring wood has larger cavities and thinner walls. In some woods the change from spring wood to summer wood may be gradual while in others it is abrupt. It depends on the kind of wood and the growing conditions when the wood is formed.

The growth of all exogenous trees is a process of formation of new wood fiber between the old wood and the inner bark. Owing to the inability of trees to sustain their physiological activities indefinitely and the effect of the alternation of seasons in all temperate zones, the growth is intermittent, and the zones (rings) of growth in general correspond to the annual rings. The succeeding rings of growth may easily be distinguished from one another in most species because of the different structure of the wood, formed rapidly in the spring and that formed more slowly in the summer. No wood is added during the winter months. The rate of growth of trees is quite variable, not only in different species, but even for different specimens of the same species. This means that the growth rings are of variable thickness.

### **2.4.2 Sapwood and Heartwood**

The living elements of the tree are called "sapwood" and the dead element of the tree is called heartwood. All young trees show a higher percentage of sapwood than old trees of the same species. The proportion of sapwood in general varies from 20 to 60 percent of the total contents of wood.

The distinction in colour between sapwood and heartwood, which is the characteristic of most woods, is due to the darkening of the deadwood by the presence of infiltrated pigments, gums, resins, tannins, latex etc. Sapwood is rich in plant food material Such as sugars, starch and albumen, which is in a putrescible form and sets up decay in wood by the process of fermentation.

Sapwood contains proportionately higher percentage of moisture than heartwood and this has an effect in reducing its strength and durability. Generally heartwood is darker in colour, has more compact annual rings, is denser and more close grained in texture than sapwood.

The cells of heartwood have stronger cell walls and contain substances like tannins, resins, gums and latex which are poisonous to fungus and other insects. These materials impart natural immunity and durability of heartwood. Heartwood is heavier and less permeable to moisture than sapwood. In general, the heartwood is more highly valued than the sapwood of the same variety. This is because the heartwood offers greater resistance to decay than the sapwood.

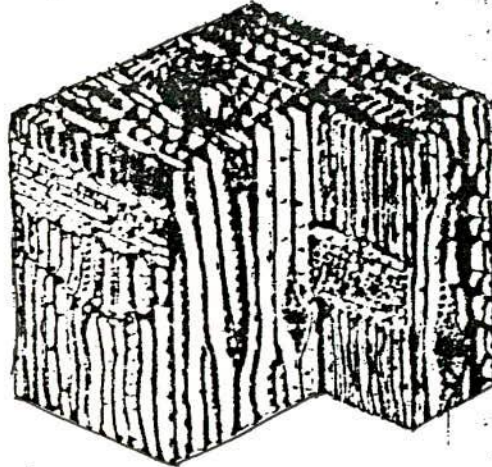
Living sapwood cells consists of enclosed cell wall and a cavity filled with protoplasm. Protoplasm is a liquid which is the physical basis of life. It is the living substance of all plant and animal cells. Heartwood cell do not contain protoplasm, therefore they do not contribute to the growth of the tree. Most of the cells are arranged in a vertical fashion, which gives wood its straight grain.

Sapwood are to help conduct sap and to store food for trees growth. Heartwood is made up of inactive cells that have already performed their functions for sap conduction and other life processes of the tree. There is no great difference in weight and strength between heartwood and sapwood when both are dry.



## 2.5 Cell Structure

Like all other plant and animal tissues, wood is composed of cells. Living units shown in fig- 2.3. Look at a piece of wood through microscopes that it's made up of long narrow tubes or cells.



**Fig-2.3:** An enlarged view of a tiny piece of wood, showing the tube structure

Fig-2.4 shows the larger ones are known as tracheids (windpipes). Greatly magnified these would appear as long hollow cigars. These cells are relatively larger in hard woods, causing open or rather porous grain. They are tightly grown together and, in cross section, have the appearance of a honey comb. In living sapwood these cells consist of an enclosed cell wall and a cavity filled with protoplasm. Protoplasm is a liquid which is the physical basis of life. It is the living substance of all plant and animal cells. Heart wood cells do not contain protoplasm; therefore they do not contribute to the growth of the tree. Mixed with the cells and running at right angles from the pitch center toward the bark are the cells known as modularly rays, mentioned in the previous paragraph. These ray cells have important functions in the growth of the trees, the most important is to carry food back and forth cross the layers of cell tubes between the cambium layer and the food storage cells in the sapwood. Food storage cells are generally arranged in the medullar rays. They store plant food between growing seasons. The walls of wood cells are in turn composed of

smaller spiral walls. These smaller fibers or tubes are known as fibrils. A fibril is a small, very slender fiber or one of the hairs of the tree. Fibrils are made up of even smaller units known as microfibrils.

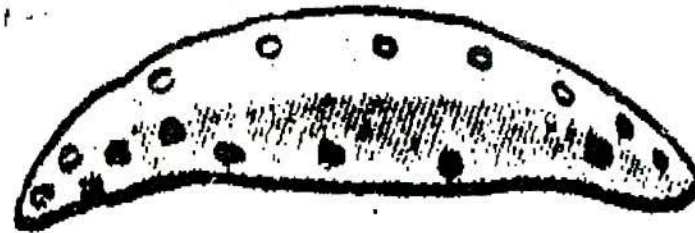


Fig-2.4: Enlarged view of a wood cell.

**Fig- 2.5** shows water exists in green wood in two conditions: as free water in the cell cavities and as water absorbed in the cell wall. The water in the cell walls is known as hygroscopic water. Wood can absorb and retain within itself a certain amount of this type of moisture and can actually pick it up from the surrounding atmosphere. Therefore, the amount of water within the cells, even of seasoned wood, depends on the relative humidity of the area to which the piece is exposed.

The amount of water also depends to some extent on whether the wood is sapwood or heartwood. At the same humidity, sapwood usually has a higher moisture content than does heartwood. Since free water dries out first, shrinkage does not begin until the fiber saturation point is reached. This point varies from about 23 to 30 percent moisture content. When a piece of wood is exposed to air, evaporation takes place and continues until there is a balance between the water in the wood and the moisture in the air. After the fiber saturation point has been reached, the cell walls begin to give up their moisture.

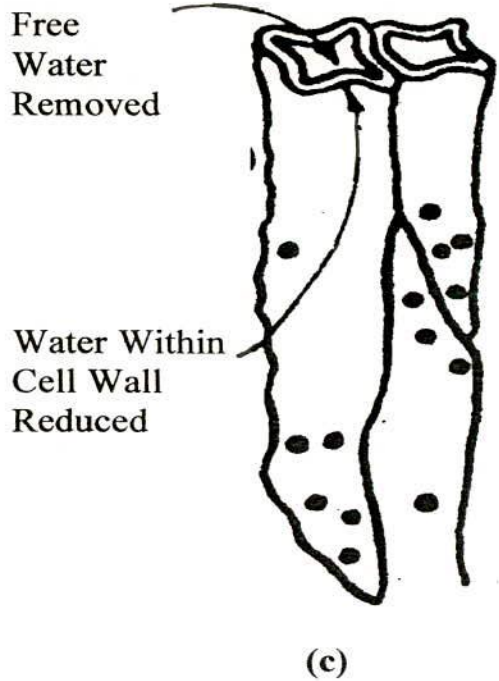
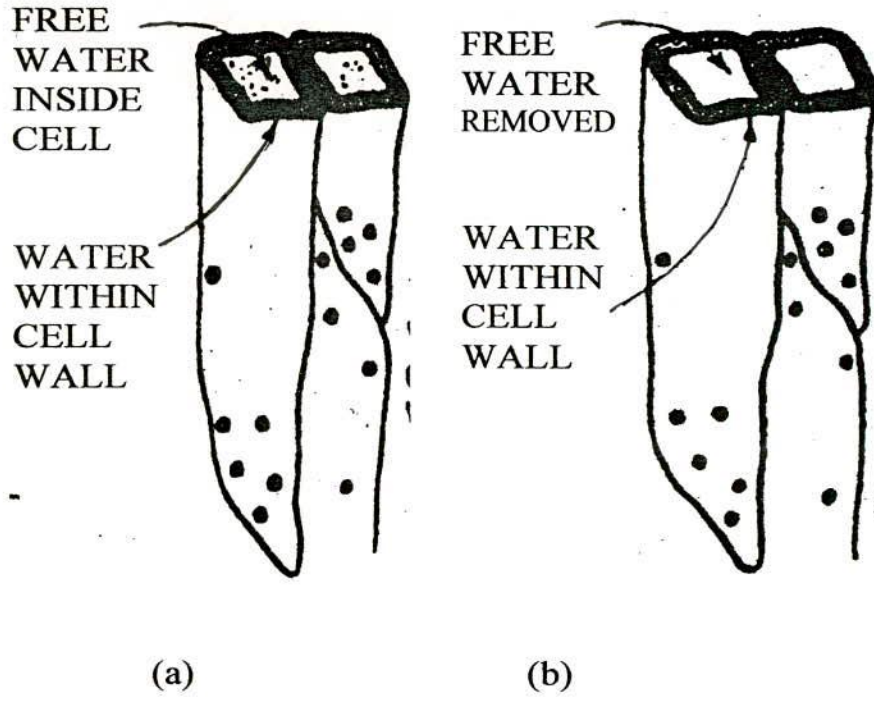


Fig-2.5: How wood cells charge as water is removed (a) Green wood (b) Fiber saturation point (c) Kiln dried.

## 2.6 Chemical Composition of Wood

Wood is an extremely heterogeneous material and it is not surprising that its chemical composition anatomy and physical properties vary within wide limits. Within each tree, the roots stem and branches may differ in chemical composition and in the stemwood there are variations with the height above the ground and with the distance from the pith.

The chemical composition of the wall is not the same for the tracheids and the ray cells in the softwoods and this also applies to the fibers, vessels and ray cells in the hardwoods. The middle lamella, the primary wall and the secondary wall do not have the same composition.

Wood is a composite material consisting of three major polymers.

- (i) Cellulose
- (ii) Hemi cellulose
- (iii) Lignin

Wood is natural polymeric composite. The principal polymeric molecules are those of cellulose shown in fig.-2.6.

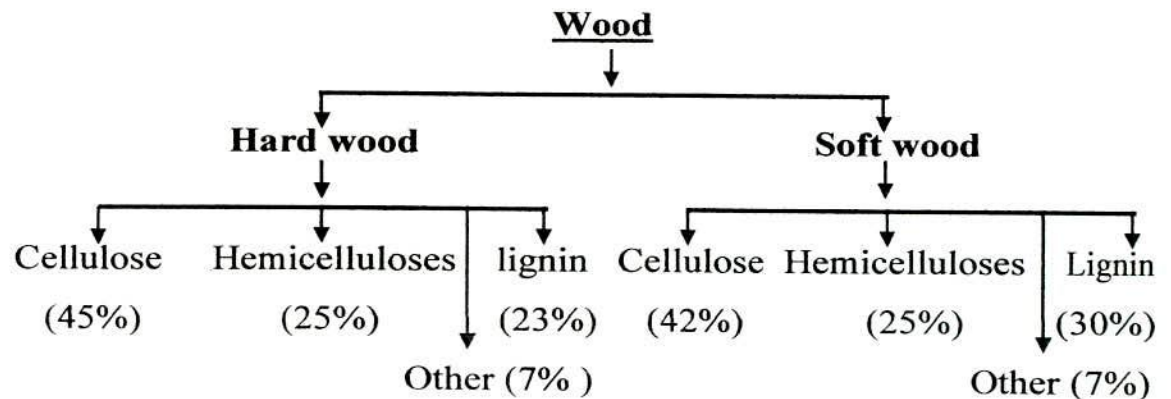


Fig.2.6: Flowchart of Wood

## 2.6.1 Cellulose

Cellulose is the most abundant organic chemical on earth. It is estimated that about 50 billion tones of cellulose are produced every year in nature. Wherever it occurs,, cellulose is present in a fibrillar form.

Cellulose is a 1,4-linked glucan consisting of B -D glucopyranose residues in the chair conformation, linked together by glycoside bonds between C - 1 in one unit and C - 4 in the next to form long, linear chains. Every glucose residue is turned over 180" with respect to its neighbors. Shown in fig-2.7.

The cellulose present in the secondary wall of wood cells has a degree of polymerization of 10,000. There are indications that this cellulose is monodisperses, that is it consists of chair molecules of the same size.

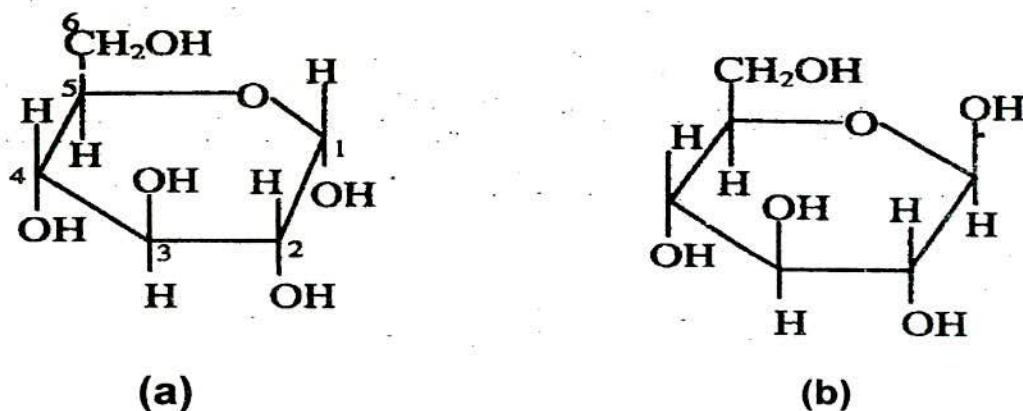


Fig-2.7(a)  $\alpha$ -D-glucose and (b)  $\beta$ -D- glucose

All cellulose fibers are partly crystalline to the extent of 50 - 60% in wood. Cellulose can occur, in two major and two minor crystallographic forms as shown in the fig-2.8.

- (i) In cellulose 1, the modification in which cellulose is found through out nature, the chains are all oriented in the same direction (Parallel). They are bound together by strong hydrogen bonds in one of the two

transverse directions but by only weak forces in the second. In addition, there are hydrogen bonds between adjacent glucose residues within each chain. Crystalline, native cellulose has a rigid structure, which are both a chain lattice and a layer lattice impermeable to water.

- (ii) Cellulose is formed when the lattice of cellulose I is destroyed either by swelling with strong alkali or by dissolution. It is thermodynamically more stable of the two modifications. In cellulose the chains are anti parallel and there are hydrogen bonds between the chains not only within each layer but also between the layers.

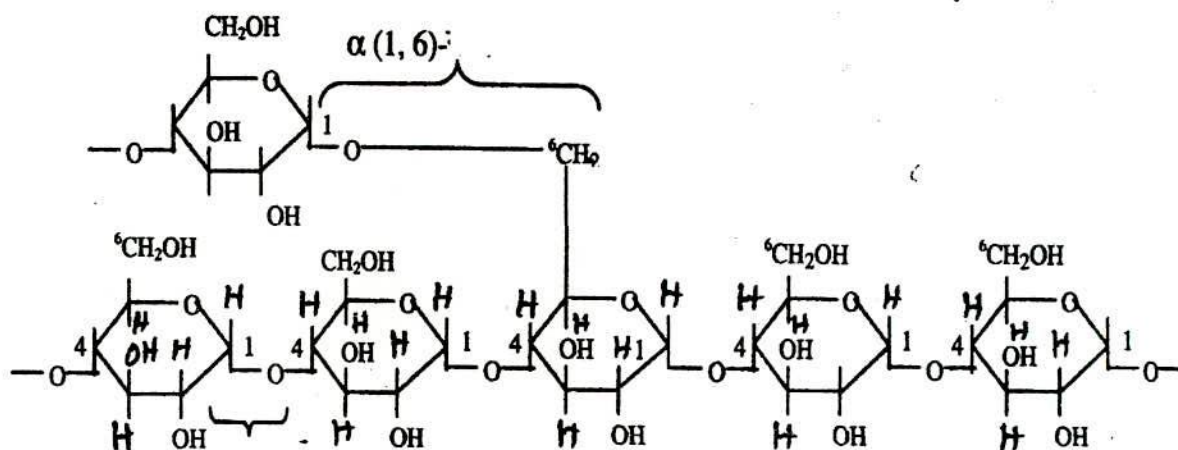


Fig-2.8: **Starch forms of wood**

### 2.6.2 Hemicelluloses

The hemicelluloses are linear polysaccharides of moderate size that are invariably associated with cellulose and lignin in plant cell walls. Pectin is a large, acidic and branched polysaccharide with 1, 4 - linked  $\alpha$ - D galacturonic acid residue as a major constituent. In wood, it is present only in the primary wall.

Some of the hemicelluloses can be isolated directly from wood by extraction with aqueous alkali, while others require prior removal of the lignin. The predominant hemicelluloses in hardwood is an acidic xylan. The xylan content can reach 35%, but in most species  $25 \pm 5$  %. Hardwood xylans consist of a main chain 1-4 linked  $\beta$ -D xylopyranan residues some of which carry a single terminal O - methyl  $\alpha$ -D glucuronic acid unit attached to. These side chains are distributed at random also the xylan backbone. Most hardwood species have on average one side chain per ten xylose residues. Hardwood xylans have a DP of 200 and are amorphous in their native state, although they can be induced to crystallize after the acetyl and some of the acid side chains have been removed. There is strong evidence that the xylan chains have orientation parallel to the chains of cellulose.

### 2.6.3 Lignin

Lignin is a three-dimensional polymer composed of phenylpropane units that encrusts the intercellular space and the cell wall after the polysaccharides have been formed. Its function in wood is to cement the cells together and to impart strength to their wall. Lignin is best isolated by extraction with organic solvents of finely ground wood, preferably after pretreatment with polysaccharide-degrading enzymes. Almost all softwoods contain a guaiacyl lignin with only one methoxyl group while hardwoods have a guaiacyl lignin with one or two methoxyl groups.

The molecular weight of lignin is indeterminate. Lignosulfonates obtained in sulfite pulping process can have a molecular weight of  $10^6$  or higher. While cellulose imparts tensile strength to wood, lignin is partly responsible for compressive strength. It also offers a certain protection against microbial attack.

Lignin, the "wood glue" that holds the other materials together, can be converted into vanillin or into a chemical material used in foundry molds. It can be made into tanning agents for leather, or used for many other purposes.

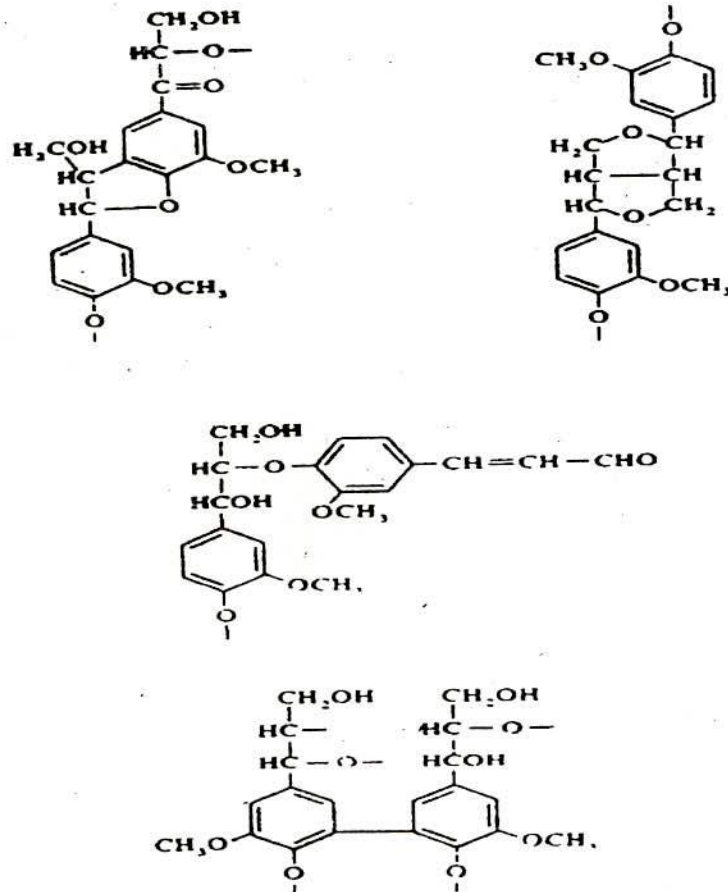


Fig--2.9

## 2.7 Seasoning

The amount of moisture in lumber is an important factor in its usability. Because of the change in size of wood cells, lumber shrinks as it dries and swells as moisture is added. If lumber holds too much moisture



(over 20%) over an extended period of time, pangs may develop which will cause the wood to deteriorate.

Moisture in green wood exists in two conditions, as free water in the cell cavities, and as water absorbed in the cell walls. When all of the free water is removed and the wood contains just enough water to saturate and the cell walls, it is said to be at fiber saturation point. The removal of free water has little effect upon the properties of wood except to reduce its weight. However, as water in the cell walls evaporates, the walls contract and wood begins to shrink. Free water removed first therefore shrinkage does not really begin until the fiber saturation point has been reached. At the fiber saturation point, wood has approximately 23 to 30 percent moisture content.

Three principal methods of seasoning of timber are follows:-

- i) Natural or Air seasoning
- ii) Artificial Seasoning
- iii) Water Seasoning

### **2.7.1 Natural or Air seasoning**

This process of seasoning is also known as air drying. The natural seasoning is done by a long outdoor exposure of timber to the action of the air. The timbers are stacked in a dry elevated platform which is covered by a temporary shed to protect timbers from the action of rain. Sometimes, permanent shed is also corrected for the same. Timber is generally turned frequently to ensure equal drying all rounds, because irregular drying causes splits and cracks. This is a very slow process and the time required varies from 2 to 3 years to remove the moisture by evaporation to the desired extent. This method is commonly employed all over Bangladesh.

## **2.7.2 Artificial Seasoning**

The drying of timber by exposure for a limited period to high temperatures in a closed chamber or by applying chemicals, steam and smoke is termed as artificial seasoning. The following are the various methods of artificial seasoning.

- (a) Kiln Seasoning
- (b) Chemical Seasoning
- (c) Electrical Seasoning
- (b) Steaming
- (e) Boiling
- (f) Smoke Seasoning

### **2.7.2.1 Kiln Seasoning**

Two types of kilns are available for artificial seasoning:

- (i) Compartment Kiln in which the conditions of temperature and humidity are changed as the drying progress, the timber being stacked in the compartment and
- (ii) Progressive Kiln in which a low temperature with high humidity condition is maintained at the entering end of the kiln and a high temperature with low humidity condition at exit end, timber being moved periodically through the kiln.

Both types of Kiln may have either natural or forced air circulation. The advantages of forced circulation of air are accurate control of humidity and faster drying without any danger to the timber.

In kiln seasoning, temperatures  $70^{\circ}\text{C}$  to  $82^{\circ}\text{C}$  are usually employed. Soft woods generally require 4 to 6 days for 1 to 2 inch planks (boards).

Hard woods (first air seasoned for 3 to 6 months to allow the first shrinkage take place more gradually and are then exposed to above temperatures in the Kiln) require 6 to 12 days for 1 to 2<sup>1</sup>/<sub>2</sub> inch boards. This method is used in Bangladesh.

#### **2.7.2.2 Chemical Seasoning**

This is also known as salt seasoning. In this method, timber is first soaked in an aqueous solution of a suitable chemical salt (usually, solution of urea) before it is passed through the process of kiln seasoning. The vapor pressure of the salt solution is less and therefore, the interior moisture of the timber is drawn out. The drying of interior moisture of the timber is, drawn out. The drying of timber from the center to the surface is at a uniform rate. The drying process is also accelerated. The most commonly used chemical is urea. It is a very good dehydrating agent and does not cause any harm to the seasoned timber. This method is not generally used in our country.

#### **2.7.2.3 Electrical Seasoning**

In this process, high frequency alternating currents are passed through timber in a closed chamber and the resistance caused by the passage of the currents produces heat which dries the timber. Electrical seasoning is generally preceded by air drying. This is a quick process of seasoning but is not used in our country.

#### **2.7.2.4 Steaming**

In this process, steam is passed through the stacked timber in a closed chamber and thereafter timber is dried gradually in natural air. The

steam is usually passed for 4 to 6 hours. This is a quick method but it reduces the plasticity and strength of timber. This method is used in certain parts of our country.

### 2.7.2.5 Boiling

In this process, the timber is immersed in boiling water for accretion period of time. Thereafter, the timber is dried slowly by natural air. This is also a quick process but it also reduces elasticity and strength of timber. This method is very rarely used in Bangladesh.

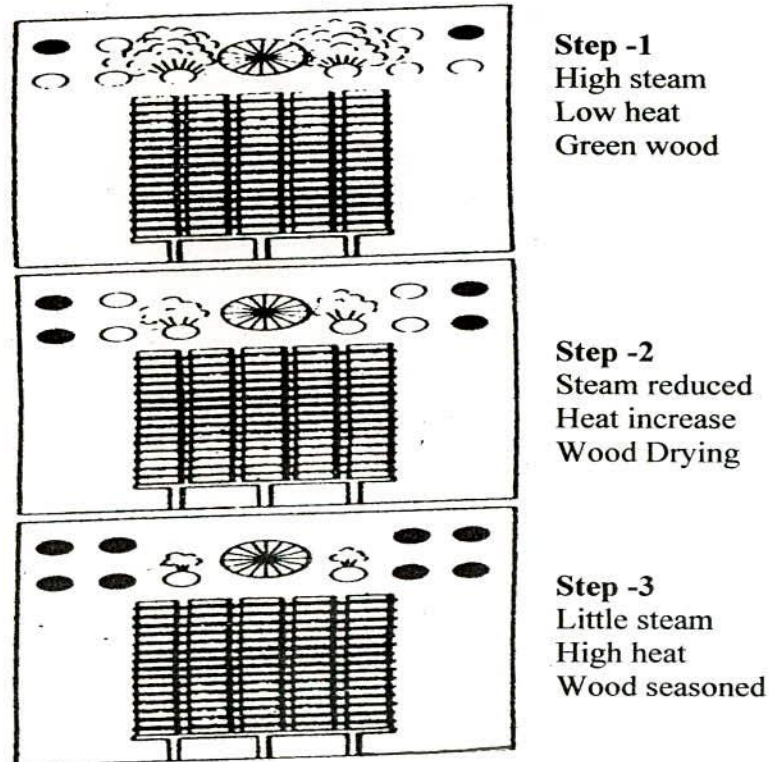


Fig 2.10 Kiln drying

### 2.7.2.6 Smoke Seasoning

This is a very old practice of drying timber in smoke heat over a fire of straw, sawdust and wood savings. This method is claimed to be efficient

to make timber more durable and resistant to decaying agents. Heat is gradually applied to prevent splitting and warping. This method is very frequently used in Bangladesh in boat-making industries.

### 2.7.3 Water Seasoning

In this process, timber and logs are immersed and allowed to remain in water for a couple of days, therefore they are dried by in natural air. In this process, the sap is dilated and is partly removed. This reduces the possibilities of decay and increases the durability of timber. Water seasoned timber also dries more quickly. This process of seasoning is good for timber containing a lot of sap, but it reduces the strength of timber to some extent. This method is commonly used all over Bangladesh.

## 2.8 Uses of Timber

The following are the various uses of timber

### i) Permanent structural works:

Timbers used in permanent structural works are mainly of two types:

- (a) Light structural members and
- (b) Heavy structural members.

### (a) Light structural members :

Beams, post, roof trusses, floor boards, door and window fame's, and battens, railway sleepers, bridge floorings, electric poles, fencing poles, poles for transmission lines, gates, ratings, etc.

### (b) Heavy structural members:

- i) Piles, bridge piers, jetty- foundation and superstructure, wood stoves, stairs, etc.
- ii) **Furniture works :**  
Chair, tables, almirah, sofa-set, dressing tables, cup boards, cots, beds, etc.
- iii) **Transportation works:**  
For making country boats, launches, speed boats, ship, body frames of railway coaches, omnibuses and air crafts, body farms of railway coaches, omnibuses and air crafts. For making jetties and landing platforms.-Also used for making cart-wheels.
- iv) **Temporary works during construction:**  
Scaffolding and general centering works of all types in R.C.C construction works. For providing shoring and strutting to support the sides of soft soil excavation. Timber is used for making packing boxes and pattern making in foundry castings.
- v) **Commercial uses :**  
Timber is used for manufacturing sport-goods, toys, and for making veneers which are used in manufacturing plywood, batten boards, laminated boards etc. and reconstructed wooden boards like insulating boards, hardboard, fiber boards, particle boards, linoleum etc.
- vi) **Industrial uses:**  
Wood is used for the manufacture of matches, paper, newsprint, card-boards, well-papers, artificial synthetic fiber, roofing felt, preservative etc.

## **Chapter - III            THEORETICAL ASPECTS**

- 3.1    Moisture Gradient Measuring Method
- 3.2    Moisture Content, Relative Humidity, and Temperature
  - 3.2.1    Electric resistance and Moisture Content
  - 3.2.2    Electric resistance and temperature
  - 3.2.3    Electric resistance, moisture constant and temperature
- 3.3    Dielectric Constant
- 3.4    Dynamic Dielectric Permittivity of Wood
  - 3.4.1    Influence of tree species on permittivity
  - 3.4.2    Influence of bulk density on permittivity
  - 3.4.3    Influence of moisture content on permittivity
  - 3.4.4    Influence of temperature on permittivity
- 3.5    DC Low-Field Conduction Phenomena
- 3.6    Alternative Current Behavior Conduction Phenomena
- 3.7    Theory of Thermal Conductivity

## Chapter - III

### Theoretical Aspects

#### 3.0. Moisture Gradient Measuring Method

Limited literature can be found on the research of moisture gradient measurement. The most commonly used method for measuring moisture gradient in wood is the band saw slicing technique presented by McMillan. But this traditional technique is bound to cause inherent errors in the results of moisture gradient measured in wood because:

- i) Moisture is lost due to the high temperature effect when cutting each slice
- ii) Moisture is lost between cutting and weighing slices due to the sensitivity of thin slices to the environment
- iii) Kerfs loss when cutting each slice

The principles of moisture movement in wood and the major factors affecting this movement. Moisture movement for the unsteady state into two periods:

- ii) The moisture gradient advanced from the surface to center of the specimen but no moisture change occurred at the center and
- iii) The moisture gradient reached at the center and kept approaching equilibrium.

An equation for calculating moisture gradient in the second period:

$$\frac{M_x - M_0}{M_a - M_0} = \text{Sin} \left\{ \left( \frac{\lambda}{2} \right) \left( \frac{x}{a} \right) \right\}, \quad (3.1)$$



where  $M_x$  is the moisture content at depth  $x$ ,  
 $M_a$  is the moisture content at the center (depth  $a$ ),  
and  $M_o$  is the equilibrium moisture content on the surface of wood.

Found that the moisture gradient was concentrated in the outer 2mm to 6mm of the wood slice during that period of drying, then focused on studying drying stresses as a result of moisture gradient in the wood.

A numerical analysis technique to evaluate the moisture dependent diffusion coefficient using drying curves, which give an accurate prediction of moisture movement through the entire drying process.

The three level finite difference scheme as follows to get the moisture profile in wood during drying.

$$\begin{aligned} [M_{t+1,j} - m_{t,j}] = & \frac{2}{3} \rho \{ D_1 [(m_{t+1,j+1} - m_{t,j+1}) + (m_{t,j+1} - m_{t,j}) + (m_{t,j} - m_{t,j-1})] \} \\ & - \{ D_2 [(m_{t+1,j} - m_{t+1,j-1}) + (m_{t,j} - m_{t,j-1}) + (m_{t-1,j} - m_{t-1,j-1})] \} \end{aligned} \quad (3.2)$$

$$\text{Where } \rho = \frac{\Delta t}{(\Delta x)^2} \quad (3.3)$$

$m$  is the fractural moisture based on the oven-dry weight,  $t$  is the drying time and  $x$  is along the thickness of the sample, and  $i, j$  refer to the location of  $m$  along the  $t$  and  $x$  co-ordinates.  $\Delta t$  and  $\Delta x$  were 0.01 hours and  $\left(\frac{1}{10}\right)$ th of the sample half-thickness.

$$D_1 = a_0 + a_1 \left[ \frac{m_{i,j-1} + m_{i,j}}{2} \right] \quad (3.4)$$

$$D_2 = a_0 + a_1 \left[ \frac{m_{i,j} + m_{i,j-1}}{2} \right] \quad (3.5)$$

for the surface moisture content

$$M_s = M_e + [M_i - M_e]e^{-\beta t}, \quad (3.6)$$

where  $M_e$  is the equilibrium moisture content  $M_i$  is the initial moisture content.

After the constants  $a_0$ ,  $a_1$ ,  $\beta$  are determined, a theoretical drying curve can be generated. By comparing the theoretical moisture content profile with the practical one deriving from the experiment data with the traditional slicing technique for measuring moisture content profile during drying, the optimum parameter values could be found if they would yield the minimum absolute value of Negative Mean Sum of Squares (NMSS).

$$NMSS = \frac{\sum(\Delta m^2)}{N} \quad (3.7)$$

Here  $\Delta m$  and  $N$  represent the difference  $m$  between the theoretical drying curve and the experimental data, and the number of data points, respectively.

### 3.2 Moisture Content, Relative Humidity, and Temperature

The relationship between Relative humidity (RH) Moisture Content (MC) and wood equilibrium MC over the range of 55 to 90% RH at 300 and 272 K were taken from Table 3-4 of the wood handbook <sup>(66)</sup>. Although a complex polynomial equation containing terms for temperature and MC more accurately describes this relationship, it can be adequately approximated at a given temperature by the equation.

$$\Phi = A + B \ln(M), \quad (3.8)$$

where  $\Phi$  - RH (%), M is wood MC (%), A is a constant or offset and B is a proportionality constant or coefficient.

### 3.2.1 Electrical Resistance and Moisture Content

In the hygroscopic range and at a constant temperature, an approximately inverse linear relationship exists between the logarithm of the DC resistivity of wood and the logarithm of its MC<sup>(67)</sup>. This relationship is the basis for determining wood MC with DC resistance measurements. For a wood specimen of given size and grain orientation, the relationship may be expressed as

$$\ln(R) = K_m \ln(M) + C_1, \quad (3.9)$$

where R is the specimen resistance, M is the specimen MC(%),  $K_m$  is a proportionality constant or co-efficient and  $C_1$  is a constant. The coefficient  $K_m$  is negative and virtually constant among wood species.

### 3.2.2 Electrical Resistance and Temperature

At a given MC in the hygroscopic range, an approximately exponential relationship exists between wood resistivity and temperature. For a wood specimen of given size and grain orientation, this relationship may be expressed as

$$\ln(R) = K_T T + C_2, \quad (3.10)$$

where R is the specimen resistance, T is the temperature,  $K_T$  is the proportionality constant or co-efficient and  $C_2$  is a constant. The coefficient  $K_T$  is negative. The value of  $K_T$  is essentially independent of wood species<sup>(68)</sup>.

### 3.2.3 Electrical Resistance, Moisture content and Temperature

The relationship between the resistance of a wood specimen of given dimensions and its MC and temperature can be derived from eq<sup>n</sup> (3.9) and eq<sup>n</sup> (3.10)

$$\ln (R) = K_m \ln (M) + K_T T + C_3, \quad (3.11)$$

which can be rearranged as

$$\ln (M) = \frac{1}{K_m} \ln (R) - \frac{K_T}{K_m} T - \frac{C_3}{K_m} \quad (3.12)$$

### 3.2.4 Electrical Resistance, Relative Humidity and Temperature

No data on this relationship is directly available in the literature. Therefore, we constructed a data set of corresponding RH, temperature and DC resistance values over the range of 55% to 90% RH at 300 K and 272K from the following Published data:

- (i)  $\frac{MC}{RH}$  data over the range of 55 to 90% RH at 300 K and 272K from provided Wood Handbook<sup>(66)</sup> with estimates of RH as a function of MC at two different temperatures
- (ii) The relationship between resistance and MC constructed from James data<sup>(67)</sup> for hard maple specimen along with the data from the wood Handbook<sup>(66)</sup>, provided with estimate of RH as a function of sensor resistance at 300 K.
- (iii) Estimates of the temperature co-efficient  $K_T$  constructed from James data<sup>(69)</sup> along with the previously mentioned data enabled us to estimate RH as a function of sensor resistance at 272K.

An approximate relationship between RH ( $\Phi$ ), resistance (R) and temperature (T) can be obtained by substituting eq<sup>n</sup> (3.12) for in (M) in eq<sup>n</sup> (3.8)

$$\Phi = a + b[\ln(R)] + (cT), \quad (3.13)$$

where a is a constant or offset and a, b and c are proportionality constants or co-efficients eq<sup>n</sup> (3.13) is an imperfect model, as the relationship between RH and the natural log of resistor M is not perfectly linear.

### 3.3 Dielectric Constant

If a given electrical voltage is impressed across a condenser in which a vacuum separates the electrodes, a certain electrical charge,  $Q_0$ , accumulates on the condenser. When the condenser is filled with substance such as wood or cellulose, some alignment of polar molecules in wood or cellulose takes place and more charges are stored in the condenser. If  $Q_w$  is the charge held by a similar condenser that is filled with a dielectric substance  $Q_w$  depends upon the properties of the dielectric substance and the ratio  $\left(\frac{Q_w}{Q_0}\right)$  is known as the dielectric constant of the material.

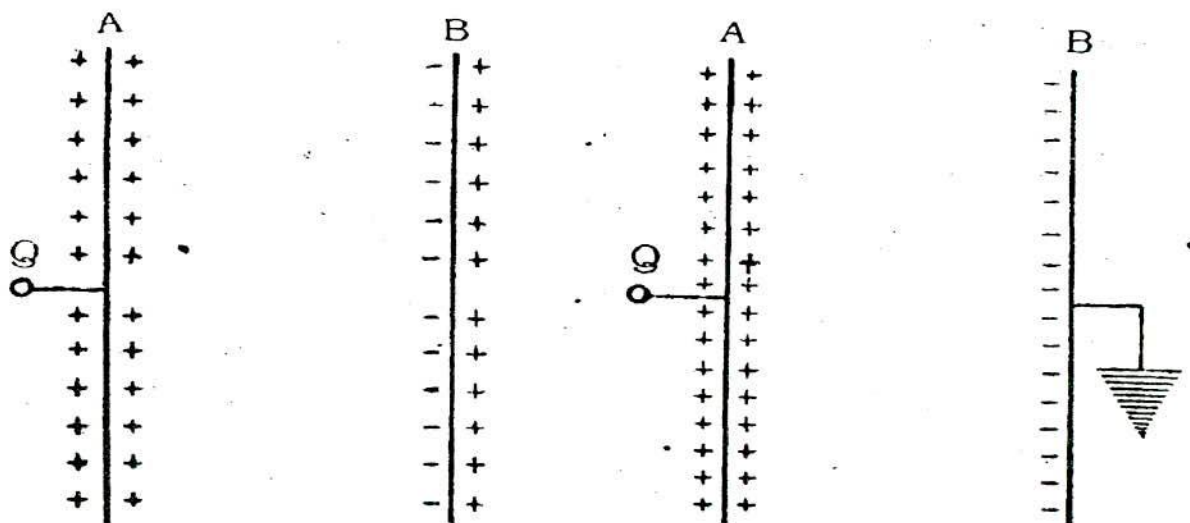


Fig-3.1 (a)

Fig- 3.1 (b)

**In fig. 3.1 (a) :** an insulating material has been placed between a set of parallel plates having a potential difference of  $V$  volts across them.

The element, constructed simply of two parallel conducting plates separated by an insulating material is called a capacitor. Expressed as an equation, the capacitance is determined by

$$C = \frac{Q}{V}, \quad (3.14)$$

where  $Q$  is the charge and  $V$  is the potential difference.

If a potential difference of  $V$  volts is applied across the two plates separated by a distance of  $d$ , the electric field strength between the plate is determined by,

$$E = \frac{V}{d} \quad (3.15)$$

Many values of capacitance can be obtained for the same set of parallel plates by the addition of certain insulating materials between the plates.

Since the material is an insulator the electrons within the insulator are unable to leave the parent atom and travel to the positive plate. The positive components (protons) and negative components (electrons) of each atom do shift however as shown in fig. 3.1 (a) to form dipoles.

When all the atoms of the insulating material become dipoles and align themselves as shown in fig. 3.1 (a), the material is polarized. The layer of positive charge on one surface and the negative charge on the other are not neutralized, however, insulating in the establishment of an electric field within the insulator shown in fig-3.1 (b). The net electric field between the plates [ $E_{\text{resultant}} = E_{\text{air}} - E_{\text{diel}}$ ] would therefore, be reduced due to the insertion of the dielectric. .

The purpose of the dielectric, therefore, is to create an electric field to oppose the electric field set up by free charges on the parallel plates.

In either case with or without the dielectric if the potential across the plates is kept constant and the distance between the plates fixed, the net electric field within the plates must remain the same, as determined by the equation  $E = \frac{V}{d}$ .

For different dielectric materials between the same two parallel plates different amounts of charge will be deposited on the plates. But  $\psi = Q$ , so the dielectric is also determining the number of flux lines  $\psi$ , between the two plates and consequently the flux density

$$D = \frac{\psi}{A}, \quad (3.16)$$

where  $A$  is a constant.

The ratio of the flux density to the electric field intensity in the dielectric is called the permittivity of the dielectric

$$\epsilon = \frac{D}{E} \text{ farad / meter} \quad (3.17)$$

For a vacuum, the value of  $\epsilon_0 = 8.854 \times 10^{-12}$  F/m. The ratio of the permittivity of any dielectric to that of a vacuum is called the relative permittivity or dielectric constant, ( $\epsilon'$ ),

$$\begin{aligned} \epsilon' &= \frac{\epsilon}{\epsilon_0} \\ \text{or, } \epsilon &= \epsilon' \epsilon_0 \end{aligned} \quad (3.18)$$

Now from equation

$$\begin{aligned} \epsilon &= \frac{D}{E} = \frac{\psi / A}{V / d} \\ \text{or, } \epsilon &= \frac{Q / A}{V / d} \\ \text{or, } \epsilon &= \frac{Qd}{VA} \end{aligned}$$

$$\text{or, } \epsilon = \frac{Cd}{A} \quad \left[ \because C = \frac{Q}{V} \right]$$

$$\text{or, } C = \frac{\epsilon A}{d} = \epsilon' \epsilon_0 \frac{A}{d} \quad (3.19)$$

where, A is the area in square meters of the plates, d is the distance between the plates and  $\epsilon'$  is the dielectric constant.

$$\text{Now, } C = \frac{\epsilon A}{d} \quad (3.20)$$

Now, the ratio,

$$\frac{C}{C_0} = \frac{\epsilon A/d}{\epsilon_0 A/d} = \frac{\epsilon}{\epsilon_0} = \epsilon'$$

$$\therefore \epsilon' = \frac{C}{C_0}$$

$$\text{Dielectric constant} = \frac{\text{Capacitance with wood.}}{\text{Capacitance without wood.}} \quad (3.21)$$

The relationship between  $\epsilon$  and C provides a method for finding the value of dielectric constant for various dielectrics.

### 3.4 Dynamic Dielectric Permittivity of Wood

The dielectric permittivity of wood is described by two quantities:

- (i) The dielectric constant  $\epsilon'$  which measures how much electric energy is stored in a volume of wood compared to a vacuum, and
- (ii) The loss factor  $\epsilon'' = \epsilon' \tan \delta$ , which measures the proportion of electric energy converted into thermal energy within a volume of wood.

These two properties may be considered as a single complex quantity, the dielectric permittivity-



$$\varepsilon = \varepsilon' - i\varepsilon'' \quad (3.22)$$

Since the scattering strength is mainly determined by the magnitude of permittivity it depends strongly on the dielectric constant ( $\varepsilon'$ ). On the other hand, the amount of energy absorbed by the wood can be shown to depend mainly on ( $\varepsilon''$ ) which is commonly called the loss factor.

Wood is an anisotropic material and three principal directions are distinguished when considering its dielectric properties, longitudinal (L), radial (R) and tangential (T) as shown in fig-3.2.

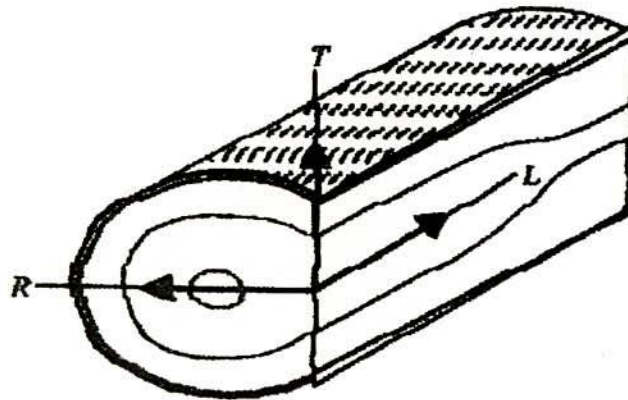


Fig. 3.2: Principal directions on a stem for dielectric properties

The dielectric permittivity in these directions are written as  $\varepsilon_L$ ,  $\varepsilon_R$  and  $\varepsilon_T$ . Since in many cases the difference between the radial and tangential directions is insignificant, the alternative designation,  $\varepsilon_L$  and  $\varepsilon_T$  may be used.

Perhaps the most well characterized dielectric properties of wood are for that of oven-dry wood. Oven-dry wood is a good starting point for considering the dielectric permittivity of wood in general. It shows many

of the general trends while the influence of moisture to be considered separately.

Over-dry wood can be considered as consisting of two components: cell wall material and air. An equation that is commonly used to express the equivalent dielectric permittivity of two component mixture is

$$\left(\varepsilon_m\right)^{1/3} = V_1\left(\varepsilon_1\right)^{1/3} + V_2\left(\varepsilon_2\right)^{1/3}, \quad (3.23)$$

where  $V_1$  and  $V_2$  are the volume fractions of each component.

As a rule  $\varepsilon_L > \varepsilon_T$  by a factor of at least 1.5, since the elongated wood cells (tracheids and fibers) are largely oriented in the longitudinal direction. This is at least partly due to polar groups of cellulose and hemicellulose having more freedom of movement along the fiber direction than in the transverse direction.

In addition to the gross structure of the wood, the anisotropy of the dielectric properties is also affected by the microstructure of the cell walls. It is well known that the dielectric properties of oven dry wood are affected by tree species, bulk density, grain orientation and temperature.

### **3.4.1 Influence of Tree species on permittivity**

The influence of tree species on dielectric permittivity is dependent on the orientation of the electric field. It has been found empirically that  $\varepsilon_L$  is influenced by tree species considerably less than  $\varepsilon_T$  tree species, virtually always a known factor in an industrial measurement scenario.

### **3.4.2 Influence of Bulk density on permittivity**

Density of wood can vary over a very wide range from  $0.13 \text{ gm/cm}^3$  (balsa) to  $1.6 \text{ gm/cm}^3$  (cell walls), and is the principal factor determining the dielectric permittivity of over-dry wood.

For wood at a given moisture content above the fiber saturation point the density has a pronounced affect on the dielectric permittivity and so on industrial measurement system has to be able to determine moisture content and density simultaneously.

### **3.4.3 Influence of Moisture content on permittivity**

The influence of moisture content on the dielectric properties of wood may be broadly considered in the following 4 (four) regions:

- (i) 0 to 5% monomolecular moisture
- (ii) 5 to 20% Adsorption moisture
- (iii) 20 to 30% capillary-condoned moisture
- (iv) > 30% free moisture.

The maximum value of the cell wall moisture content that can be achieved if wood is moistened directly in water is called the Fiber Saturation Point (FSP) and for wood species in temperate zones, is around 30% (wet basis). Moisture in wood below the FSP is largely bound and has a dielectric permittivity similar to that of ice ( $\sim 5 - i 0.2$ ). Moisture in wood above the FSP. has the dielectric permittivity of liquid water  $\sim (80 - i 20)$  and shows a significant frequency dependence. At microwaves frequency

the dielectric permittivity in the longitudinal direction of moist wood above the FSP ranges from values of  $\epsilon_L = 7.5 - i 0.25$  to  $\epsilon_L = 40 - i 10$ .

#### **3.4.4 Influence of Temperature on permittivity**

Temperature has a direct influence on the dielectric permittivity of wood for moist wood. For moist wood, this effect is large due to the temperature dependence of the dielectric properties of water. At temperature above  $0^\circ\text{C}$ , an increase in temperature causes a reduction in the relaxation time constant of the dielectric permittivity. At a given microwave frequency this has the effect of decreasing the dielectric constant and increasing the loss factor.

Below  $0^\circ\text{C}$ , moisture in wood occurs both as ice and in a nonfreezing condition. It is the ratio between these two forms that dominates the dielectric properties at negative temperatures. For industrial measurement scenarios, where the temperature of the wood will vary significantly, compensation for temperature is often required.

#### **3.5 DC Low-field Conduction phenomena**

When a constant electric field is applied to a material, the current rapidly or slowly reaches a equilibrium direct value. This current can be represented in terms of the number of charged particles present and their drift velocity and the presence of an electric field. The electric current density ( $J$ ) is defined as the charge transported through a unit area in a unit time. If the number of charge carriers of species per unit volume is  $N_i$  with a drift velocity  $V_i$  and a charge per particle is  $Z_i e$ . Where  $Z_i$  is the valence and  $e$  is the electronic charge, then the electrical current density is given by.

$$J_i = N_i Z_i e V_i \quad (3.24)$$

The electrical conductivity  $\sigma$  is defined by the general relationship

$$\sigma = \frac{J}{E} \quad (3.25)$$

Consequently,  $\sigma_i$  is defined from the relations eq<sup>n</sup> (3.24) and eq<sup>n</sup> (3.25).

$$\sigma_i = (N_i Z_i e) \frac{V_i}{E} \quad (3.26)$$

The drift velocity is directly proportional to the locally acting electric field strength and this ratio is defined as the mobility.

$$\mu_i = \frac{V_i}{E} \quad (3.27)$$

The conductivity is then the product of the concentration and mobility of charge carriers,

$$\sigma_i = (N_i Z_i e) \mu_i \quad (3.28)$$

In the case of crystalline materials in which the transport is clearly attributable to free carriers, the expression of conductivity ( $\sigma$ ) may be written in the simple form.

$$\sigma = \sum_r \sigma_r = \sum_r q_r \mu_r N_r, \quad (3.29)$$

where the saturation extends over all species  $r$  of available carriers and processes. Eq<sup>n</sup> (3.29) implies a clear distinction between the available carrier densities  $N_r$  and their mobilities. This distinction arises naturally in the case of conduction occurs by transitions from occupied to empty levels and this very fact precludes a clear distinction between the number of available carriers and their mobility.

The transition probabilities of all the localized electrons (at all energies) which correspond to mobility are partially dependent on the availability of neighbouring empty sites. The expression for conductivity in this situation is given,

$$\sigma = e N_e \mu, \quad (3.30)$$

where  $N_e$  is the effective density of localized carriers, the hopping mobility in terms of drift velocity  $V_d$  in the applied field  $E$ . This equation corresponds to conduction in localized state at the Fermi level and its representation of the causes covered by the eq<sup>n</sup> (3.28). Other processes, which may be involved are conduction in excited or extended states.

The effect of variables such as composition, structure and temperature is to change the concentration of charge carriers and their mobility for conduction. However, the temperature dependence of the direct current (D.C) conductivity  $\sigma_{DC}(T)$  under a small external applied field given information on activation energies which distinguishes between free carrier and hopping conduction<sup>(70-71)</sup>.

In the case of amorphous semiconductors and insulators the conductivity expression over the whole temperature range is expected to contain three terms; the following relation can express the temperature dependence of conductivity.

$$\sigma = C e^{-E/KT} + C_1 e^{-E_1/KT} + C_2 e^{-E_2/KT} \quad (3.31)$$

The following details may be noted :

(i) The first term is due to intrinsic behavior and the conduction is assumed to take place at the extremities of the conduction band. The value of  $C \approx 10^3$  to  $10^4 \Omega^{-1} \text{cm}^{-1}$  is expected. If this conduction for the magnitude of the first term is satisfied then one can usually. Consider  $E_A = \Delta E \leq \frac{1}{2} E_0$

where  $E_0$  is the optical gap<sup>(72)</sup>. In the case of intrinsic behavior the number of electrons,  $n$  is equal to the number of holes. This condition determine the position of Fermi level  $E_F$  in terms of the conduction and valence bands parameters, so that

$$\sigma_{\text{intrinsic}} = ce^{-\frac{E_c - E_v}{kT}} \quad (3.32)$$

In disordered materials  $n \neq p$  because of the much larger number of electrons and holes in localized tail states and gap states. So that eq<sup>n</sup> (3.32) can not be valid at low temperature. The energy separation ( $E_C - E_V$ ) between the mobility edges electrons and holes has no immediate relation with the optical gap  $E_0$ .

- (i) The second term of eq<sup>n</sup> (3.31) is due to transport by carriers excited in to the localized states at the edges of the conduction and valence band and for this  $C_1 \approx 1 \Omega^{-1} \text{ Cm}^{-1}$ .
- (ii) The last term of eq<sup>n</sup> (3.31) is due to hopping conduction by electrons with energies nears  $E_F$ . In this situation  $C_2 \ll C_1$  and  $E_2 \ll E_1$ .

At low temperature  $e^{-E_2/KT}$  is replaced by  $e^{-\frac{B}{T^{1/4}}}$ . As the temperature is lowered, the activation energy,  $\Delta E_A$  will full, i.e. the predominant hopping path in the localized state distribution moves progressively closer towards the Fermi energy and conductivity is

expressed in the form:  $\sigma \propto e^{-\frac{B}{T^{1/4}}}$ , (3.33)

where  $B$  is constant depending on the density and the degrees of localization of states through which hopping transport of carriers take

place. This is based on variable range hopping between states with energy near Fermi level.

### 3.6 Alternating Current Behavior Conduction Phenomena

The band and hopping conduction mechanism basically have different non-steady state behaviour. For band conduction, current is associated with electronic states and electrons (or holes) do not change their states in order to carry current. In hopping conduction, on the other hand current is produced only by hopping carriers. The conductivity of a hopping process is an increasing function of frequency, this is in contrast to band conduction which exhibits a slow decrease due to free movement of charge carriers through a periodic lattice<sup>(73)</sup>. The frequency dependence of the real part of conductivity is represented by

$$\sigma(\omega) = \sigma_0 + \sigma'(\omega), \quad (3.34)$$

where  $\sigma_0$  is the DC conductivity and true AC conductivity  $\sigma'(\omega)$  is represented by an empirical relation of the form

$$\sigma'(\omega) \propto \omega^n, \quad (3.35)$$

where  $n = 0.8$ .

This dependence is based on pair approximation in which the carriers are assumed to hop between pairs of localized sites, with an average being taken over all pairs of sites. These are distributed randomly in space and in energy in a disordered solid. The probability for hopping between two centers is proportional to.



$$\sigma'(\omega) = \sigma(\omega) = \sigma_0 \propto \frac{\omega^2 \tau^2}{1 + \omega^2 \tau^2}, \quad (3.36)$$

where  $\tau$  is the mean of the times taken to jump back and forth. The polarization, resulting from hopping carrier, depends not only on the hopping distance but also on the energy separation between the two member states of a pair in which hopping occurs. The time  $\tau$  is an exponentially increasing function of the jumping distance; the need to average over all responsible pair leads to domination by pairs for which  $\omega \tau = 1$  and hence the conductivity is proportional to  $\omega$ . Frequency dependence of conductivity for amorphous semiconductors and disordered solids. At  $\omega \neq 0$  a charge carrier contributing to the current has not to move across the specimen from electrode to electrode.

Two kinds of hopping mechanisms may be responsible for. Real part of  $\sigma^{(1)}(\omega) \propto \omega^{0.8}$  behavior in the low frequency range near low temperature. These are:

- i) Transport by hopping carrier excited into the localized states at the edges of the valance or conduction band.
- ii) Hopping by carriers with energies near the Fermi level with finite  $N(E_F)$ .

The two processes can be distinguished by observing the temperature dependence by  $\sigma(\omega)$  and the frequency at which  $\omega^{0.8}$  behaviors begins i.e. the onset from the DC level of the  $\text{Re } \sigma^{(1)}(\omega) \propto \omega^{0.8}$  law. In case (i), where multiple hopping is occurring the temperature dependence of the AC component of  $\text{Re } \sigma'(\omega)$  should be the same as that of  $\sigma_0$  and the onset of  $\text{Re } \sigma(\omega) \propto \omega^{0.8}$  occurring at higher frequencies. In case (ii) the AC component of  $\text{Re } \sigma(\omega)$  is weakly dependent on

temperature and  $\text{Re } \sigma(\omega) \propto \omega^{0.8}$  law is followed from the lowest frequencies to upwards.

Frequency dependence of  $\sigma(\omega)$  is found not only in disordered, glassy and amorphous solids but also in ordered molecular solids. The carriers involved are not necessarily electrons, but may be polarons, protons or ions. The principal drawback of all the previous theories of frequency dependence of  $\sigma'(\omega)$  is that they are based on this pair approximation of hopping conduction. Moreover, it is difficult to obtain an adequate physical insight into the mechanism involved, especially in view of the extremely wide range of physical systems, which other people are considering has suggested the Universal law dielectric loss

$$\varepsilon''(\omega) = \frac{\sigma(\omega)}{\varepsilon_0 \omega} \propto \omega^{n-1}$$

or  $\sigma'(\omega) \propto \omega^n$ , (3.36)

with  $n < 1$ . A wide range of materials follows this law over a wide range of frequency (Between sub-audio and microwave).

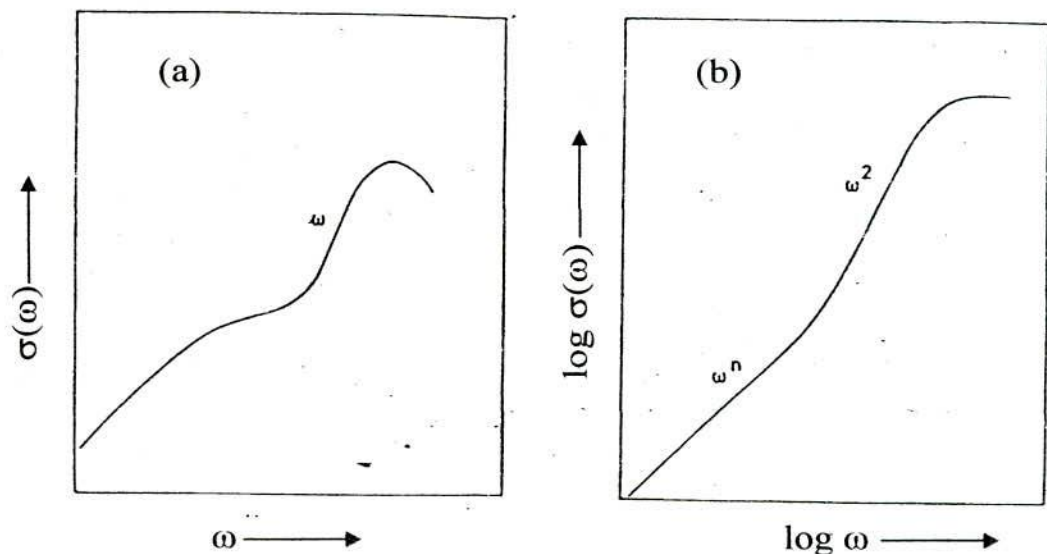


Fig-3.3: Schematic representation of the frequency dependence of the real part of the electrical conductivity  $\sigma(\omega)$  for ordered systems

It is pointed out that the exponent  $n$  is not a constant for all system but is a function of temperature approaching unity at low temperature and decreasing to 0.5 or less at higher temperatures. In general, there seems to be no correlation between the values of  $\sigma_0$  and  $\sigma'(\omega)$  for various materials. This type of frequency dependence is found in both hopping and dipolar systems.

With electron hopping there is a relatively small contribution to dielectric constant  $\epsilon'$ . The value of  $\epsilon'$  increases with temperature but the change is smaller at higher frequency

In the Debye dipolar mechanism this frequency dependence of this complex permittivity ( $\epsilon'$ ,  $\epsilon''$ ) is expressed in the form

$$\epsilon''(\omega) \propto \omega\tau (1 + \omega^2\tau^2) \text{ and}$$

$$\epsilon'(\omega) - \epsilon_\infty \propto \frac{1}{1 + \omega^2\tau^2}, \quad (3.37)$$

and thus ratio is

$$\frac{\epsilon''(\omega)}{\epsilon'(\omega) - \epsilon_\infty} = \omega\tau, \quad (3.38).$$

where  $\epsilon_\infty$  is the dielectric constant at high frequency. The AC electrical conductivity corresponding to the dipolar process can be represented by

$$\sigma'(\omega) \propto \omega^2(1 + \omega^2\tau^2), \quad (3.39)$$

and shown a rise proportional to  $\omega^2$  at frequencies below  $\left(\frac{1}{\tau}\right)$  and a saturation region above. The term  $\tau$  is the relaxation time, which is equal to the reciprocal jumping frequency. This saturation is exactly analogous to the case of two center hopping. Therefore, hopping of a charge carrier between two center is both physically and mathematically indistinguishable from a dipole jumping between two orientation.

According to the Kramere Kroning relation, the empirically observed law of eq<sup>n</sup> (3.36) for  $\epsilon''(\omega)$  implies the same frequency dependence for the real part  $\epsilon'(\omega)$  which these takes the form:

$$\epsilon'(\omega) - \epsilon_{\infty} \propto \omega^{n-1} \quad (3.40)$$

The ratio  $\frac{\epsilon''}{\epsilon' - \epsilon_{\infty}}$  is independent of frequency. This is in stark contrast with the Debye dipolar behavior of eq<sup>n</sup> (3.38), where this ratio is equal to  $\omega\tau$ . The consequence of this that,

$$\frac{\epsilon''(\omega)}{\epsilon'(\omega) - \epsilon_{\infty}} = \cot\left\{\frac{n\pi}{2}\right\}, \quad (3.41)$$

with  $n < 1$ . This universal law of dielectric response is characteristic of either non-Debye dipolar system. It is difficult to obtain conclusive evidence hopping charge carrier from the eq<sup>n</sup> (3.41). There is a general lack of good correlation between DC conductivity and  $\sigma'(\omega)$ . It has been suggested that the correlation between the magnitudes of  $\sigma_0$  and  $\sigma'(\omega)$  and especially a similarity between the respective activation energies would provide strong evidence for the hopping charge origin of the polarization.

On the other hand if the polarization is dipolar, the DC and AC response will not be correlated at all.

### 3.7 Theory of Thermal Conductivity

The basic formula for calculating the rate of heat flow by conduction  $Q_{cd}$  under steady-state conditions was developed by Fourier in 1822 and may be expressed as follows,

$$Q_{cd} = \frac{KA (T_2 - T_1)}{l}, \quad \text{cal sec}^{-1} \quad (3.42)$$

where  $A$  is the area of the slab under investigation,  $l$  is its thickness and  $T_1, T_2$  are the temperature. In other words, the rate of heat flow by conduction through a flat slab is proportional to the area and the temperature difference between the two surfaces. It is inversely proportional to the thickness.  $K$  is a factor called the co-efficient of thermal conductivity.

The thermal conductivity of a wood can be determined by Lee and Chorlton's method. In measuring the conductivity of such a poor conductor a thin layer of wood (slab) is used. But difficulty arises in maintaining the slab face at uniform temperature and in measuring that temperature. Lee and Chorlton's overcome this difficulty by placing a slab of a good conductor of exactly of the same diameter as the experimental slab on each side of the layer of poor conductor.

But the conventional Lee's method have three limitations:

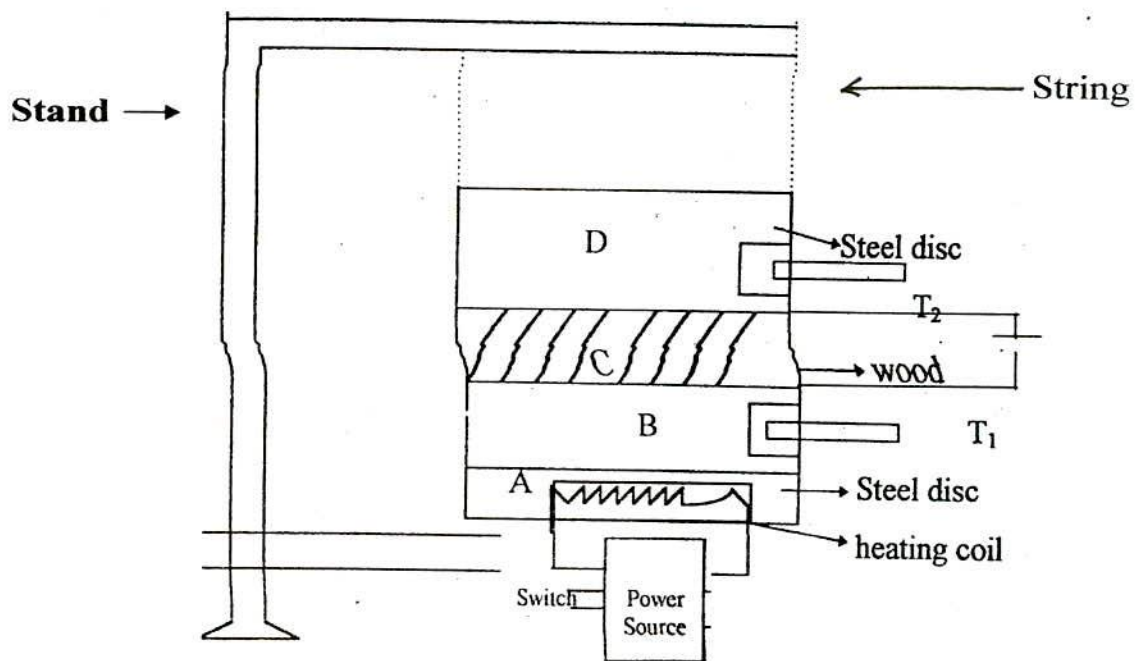
- (i) The thermal resistance of the air gap between the specimen and the metallic disc. The conductivity of air is much lower, than that of the specimen under investigation, as a result the

effect of the air gap is quite high and cannot be neglected as is usually done.

- (ii) The conductivity of the material is measured only on a, fixed temperature depending on the steady state attained by the particular experimental step.
- (iii) The effect of moisture is not taken into account, which can be important for material like wood which can absorb quite a good amount of moisture and affect the thermal properties.

In the present work, a technique has been developed to account for this air gap by using specimens of two different thickness so as to cancel out the effect of air gap from the two simultaneous equations.

In measuring the thermal conductivity of such a bad conductor (wood) a thin layer (slab) of the wood material is used by placing two slab of good conductor of exactly the same diameter as the experimental slab in each side of the layer of poor or bad conductor. The experimental arrangement of the apparatus is shown in fig-3.4



**Fig- 3.4 Experimental set up of thermal conductivity measurements**

The stainless steel disc A of about 10.41 cm in diameter is supported by means of strings from a large ring on a retort stand. A heating coil is placed on it. B is a stainless steel disc, having the same surface area as of A. A thermometer  $T_1$ , is introduced into a hole drilled into the base of B, C is an experimental specimen (wood) in the form of a thin circular slab. There is one kind of wood is Sundari have different thickness is used. D is a stainless steel disc having the same surface area as that of B. Thermometer  $T_2$  is introduced into a hole drilled in the base of D, B and D have same diameters but having different thicknesses.

The whole system is suspended horizontally from a stand by means of three threads attached to three small hooks provided symmetrically along the circumference of A.

In fig-3.4, let C be the disc of a poor conductor (Sundari Wood) and B and D be the stainless steel discs one on either side of C. A is a stainless steel disc, which consist of a heating element from which heat passes through B to C and D.

When heat is passed through A, then B is warmed up by the heat conducted by A. The specimen C is a thin disc and it is warmed by B. After sometime D is warmed by C.

When the rate of flow of heat through C equals the heat lost from D by radiation and convection then a steady state will be reached.

If,  $\theta_1$  = temperature of B in the steady state (for  $d_1$  thickness).

$\theta_2$  = temperature of D in the steady state (for  $d_1$  thickness).

A = area of cross-section of the specimen C.

$d_1$  = thickness of the specimen.

$d'$  = thickness of the air film.

$d_2$  = another thickness of the specimen.

$k'$  = Thermal conductivity of the air film

$k_1$  = thermal conductivity of the specimen.

$\theta_1'$  = Temperature of B in the steady state when thickness  $d_2$ .

$\theta_2'$  = Temperature of D in the steady state (for  $d_2$  thickness).

$m$  = Mass of the disc D.

$S$  = specific heat of the material of D.

$$\begin{aligned} \text{Area of cross section, } A &= \pi(D'/2)^2 \text{ sq. cm.} \\ &= \frac{\pi D'^2}{4} \text{ sq. cm.} \end{aligned}$$

$D'$  = Diameter of the specimen disc, C.

Then the quantity of heat conducted per second, through the bad conducting slab C is,

$$\begin{aligned} Q &= \frac{A(\theta_1 - \theta_2)}{\frac{d'}{k'} + \frac{d_1}{k_1}} \\ Q &= \frac{Ak_1(\theta_1 - \theta_2)}{\alpha + d_1}, \end{aligned} \tag{3.42}$$

$$\text{where, } \alpha = \left(\frac{d'}{k'}\right)k_1.$$

In the steady state, this heat  $Q$  is radiated per second from the upper disc D. Let  $\frac{d\theta}{dt}$  be its rate of cooling at its temperature  $\theta_2$ , then the heat lost per second from D is

$$Q = ms \frac{d\theta}{dt} \text{ (for } d_1 \text{ thickness)} \tag{3.43}$$

From eq<sup>n</sup> (3.42) and eq<sup>n</sup> (3.43), we get,



$$ms \frac{d\theta}{dt} = \frac{Ak_1(\theta_1 - \theta_2)}{\alpha + d_1} \quad (3.44)$$

For another thickness similarly we get,

$$ms \frac{d\theta'}{dt'} = \frac{Ak_1(\theta_1' - \theta_2')}{\alpha + d_2} \quad (3.45)$$

Now dividing eqn (3.44) by eqn (3.45), then we get

$$\begin{aligned} \frac{\frac{d\theta}{dt}}{\frac{d\theta'}{dt}} &= \left( \frac{\theta_1 - \theta_2}{\theta_1' - \theta_2'} \right) \times \left( \frac{\alpha + d_2}{\alpha + d_1} \right) \\ \text{Or, } \left( \frac{\theta_1' - \theta_2'}{\theta_1 - \theta_2} \right) \left\{ \left( \frac{d\theta}{dt} \right) / \left( \frac{d\theta'}{dt} \right) \right\} &= \frac{\alpha + d_1 + (d_2 - d_1)}{\alpha + d_1} \\ \text{Or, } \left( \frac{\theta_1' - \theta_2'}{\theta_1 - \theta_2} \right) \left\{ \left( \frac{d\theta}{dt} \right) / \left( \frac{d\theta'}{dt} \right) \right\} &= \frac{\alpha + d_1}{\alpha + d_2} + \frac{d_2 - d_1}{\alpha + d_1} \\ \text{Or, } \left( \frac{\theta_1' - \theta_2'}{\theta_1 - \theta_2} \right) \left\{ \left( \frac{d\theta}{dt} \right) / \left( \frac{d\theta'}{dt} \right) \right\} &= 1 + \frac{d_2 - d_1}{\alpha + d_1} \\ \text{Or, } \frac{d_2 - d_1}{\alpha + d_1} &= \left( \frac{\theta_1' - \theta_2'}{\theta_1 - \theta_2} \right) \left\{ \left( \frac{d\theta}{dt} \right) / \left( \frac{d\theta'}{dt} \right) \right\} - 1 \\ \therefore \frac{1}{\alpha + d_1} &= \frac{1}{d_2 - d_1} \left\{ \left( \frac{\theta_1' - \theta_2'}{\theta_1 - \theta_2} \right) \left( \frac{d\theta}{dt} \right) / \left( \frac{d\theta'}{dt} \right) - 1 \right\} \quad (3.45) \end{aligned}$$

Now substituting this value in eq<sup>n</sup> (3.44) it becomes,

$$ms \frac{d\theta}{dt} = \frac{1}{d_2 - d_1} \left[ \left( \frac{\theta'_1 - \theta'_2}{\theta_1 - \theta_2} \right) \left\{ \left( \frac{d\theta}{dt} \right) / \frac{d\theta'}{dt} \right\} - 1 \right]$$

$$\text{Or } k_1 (\theta_1 - \theta_2) \left[ \left( \frac{\theta'_1 - \theta'_2}{\theta_1 - \theta_2} \right) \left\{ \left( \frac{d\theta}{dt} \right) / \frac{d\theta'}{dt} \right\} - 1 \right] = (d_2 - d_1) \frac{d\theta}{dt} \cdot \frac{ms}{A}$$

$$\text{Or } k_1 \left[ (\theta'_1 - \theta'_2) \left\{ \frac{d\theta}{dt} / \frac{d\theta'}{dt} \right\} - (\theta_1 - \theta_2) \right] = (d_2 - d_1) \frac{ms}{A} \cdot \frac{d\theta}{dt}$$

$$\text{Or } k_1 \left[ (\theta'_1 - \theta'_2) \left\{ \frac{d\theta}{dt} / \frac{d\theta'}{dt} \right\} - (\theta_1 - \theta_2) \right] = \frac{600 \times .089}{8 \times 8 \times \pi} \times (d_2 - d_1) \cdot \frac{d\theta}{dt}$$

$$\text{Or } k_1 \left[ (\theta'_1 - \theta'_2) \left\{ \frac{d\theta}{dt} / \frac{d\theta'}{dt} \right\} - (\theta_1 - \theta_2) \right] = 0.83987 (d_2 - d_1) \cdot \frac{d\theta}{dt}$$

$$\text{Or } k_1 = \frac{0.8398 (d_2 - d_1) \frac{d\theta}{dt}}{\left( \theta'_1 - \theta'_2 \right) \left\{ \left( \frac{d\theta}{dt} \right) / \left( \frac{d\theta'}{dt} \right) \right\} - (\theta_1 - \theta_2)}, \quad (3.46)$$

where,  $k_1$  is the thermal conductivity of the specimen and its unit is  $\text{cal cm}^{-1} \text{sec}^{-1} \text{ } ^\circ\text{C}^{-1}$

## **Chapter-IV      EXPERIMENTAL DETAILS**

- 4.1      Processing of Sundari Wood Samples
- 4.2      Description of the Sensor for Measuring Relative Humidity
  - 4.2.1    Sensor calibration
- 4.3      Experimental Procedure for Measuring Moisture Content
  - 4.3.1    Accuracy in Moisture Measurement
- 4.4      Experimental Techniques for Measuring Dielectric Properties
  - 4.4.1    Experimental Source and Dielectric Jig
  - 4.4.2    Frequency characteristics of Dielectric properties of Sundari Wood
- 4.5      Experimental Procedure for Measuring Thermal Conductivity
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## Chapter-IV

### Experimental Details

#### 4.1 Processing of Sundari wood samples

While wood is a very old material that has been used from the time man has been on earth, only in recent years has it developed into material with thousands of uses. This is particularly true of the many man made wood products now utilized in furniture and building construction. Also wood remains the favorite building material for homes, furniture, boats, musical instruments, sports equipment and thousands of other items. But to select wood wisely, one must know its thermal and electrical properties. Some woods which are strong and of good enough quality for the exposed part of furniture lack necessary hardness. Some woods should have minimum tendency toward warpage, excessive shrinking and swelling. The electrical properties of wood are of particular interest because these properties undergo drastic changes depending on the water content. Since wood consists of small crystalline regions called wood fibers, which are dispersed in lignin that serves as amorphous materials. Wood is very much hygroscopic.

The electrical properties of Sundari wood specimen were measured as affected by moisture and salt content. The dielectric constant of a material is a measure of the electric energy it will absorb from an electric field and store internally as polarization. This is of practical importance because, while wood are used as electrical switch boards there are often short circuits due to absorption of saline water from the walls specially, in the rainy season.

The electrical properties of wood are complex because of its complex hygroscopic structure. Wood consists of small crystal like region dispersed in a matrix of amorphous material is hygroscopic. So wood contains moisture in proportion to the humidity of its environment. The experimental measurements considered here are relative humidity, moisture content and dielectric constant.

## **Procedure:-**

In preparing the good quantity of research samples Sundari wood has been cut into thin pieces with various thicknesses (2, 3, 4, 5 and 6mm). The broad faces of the samples have been polished by sand paper. The diameter of Sundari wood specimen has been nearly same.

### **Process - I**

The weight of each of these samples has been measured prior to soaking and then soaked in distilled water for 48 hours. The soaked samples were again polished by sand paper. Later on, those were dried in an oven at a temperature of 120<sup>0</sup>C. After one hour, one sample of Sundari wood has been taken out, then their weight has been measured and the moisture content and dielectric constant were determined. Similar measurement has been carried out at the end of every hour up to 12 hours, for the remaining Sundari wood samples.

### **Process- II**

For the study of the effects of NaCl treatment on the saline water absorption and dielectric constants of various thicknesses and constant diameter of Sundari wood specimen has been taken and weighed. These were soaked in 0.5% of NaCl solution for 48 hours. After soaking, those samples were polished by sand paper and their actual thickness has been measured. Samples were then dried in an oven at a temperature of 120<sup>0</sup>C. After one hour samples were weighed and the moisture content was determined (by difference of weight) and dielectric constant of those samples with the help of an LCR bridge.

### Process- III

In order to study the effect of higher concentration of NaCl on the same dimensions the samples were soaked in 1, 1.5, 2 and 3% NaCl solution for 48 hours. By similar measurements as before the moisture content and dielectric properties of those specimens (soaked in NaCl solution in different concentration) were determined.

#### 4.2 Description of the Sensor for Measuring Relative Humidity

The relative humidity is a measure of the degree of saturation of the air and of Sundari wood contact within that air assuming that the air and wood material are in moisture. Relative humidity is a more useful direct value determined by S.Hm (Selling Hygrometer) B.S.-2845. The specimen configuration has been expected to result in slower sensor response to result in slower sensor response to changing RH than the other configuration shown in fig- 4.1

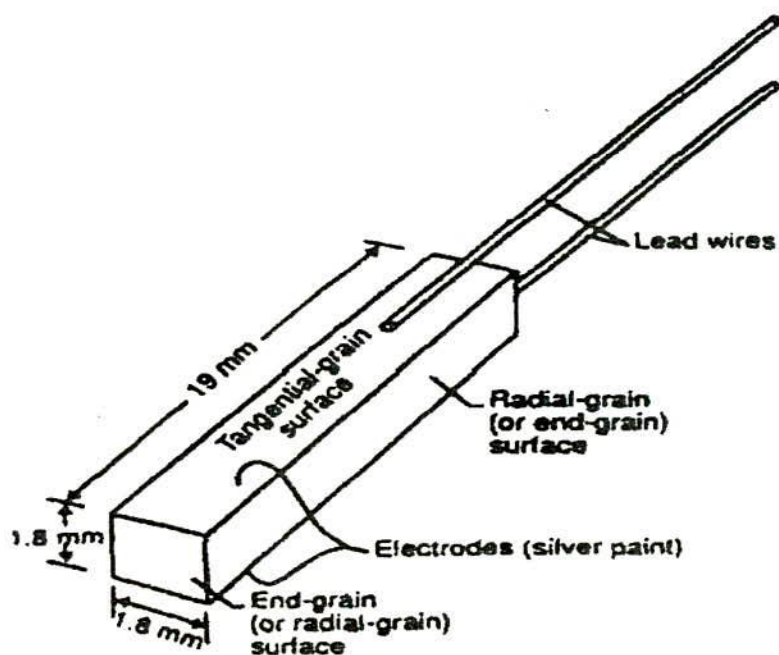


Fig -4.1. Wood resistance Sensor

A room with controlled variable temperature and humidity has been used and room conditions were monitored with a dew point hygrometer and mercury thermometer, in some cases with wet-bulb /dry-bulb thermometers. The series of temperatures relative humidity (RH) conditions during the two runs were not identical. At any given set point, room condition on the order of  $\pm 2\%$  RH and  $2.7^{\circ}\text{C}$  over time. Room condition was changed rapidly in approximate step changes. The time period between programming a change in room conditions and taking resistance reading ranged from 1hr to approximately 48hrs. The change of relative humidity (RH) setting divided by the time between change in RH setting and sensor reading has less than 10% RH change per hour. This ratio has slightly higher for two readings, which has been taken after increases in RH setting. The data from these readings suggested that despite the fast increase in RH conditions, the sensors were approximately at equilibrium at the time of measurement.

#### 4.2.1 Sensor calibration

After sensors are fabricated, it is advisable to screen and calibrate them to identify outlier sensors to be discarded and to identify the offset value  $a$  in eq<sup>n</sup>

$$\Phi = a + b [\ln (R)] + c(T), \quad (4.1)$$

for the rest of the sensors. Alternatively, multipoint calibration over an range of temperature and RH conditions could be performed for each sensor to derive sensor specific values for co-efficiently  $b$  and  $c$  and the off set value  $a$  in eq<sup>n</sup> (4.1)<sup>(74)</sup>. In this study, we performed such multipoint calibrations to determine if this procedure improves the measurement accuracy.

A data set consisting of resistance values for sensor taken over a range of temperature and RH conditions identified the followings:

- (i) Goodness of fit individual sensor calibration data to eq<sup>n</sup> (4.1)

- (a) Error in predicted RH values
  - (b) Distribution of error: Randomly distributed error would indicate non repeatability of measurements, whereas systematic distribution of error would indicate a deficiency in eq<sup>n</sup>(4.1) as a model.
- (ii) The nature and magnitude of between-sensor is variation.

### **4.3 Experimental Procedure for Measuring Moisture Content**

Traditionally the method for measuring moisture gradients in Sundari wood has been cut a piece of wood into slices, measure the moisture content of each slice using the oven dry method according to determined with Kett. (M.C.M) Moisture Content Meter (M.T-8AS-S). Due to the sensitivity of thin slices to environmental conditions of temperature, relative humidity and heat from the cutting procedures, moisture content may deviate from its true value. So in turn, the moisture gradient in wood derived using this method is affected.

Resistance Moisture Content (MC) meters are based on the relationship between the electrical resistance (or conductance) and the moisture content of wood. The moisture meter is a popular method in the industry for its rapid and nondestructive advantage. But these advantages are compromised by the low degree of accuracy. The oven dry method has been considered as one of the most accurate methods so far measuring moisture content in wood, but it is destructive and drying time is required. The moisture gradient measured in wood depends on the thickness of slices. So the second objective of this study has been to test the thickness effect with various saline concentrations of slices on measuring moisture gradients in Sundari wood using newly developed technique.



### **4.3.1 Accuracy in moisture measurement**

The sensor registers accurately to within 1% MC. We were claimed an error of  $\pm 2\%$  MC, but presented on empirical evidence for this estimate of error. The error stated were not based on empirical evidence but on a screening procedure in which all sensors that do not read to within 0.5% MC with a resistance moisture meter for wood of the value expected at 90% RH are discarded. We are found that with individual calibrations of sensors error in estimate of sensor MC could be small, although they do not state a specific level.

### **4.4 Experimental Techniques for Measuring Dielectric Parameters**

Dynamic dielectric properties of Sundari wood slice system have been determined using a low frequency impedance analyzer Agilent (4192A LF). Free space methods are some times employed in the measurement of dielectric constants of Sundari wood in slice form. These measurements however, are rather difficult to make accurately since they involve a host of special problem such as the suppressing of unwanted reflections, the launching of a phase wave in a limited space, and diffraction from the edge of the sample. It is best, therefore, to cut smaller from such slice and to measure them in circular shape.

The dielectric constants of solids can be considered as either "lossless" or as "complex" or "lossy", where the lossless case is of course a special case of complex case, but is the sufficient importance to be treated separately. Since, from a measurement point of view, no clear dividing line exists between lossless and complex dielectric constants. The division between them must be based on the sensitivity of the Impedance Analyzer used and the point of view of the experiment.

In general, it can be said that whenever the values of nanofarad capacitance involved are so high that they no longer be measured with any degree of accuracy or whenever it is known a priori that the loss tangent ( $\tan \delta$ ) of a given Sundari wood sample is very small and of interest. The dielectric can be considered to be loss factor. Then this is the case both the measurements and the subsequent computations are similar and quicker than when the conductance (G) must be considered as complex. The accuracy of such measurement depends to a large extent on the accuracy with which the Impedance analyzer and the position of the minimum current (0.4 mA) and low voltage can be applied. It is then vary sensitivity which make stable power source and accurate frequency measuring equipment necessary when these technique and employed. This method has been used in the present investigation over the frequency range 1kHz to 13 MHz at room temperature.

The usual methods of measuring the dielectric constant are based on a comparison of the capacitance C of a capacitor filled with the substance and the capacitance  $C_0$  of the empty capacitor. The ratio  $\frac{C}{C_0} = \epsilon$  the dielectric constant. The determination of the value of the capacitance may be principle be accomplished by using LCR bridge at room temperature.

#### **4.4.1 Experimental source and dielectric Jig**

Inserting a jack into the external source socket corrects the LCR Bridge to the minimum current (0.4mA) at the same time disconnecting both the output. A specially fabrication dielectric testing Jig has been used to hold the samples Sundari wood. The resistance of the Jig is in the order of nearly  $10^{10}\Omega$ . The diameter of the electrode of the Jig is about 9.0 cm. The experimental set up is shown in fig-4.2. The wood sample has then be inserted in between the electrode in fig 4.2. The capacitance (C), loss tangent

( $\tan \delta$ ) and conductance ( $G$ ) were directly noted a function of frequency by the LCR bridge.

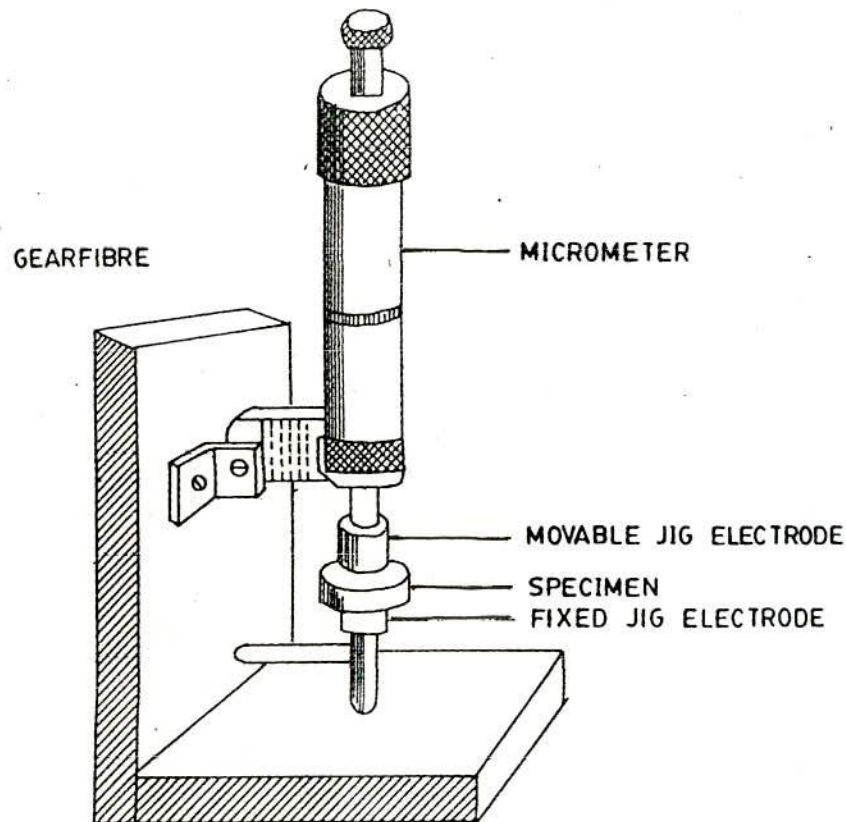


Fig-4.2. Dielectric Jig for measuring dielectric properties at room temperature.

#### 4.4.2 Frequency characteristics of dielectric properties of Sundari wood

The dielectric properties of the Sundari wood slice specimen were measured over the frequency range 1 kHz to 13 MHz using Agilent Impedance Analyzer 4192A LF at room temperature. The interaction between Sundari wood samples and frequency depends strongly on the sample's dielectric permittivity. This is normally expressed as a dimensionless quantity by relating to the permittivity by relating to the permittivity of free space. For isotropic materials the relative permittivity ( $\epsilon$ ) is a complex number.

$$\text{i.e. } \epsilon = \epsilon' - i \epsilon'' \quad (4.2)$$

For most of wood samples  $\epsilon' \gg \epsilon''$ . and since determined by the magnitude of the permittivity it depends strongly on the dielectric constant  $\epsilon'$ . The values of measured parameters obtained as a function of frequency and real and imaginary parts of dielectric permittivity and the loss tangent  $\epsilon''$  is calculated by using formula

$$\begin{aligned} C &= C_0 \epsilon' \\ \text{or } \epsilon' &= \frac{C}{C_0} \end{aligned} \quad (4.3)$$

Another method of the dielectric constant  $\epsilon'$  from the relation

$$\epsilon' = \frac{Cd}{C_0 A}, \quad (4.4)$$

$d$  is the thickness in cm, 'A' is the area of the electrode in sq.cm. and the  $\epsilon_0$  is called the permittivity of free space having a value of  $8.854 \times 10^{-14}$  F/cm.

On the other hand, the amount of energy absorbed can be shown to depend mainly on imaginary parts of dielectric permittivity ( $\epsilon''$ ), which is commonly called the loss factor

$$\begin{aligned} \tan \delta &= \frac{\epsilon''}{\epsilon'} \\ \epsilon'' &= \epsilon' \tan \delta \end{aligned} \quad (4.5)$$

The capacitance (C), loss tangent ( $\tan \delta$ ) and the conductance (G) were directly observed by Impedance Analyzer. The obtained data have been used to derive the real part of the conductivity  $\sigma(\omega)$ .

$$\therefore \sigma(\omega) = \frac{d}{A} G \quad (4.6)$$

#### 4.5 Experimental Procedure for Measuring Thermal Conductivity

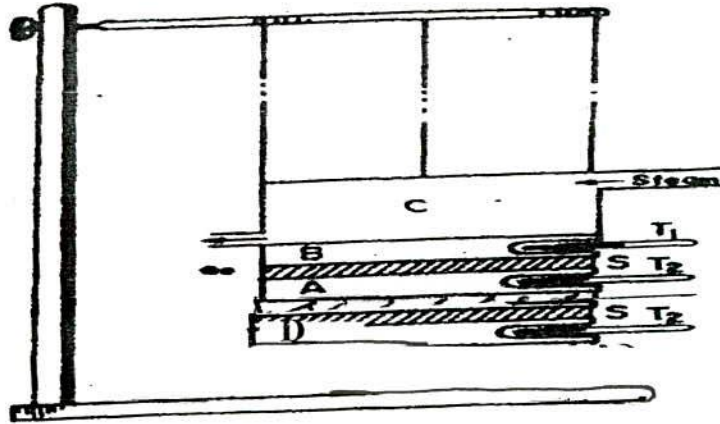
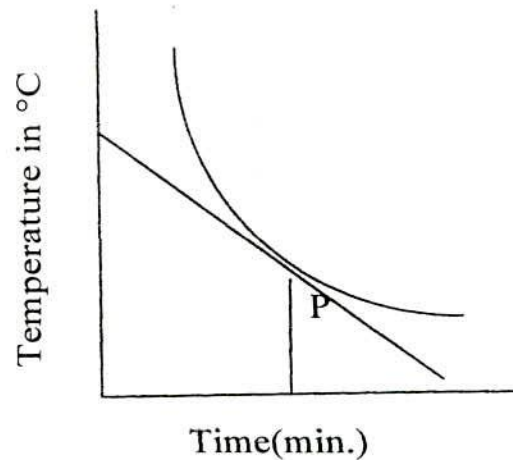


Fig-4.3. Experimental set up of thermal conductivity measurement.

#### Procedure :

- (i) To measure the diameter of the Sundari wood slices  $S_1$  and  $S_2$  with a slide calipers. B using a screw gauge the thicknesses  $d_1$  and  $d_2$  of the samples were determined.
- (ii) The apparatus was arranged as shown in fig 4.3 and the thermometer  $T_1$ ,  $T_2$  and  $T_3$  were placed in position.
- (iii) Then passed the steam from the inlet of the cylindrical vessel and temperatures  $\theta_1$ ,  $\theta_2$  and  $\theta_3$  of B, A and D respectively at the interval of 5 minutes were noted until they remain steady at least three consecutive intervals i. e. for 15 minutes.  $\theta_1$ ,  $\theta_2$  and  $\theta_3$  from thermometer  $T_1$ ,  $T_2$  and  $T_3$  were noted.
- (iv) The cylindrical vessel B, C and D were moved. Heat the disc A taking  $S_1$  top of A and  $S_2$  top of D by moving burner was heated under it till its temperature rises about  $10^\circ\text{C}$  ( $\theta_2 + 10^\circ\text{C}$ ) above the steady temperature  $\theta_2$ . Similarly about  $10^\circ\text{C}$  ( $\theta_3 + 10^\circ\text{C}$ ). Now the burner is removed and the temperature at the interval of half a minute noted until the temperature falls by about  $10^\circ\text{C}$  from  $\theta_2$  ( $\theta_2 - 10^\circ\text{C}$ ). Similarly from  $\theta_3$  ( $\theta_3 - 10^\circ\text{C}$ ).

A graph as taking time of cooling as abscissas and temperature ( $\theta$ ) as ordinate is plotted. Draw tangents at points at which the values of the ordinate are  $\theta_2$  and  $\theta_3$  and are shown in fig-(4.4.)



**Fig-4.4.** Time versus Temperature cooling curve for Temperature gradient measurements

#### **4.5.1 Experimental measurement procedure of thermal conductivity for various voltage Laval**

In preparing the good quality sample Sundari wood has been cut in to thin pieces. The broad faces of the specimen sample were polished by sand paper. Samples considered were of five different thicknesses (2, 3, 4, 5 and 6mm). But the diameter of these samples was same as 9.0 cm.

##### **Process 1**

Dry samples having two different thicknesses of Sundari wood were considered. Then the thickness  $d_1$  (2mm) and  $d_2$  (4mm) of the two types of samples were accurately determined with the help of a screwgauge. Mass of the disc  $D$  is determined and the diameter ( $D' = 2r$ ) of the sample specimen  $C$  is measured. The experimental set up is shown in fig- 3.4.

To start with, sample of Sundari wood of thickness 2mm was put in place. When switched on, the heat passed from power source into A. After a linear steady state temperature gradient is set up across the slab the amount of heat required to maintain that gradient per unit time becomes constant. When the temperatures  $\theta_1$  and  $\theta_2$  became steady, these were noted. Then the supply of current was stopped and the discs A and D were removed. With the disc C still on top of D, the disc D has been heated by the heating source under it till its temperature has about  $10^{\circ}\text{C}$  above the steady temperature  $\theta_2$ . Then, heating source has been removed and allowed C to cool. By keeping C on it, it has ensured the D loses heat in the same surrounding as in the first phase of experiment, when it gained heat. The temperature has noted every half minutes until the temperature went down by about  $10^{\circ}\text{C}$  below  $\theta_2$ .

The graph was drawn with the time of cooling as abscissa and the temperature of D as ordinate A, tangent has drawn at a point at which the value of the ordinate is  $\theta_2$ . The slope of this tangent gives the rate of cooling  $\frac{d\theta}{dt}$  at  $\theta_2$ . With these results the value of conductivity at a temperature was calculated.

By changing the applied voltage at the power source i.e the heat source another value of conductivity at difference temperatures were obtained. Three different voltages were considered. Thus, for thickness  $d_1$ , three different values of conductivity for Sundari wood were obtained. Similarly, for samples of 3mm thickness similar measurements were carried out. Thus three different conductivity K values for Sundari wood at three different temperatures were obtained.

## **Process II**

Five samples of Sundari wood of different thicknesses were studied. The weight of these samples was separately measured. These samples were then soaked in 1% NaCl solution for 48 hours. After soaking, those samples

were polished by sand paper and weighed. The thermal conductivity of these samples at different temperatures were measured by the same procedure as followed in Process I. In order to study the effects of NaCl solution on wood conductivity use five samples of different thicknesses and these were soaked in 1% NaCl solution. Using these NaCl solution soaked samples value of five different conductivities for Sundari wood was measured.

### Process III

In order to study the effect of higher concentration of NaCl, the Sundari wood samples of same dimensions were soaked in 2% and 3% NaCl solution for 48 hours. By similar measurement five different K values for each Sundari wood samples were obtained.

#### 4.5.2 Calculation of air gap thickness for Sundari wood Sample

We know from eq<sup>n</sup> (3.44)

$$ms \frac{d\theta}{dt} = \frac{k_1 A (\theta_1 - \theta_2)}{\alpha + d_1}, \quad (4.7)$$

and another thickness from eq<sup>n</sup> (3.45)

$$ms \frac{d\theta'}{dt} = \frac{k_1 A (\theta_1' - \theta_2')}{\alpha + d_2}, \quad (4.8)$$

where  $d_1$  and  $d_2$  are specimen thickness and  $\alpha$  is the air gap

Now from above eq<sup>n</sup> (4.7) and eq<sup>n</sup> (4.8) we get

$$K_1 = \frac{0.8398(d_2 - d_1) \frac{d\theta}{dt}}{(\theta_1' - \theta_2') \left\{ \frac{d\theta}{dt} / \frac{d\theta'}{dt} \right\} - (\theta_1 - \theta_2)} \quad (4.9)$$



For dry sample:

$$\begin{aligned}
 K_1 &= \frac{0.8398(d_2 - d_1) \frac{d\theta}{dt}}{(\theta_1' - \theta_2') \left\{ \frac{d\theta}{dt} / \frac{d\theta'}{dt'} \right\} - (\theta_1 - \theta_2)} & [\because d_2 - d_1 = 2mm = 0.2cm] \\
 &= \frac{0.8398 \times (0.4 - 0.2) 0.05925}{40 \times \frac{0.05925}{0.04197} - 33} \\
 &= 0.009951867 / 23.46890636 \\
 &= 0.000424042
 \end{aligned}$$

i.e. from eqn (4.7) we have

$$\begin{aligned}
 \alpha &= \frac{K_1 A (\theta_1 - \theta_2)}{ms \frac{d\theta}{dt}} - d_1 \\
 &= \frac{0.000424 \times 33 \times 0.8398}{600 \times 0.089 \times 0.05925} - 0.2 & [\because d_1 = 2mm = 0.2cm] \\
 &= 0.2811915 - 0.2 \\
 &= 0.0811915
 \end{aligned}$$

i.e.  $\alpha + d_1 = 0.2811915$  and  $\alpha + d_2 = 0.4811915$   $[\because d_2 = 4mm = 0.4cm]$

## **Chapter-V      RESULTS AND DISCUSSIONS**

- 5.1    Measurements of Dielectric Constant of Sundari Wood under Different Moisture Content
- 5.2    Measurements of Relative Humidity, Moisture Content and Temperature
- 5.3    Measurements of Dynamic Dielectric Permittivity of Sundari Wood slice and its saline effect
  - 5.3.1    Measurements of dynamic loss factor of Sundari Wood slice and its saline effects
  - 5.3.2.    Measurements of dynamic conductivity of Sundari Wood slice and its saline effects
- 5.4.    Salinity effects on thermal conductivity of Sundari Wood
  - 5.4.1    Voltage dependence of thermal conductivity of Sundari Wood slice
  - 5.4.2    Effect of mean temperature on thermal conductivity of Sundari Wood specimen and its various saline concentration

## Chapter-V

### Results and Discussions

#### 5.0 Measurements of Dielectric Constant of Sundari Wood under different Moisture Contents

The dielectric constant of Sundari wood under different moisture conditions, covering the range from 6 to 18% at room temperature (30<sup>0</sup>C). The results of these samples are shown in table 5.1.

**Table 5.1** Percentage of Moisture content and Dielectric constant of Sundari wood (for normal dry sample soaked in distilled water for 48 hours)

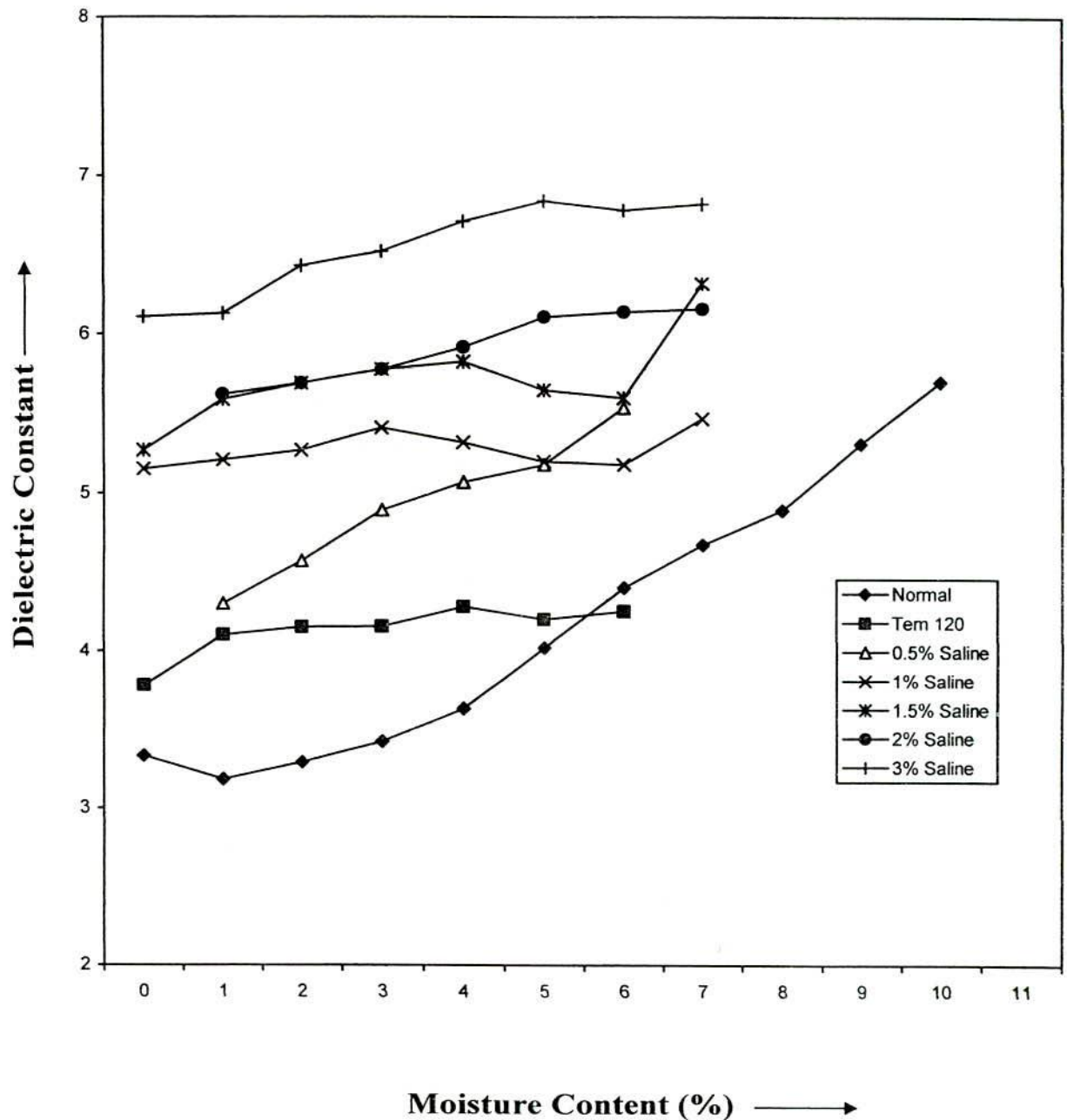
Thickness	Time	After 1 hour	After 2 hour	After 3 hour	After 4 hour	After 5 hour	After 6 hour	After 7 hour
2mm	MC	17.80	17.79	17.79	17.53	17.09	16.39	15.74
	DC	5.10	4.64	4.43	4.15	4.01	3.31	3.15
3mm	MC	14.02	13.65	11.16	11.07	10.27	9.76	9.50
	DC	8.41	7.54	7.26	6.80	6.44	6.05	5.57
4mm	MC	9.78	9.59	9.36	9.17	8.80	8.40	8.14
	DC	5.26	4.86	4.25	4.06	3.62	3.31	3.13
5mm	MC	9.42	9.17	8.95	8.67	8.47	7.98	7.52
	DC	6.03	5.62	5.22	4.82	4.26	3.62	3.33
6mm	MC	9.28	8.53	8.13	7.68	7.37	7.08	6.94
	DC	7.20	6.77	5.72	5.10	4.32	3.57	3.03

The moisture content of Sundari wood sample has been determined by weighing a sample before and after oven drying where different thickness of wood slice was used. The same procedure has been applied to induce salinity in the Sundari wood samples where NaCl solution of different strengths has been used. The results of these samples are shown in table -5.2

**Table-5.2.** Effect of salinity on percentage of Moisture content and Dielectric constant of Sundari wood (soaked in different saline solutions for 48 hours)

Thickness	Saline concentration	Time	After 1 hour	After 2 hour	After 3 hour	After 4 hour	After 5 hour	After 6 hour	After 7 hour	
2mm	0.5%	MC	15.87	15.79	15.75	15.39	14.79	14.72	14.26	
		DC	5.54	5.31	5.07	5.96	4.74	4.57	4.30	
	1%	MC	17.32	16.61	15.95	14.31	14.54	14.23	13.98	
		DC	6.31	5.81	5.6	5.47	5.25	4.89	4.64	
	1.5%	MC	13.92	13.46	12.76	12.72	12.34	11.91	11.41	
		DC	6.25	6.00	5.90	5.71	5.36	5.01	4.84	
	2%	MC	12.05	12.04	12.01	11.75	11.51	11.27	10.85	
		DC	6.85	6.49	6.00	5.71	5.36	5.04	4.82	
	3%	MC	14.02	13.65	13.07	11.16	11.07	10.27	9.76	
		DC	7.45	7.26	6.81	6.44	6.05	6.57	5.17	
	3mm	0.5%	MC	15.38	14.95	14.68	14.28	13.80	13.25	13.09
			DC	7.08	6.68	6.31	5.95	5.74	4.39	4.19
1%		MC	15.19	14.41	14.13	13.88	13.61	13.17	12.60	
		DC	6.97	6.50	6.31	5.98	5.79	5.42	5.02	
2%		MC	16.62	14.13	13.88	13.61	12.60	11.59	11.36	
		DC	7.67	7.43	7.21	6.86	6.43	6.24	6.13	
3%		MC	14.44	13.86	13.16	12.72	12.21	12.02	11.94	
		DC	6.77	6.50	6.14	5.08	4.73	4.52	4.17	
4mm		0.5%	MC	11.32	10.56	10.51	9.59	9.36	9.17	9.10
			DC	7.00	6.33	5.46	5.13	4.68	4.56	4.25
	1%	MC	11.32	10.56	10.51	9.59	9.36	9.17	8.80	
		DC	8.43	8.06	7.46	6.6	5.93	5.37	5.31	
	1.5%	MC	7.97	7.79	7.78	7.77	7.72	7.70	7.69	
		DC	8.86	8.6	8.33	7.93	7.46	6.4	5.56	
	2%	MC	7.87	7.56	7.54	7.51	7.45	7.41	6.56	
		DC	9.14	8.33	8.06	7.46	7.06	6.37	5.5	
	3%	MC	7.97	7.87	7.82	7.80	7.77	7.76	7.70	
		DC	9.85	9.06	8.8	8.06	7.86	7.18	7.37	
	5mm	0.5%	MC	10.49	10.18	9.95	9.47	8.98	8.51	3.73
			DC	6.21	5.80	5.22	4.82	4.52	4.22	3.84
1%		MC	10.43	10.18	9.95	9.47	8.98	8.51	7.37	
		DC	7.83	7.41	6.81	6.31	6.00	5.25	4.78	
1.5%		MC	10.6	8.76	8.16	7.45	7.33	6.35	6.31	
		DC	8.28	7.94	7.52	6.92	6.52	5.94	5.55	
3%		MC	9.67	9.38	9.12	8.89	8.52	8.27	8.11	
		DC	10.90	10.62	10.17	9.64	9.21	7.84	7.26	
6mm		0.5%	MC	7.97	7.70	7.21	6.67	6.45	6.06	6.02
			DC	7.93	7.28	6.84	5.91	5.62	4.32	4.64
	1%	MC	7.70	7.48	7.01	6.68	6.26	6.21	6.81	
		DC	8.15	7.71	7.06	6.66	6.02	5.31	4.68	
	1.5%	MC	7.84	7.56	7.29	7.01	6.55	6.28	6.06	
		DC	8.91	8.58	7.82	7.41	6.98	6.04	5.41	
	2%	MC	10.39	9.92	9.06	8.10	7.21	6.50	6.39	
		DC	10.65	10.10	9.56	8.92	8.49	7.81	6.97	
	3%	MC	9.91	9.68	8.84	7.90	7.40	6.34	6.22	
		DC	8.65	8.10	8.56	8.10	7.81	6.97	6.49	

The value of dielectric constant of these samples soaked in NaCl solution were found to be higher than the general value of dielectric constant of Sundari wood not soaked is presented in tables 5.1. and 5.2. In general, the dielectric constant has been found to increase with increasing moisture content.



**Fig-5.1:** Dielectric constant as a function of moisture content for different salinity effect at the 2mm thick Sundari wood sample.

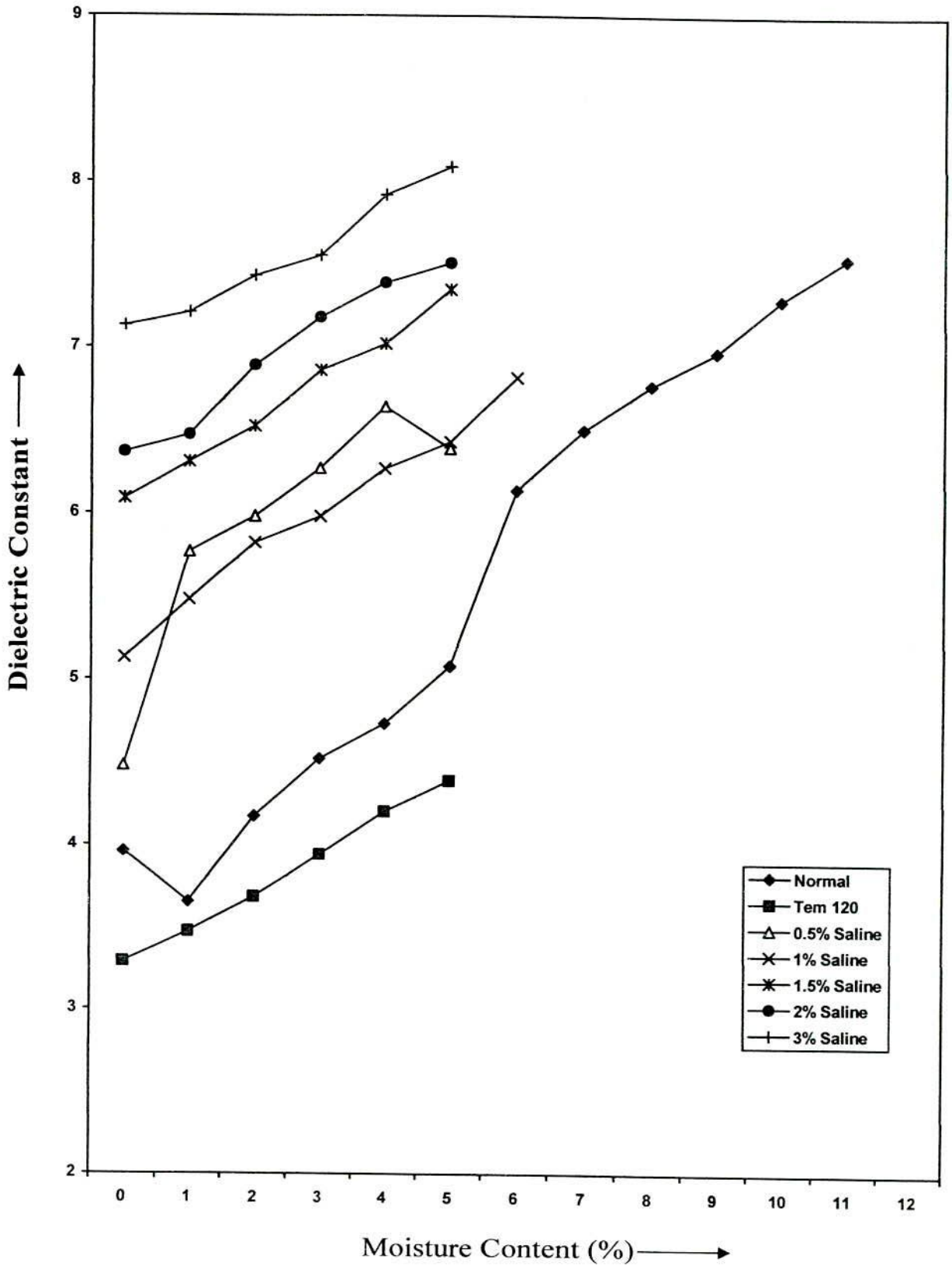
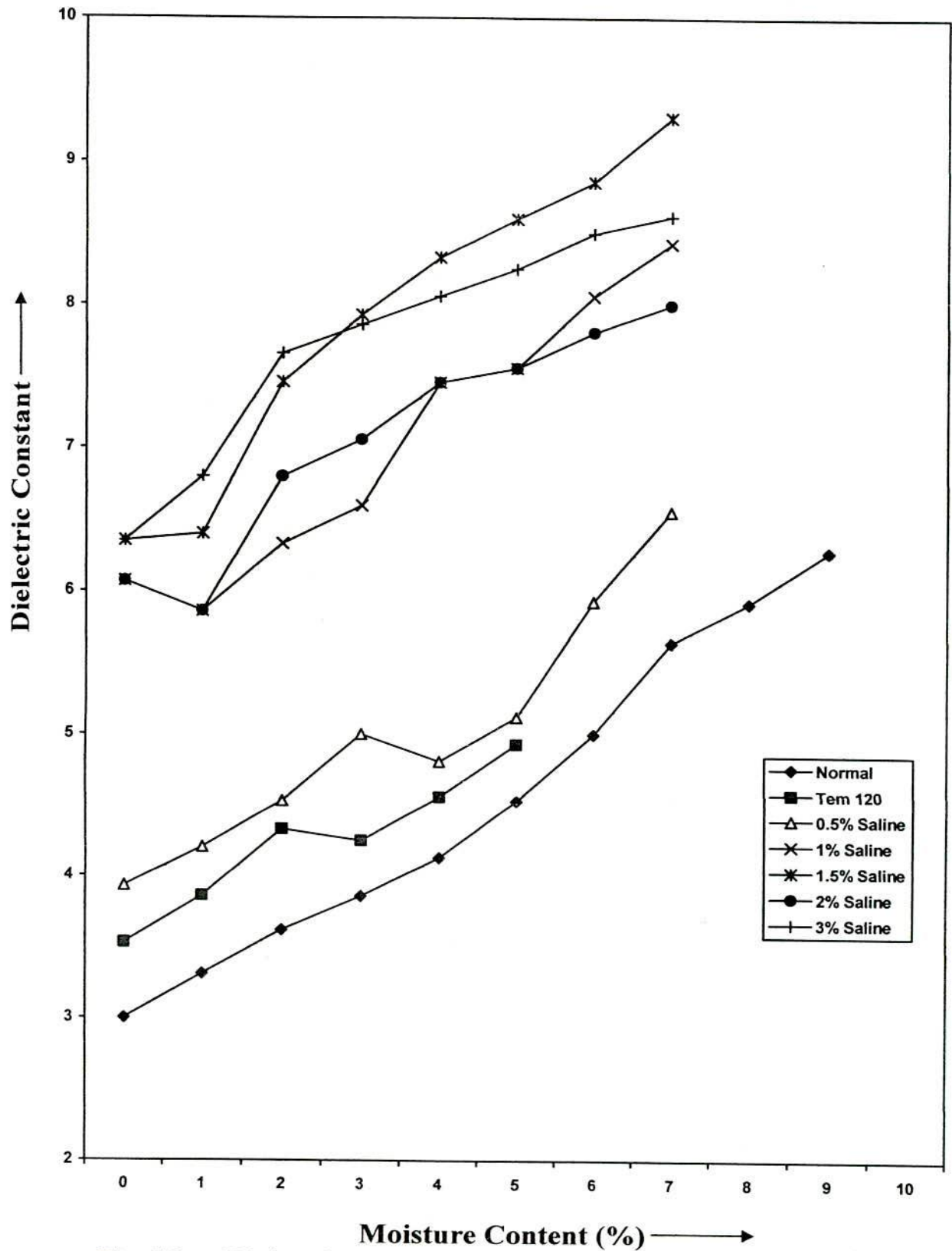
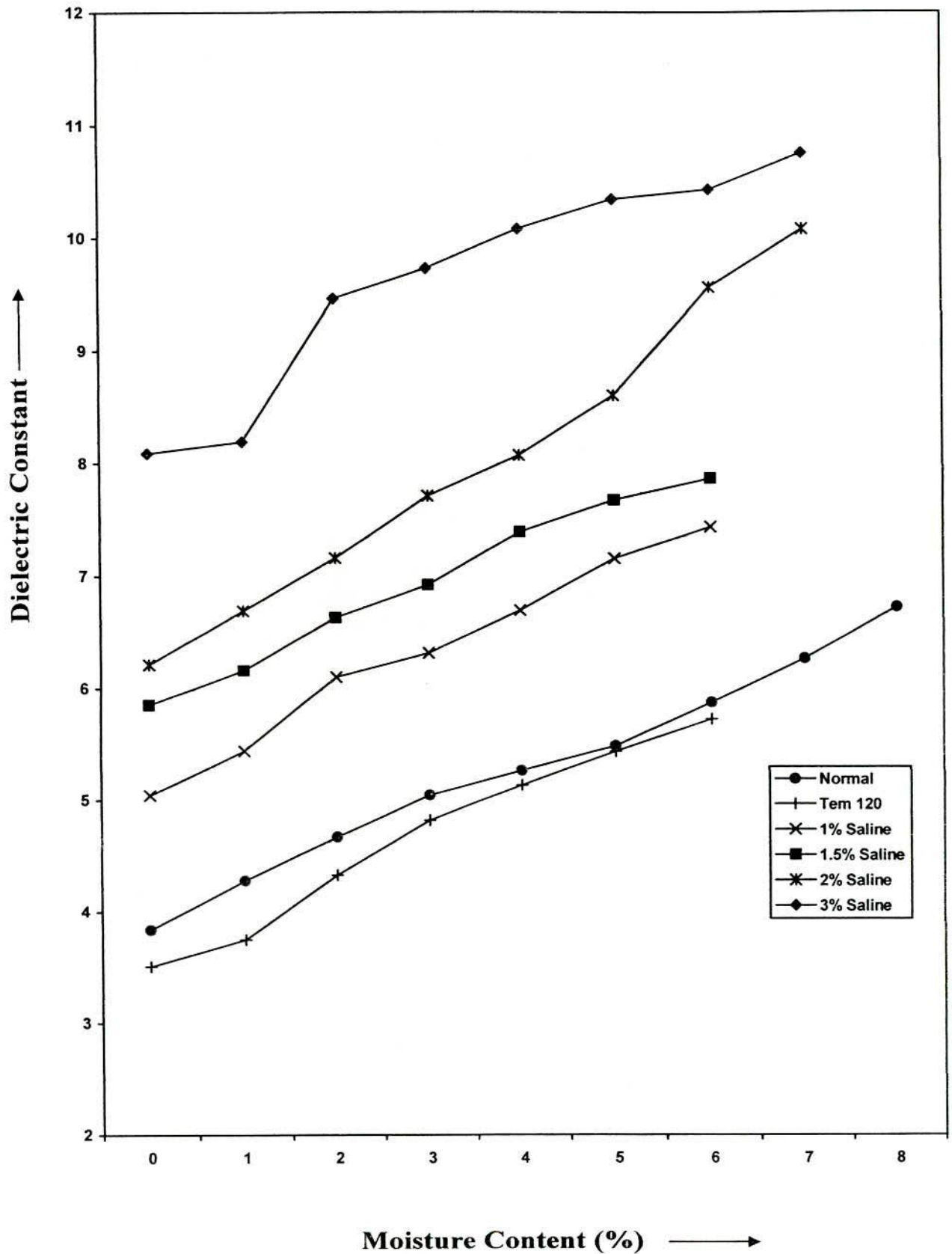


Fig-5.2: Dielectric constant as a function of moisture content for different salinity of the 3mm thick Sundari wood sample.



**Fig-5.3:** Dielectric constant as a function of moisture content for different salinity effect at the 4 mm thick Sundari wood sample.



**Fig-5.4:** Dielectric constant as a function of moisture content for different salinity effect at the 5 mm thick Sundari wood sample



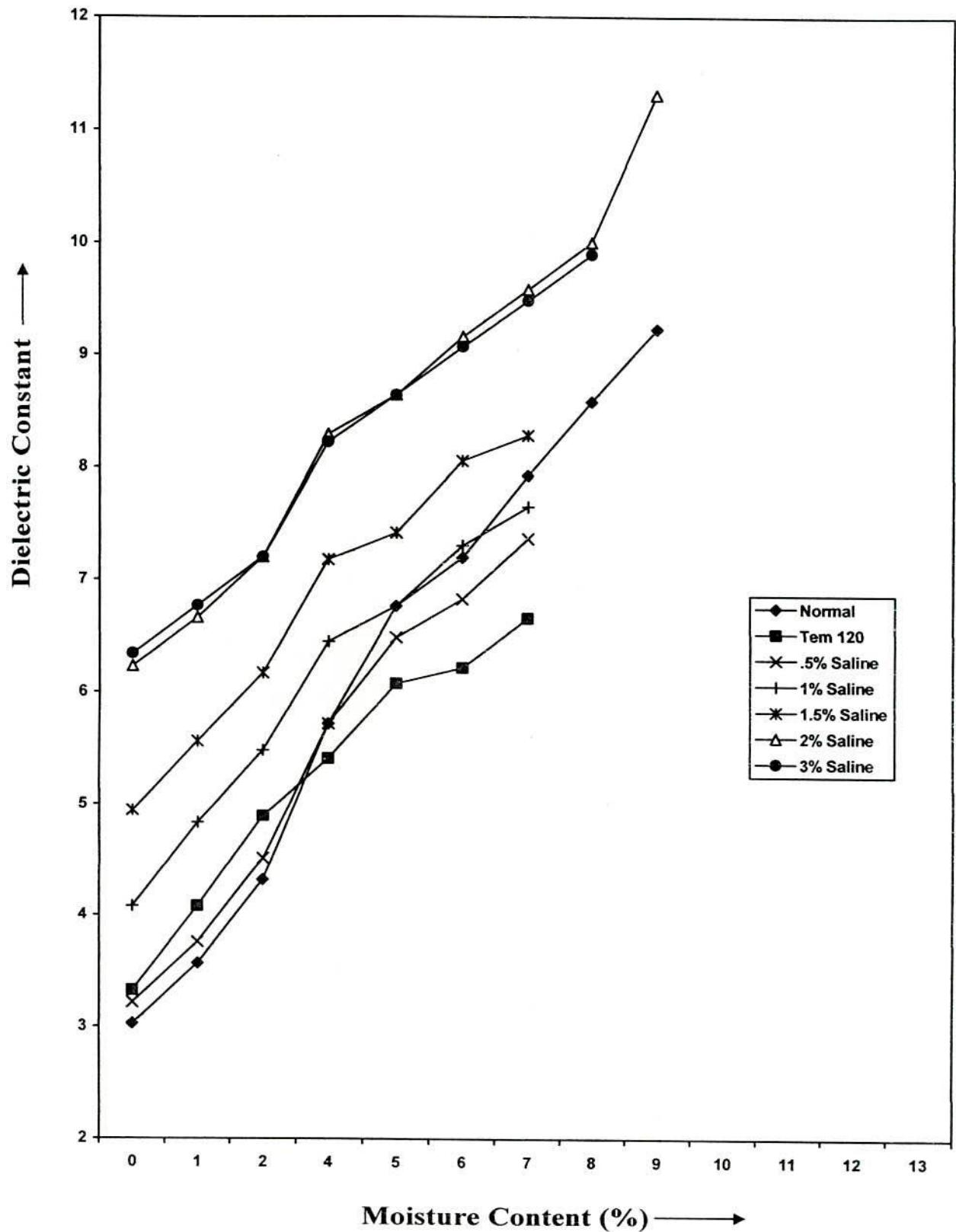
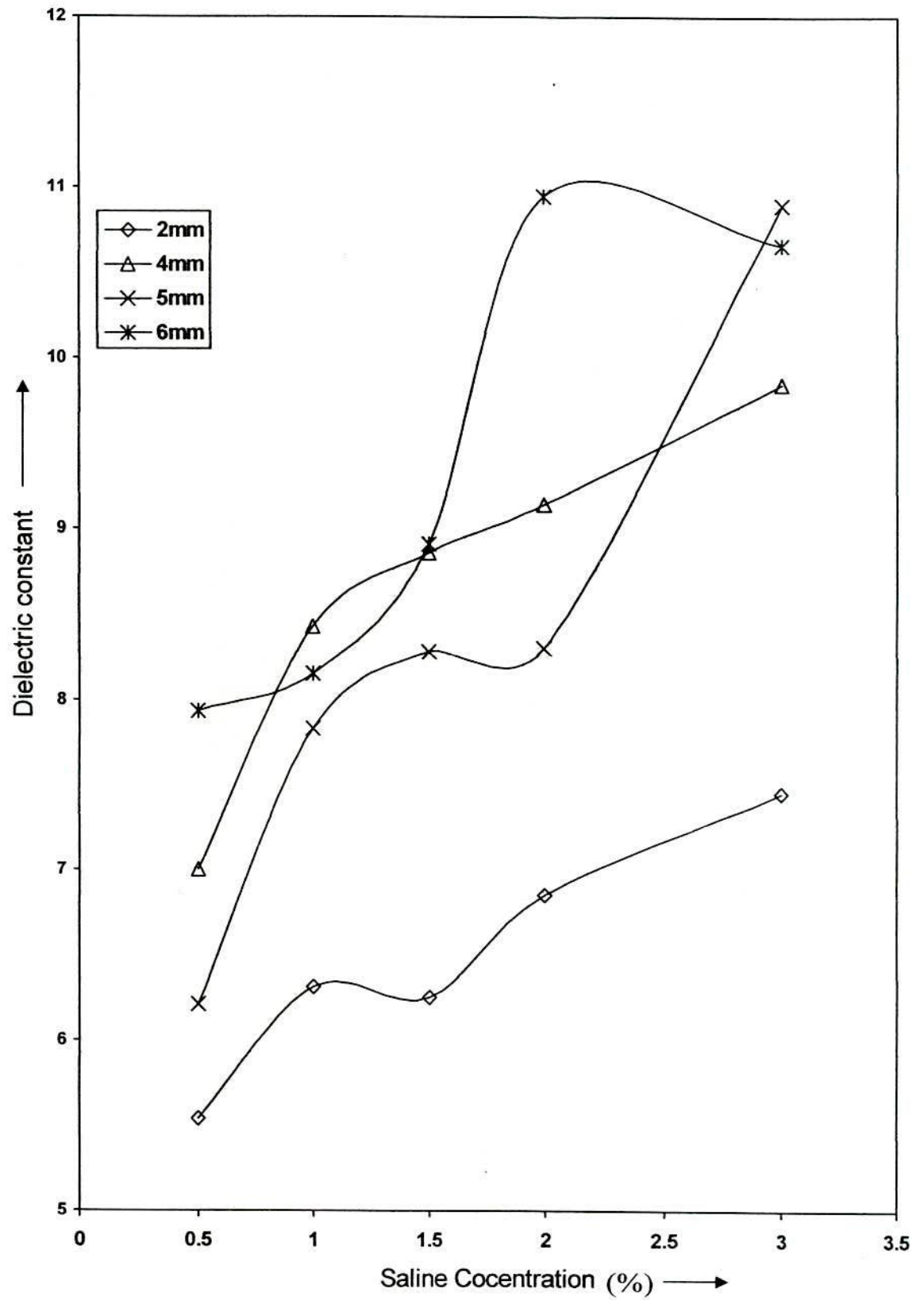


Fig-5.5 : Dielectric constant as a function of moisture content for different salinity effect at the 6 mm thick Sundari wood sample.



**Fig-5.6:** Dielectric constant on Percentage of saline effect on various thicknesses of Sundari wood sample.

The dielectric constant of Sundari wood under salinity also increased. The results shown in fig- 5.1 to fig- 5.5 show that dielectric constant increases with increasing moisture content above salinity and thickness of the Sundari wood. Wood is affected by the moisture vapour which is always present in the air, with increasing moisture content of air the amount of water within the wood matrix increases, which itself is characterized by high dielectric values. The polar component of the cell wall and the cellulose get more pronounced dielectric constants. However, as the fiber saturation point approaches the importance of the polar groups of the wood does not increase any more because their freedom of rotation gets to a maximum.

Absorption of salts from solution by Sundari wood is very small. A slight negative absorption of chloride ions may take from sodium chloride. An ionic bond is formed when one or more electrons from one atom is transferred to the other and the resulting positive and negative ions attract each other. An example is NaCl where the bond exists between  $\text{Na}^+$  and  $\text{Cl}^-$  ions and not between Na and Cl. When wood is treated with NaCl solution salts enter into the cell walls to give a concentration practically as great as the bulk concentration. When the wood is dried, water is first lost from the coarse capillary structure. The concentration of the solute in the coarse structure thus increases. Hence, solute diffuses into the cell walls in an effort to equalize the concentration.

In all wood materials continuous random vibration of molecules are noticed. The temperature of the material is a measure of the energies of these vibrations. The vibrations that are induced in the interior of the dielectric material are based on a rotation of the polar molecules under the randomly oriented dipoles align themselves in a direction opposite to that of the external electric field. In this ordered configuration the energy supplied by the field is stored in the molecules in the form of potential

energy. On removal of the field the potential energy is converted into kinetic energy of disordered dipoles. The total stored energy consists of the sum of potential and kinetic energies of the rotating molecules. The amount of energy that can be stored in the wood material is related to its dielectric constant. The greater the polarization of the wood material the greater will be the dielectric constant.

We concluded that the oven dry method for determination is based on the relationship between dielectric constant and moisture content of Sundari wood. With increasing moisture content the amount of water within the Sundari wood matrix increases which itself is characterized by high dielectric values connected with increasing thickness. On the other hand, the polar components of the cell wall and cellulose get more freedom of rotation. At higher moisture contents with connected with increasing saline concentration and in this way also contribute to a more pronounced dielectric behavior and showed that moisture within 6 to 18% ranges in various thicknesses such as saline could be effectively measured. Fig-5.6 shows that the dielectric constant of Sundari wood increases with increasing salt concentration and increasing thickness of this sample slice. Oven dry wood a good starting point for considering the dielectric constant of Sundari wood is general, which allowing the influence of moisture to be considered separately.

## **5.2 Measurements of Relative humidity, Moisture content and Temperature**

Air at any given temperature can hold so much moisture that the relative humidity on a wet day can be as much as 100 percent. All timbers tend to come to an equilibrium with the relative humidity of the surrounding air. Indoor or in dry weather, the relative humidity decreases although it seldom falls much below 30 Percent even in hot dry climate.

The moisture therefore, has important effect on the Sundari wood slice. So, these slice samples taken from oven is carefully and quickly put into glass jar at constant temperature. Extreme care has been taken in measuring direct value of relative humidity determined by S.H.M. (Selling Hygrometer) B.S. 284S and moisture content of these samples is often determined with Kett, (M.C.M) Moisture Content. Meter (M.T.- 8AS-S). The Moisture content has important effect on the Sundari wood as affected by the moisture vapour, which is always present in the air. The results are presented in table- 5.3 to table- 5.7.

Table 5.3: Percentage of Relative humidity, Moisture content and temperature of 2mm thick Sundari wood slice. (Normal drying)

SL.No.	Time	M.C	C(nF)	Co(nF)	D.C	Temp.	R%
1	after 1hr	33	0.185	0.0296	6.25	30	75
2	after 1hr	24	0.178	0.0312	5.7051	30	75
3	after 1hr	23	0.169	0.0318	5.3145	31	74
4	after 1hr	21	0.159	0.0325	4.8923	32	74
5	after 1hr	20	0.152	0.0325	4.6769	32	77
6	after 1hr	19	0.145	0.0329	4.4073	32	77
7	after 1hr	19	0.139	0.0345	4.029	32	77
8	after 1hr	19	0.129	0.0355	3.6338	31	76
9	after 1hr	17	0.125	0.0365	3.4247	31	76
10	after 1hr	18	0.21	0.0367	3.297	31	76
11	12 hr	18	0.118	0.0371	3.1806	30	76
12	12 hr	17	0.125	0.0375	3.3333	30	75

Table 5.4: 0.5% Saline effect of Relative Humidity, Moisture content and Temperature of 2mm thick Sundari wood slice.

S.NO	Time	M.C	C(nF)	Co(nF)	D.C	Temp.	R%
1	after 1hr	30	0.377	0.0296	12.736	30	75
2	after 1hr	29	0.375	0.0312	12.019	30	75
3	after 1hr	28	0.371	0.0318	11.667	31	74
4	after 1hr	27	0.368	0.0325	11.323	30	80
5	after 1hr	25	0.366	0.0325	11.262	32	79
6	after 1hr	25	0.365	0.0329	11.094	31	80
7	after 1hr	24	0.361	0.0345	10.464	31	81
8	after 1hr	23	0.359	0.0355	10.113	31	75
9	after 1hr	22	0.358	0.0365	9.8082	31	76
10	after 1hr	20	0.356	0.0367	9.7003	31	76
11	12 hr	20	0.199	0.0371	5.3639	30	77
12	12 hr	21	0.208	0.0375	5.5467	30	77

Table 5.5: 1% Saline effect of Relative humidity, Moisture content and Temperature of 3mm thick Sundari wood slice

S.NO	Time	M.C	C(nF)	Co(nF)	D.C	Temp.	R%
1	after 1hr	30	0.088	0.014	6.285714	29	77
2	after 1hr	29	0.083	0.014	5.928571	29	77
3	after 1hr	28	0.079	0.014	5.642857	30	75
4	after 1hr	27	0.075	0.015	5	30	75
5	after 1hr	27	0.068	0.015	4.533333	29	75
6	after 1hr	26	0.062	0.015	4.133333	29	76
7	after 1hr	25	0.058	0.015	3.866667	29	78
8	after 1hr	24	0.058	0.016	3.625	29	78
9	after 1hr	23	0.053	0.016	3.3125	29	78
10	after 1hr	22	0.048	0.016	3	31	77
11	12 hr	22	0.047	0.016	2.9375	31	75
12	12 hr	21	0.047	0.015	3.133333	32	75

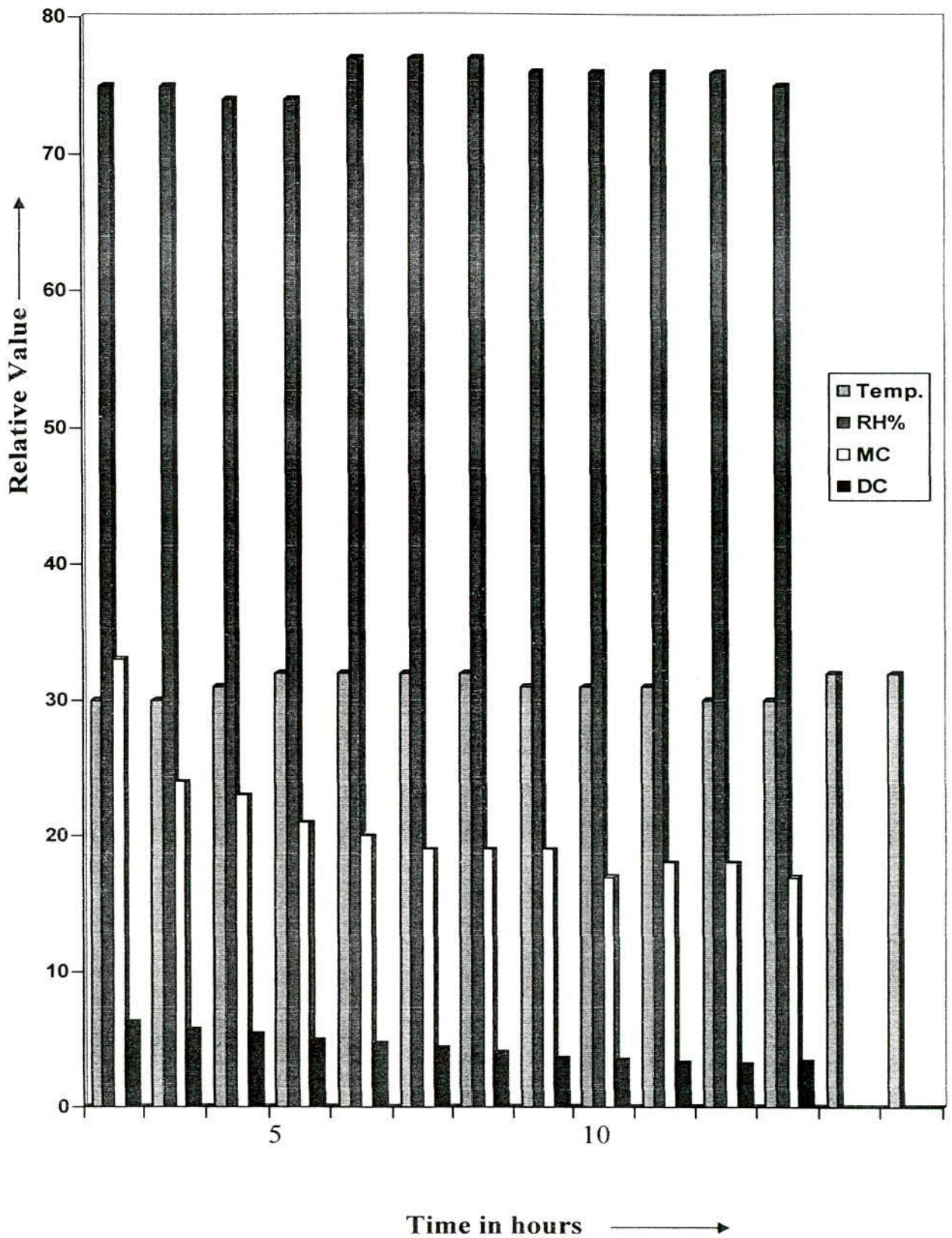
Table 5.6: 1.5% Saline effect of Relative humidity, Moisture content and Temperature of 4mm thick Sundari wood slice

S.NO	Time	M.C	C(nF)	Co(nF)	D.C	Temp.	R%
1	after 1hr	37	0.112	0.014	8	29	77
2	after 1hr	34	0.105	0.014	7.5	29	77
3	after 1hr	30	0.102	0.014	7.285714	31	75
4	after 1hr	27	0.096	0.015	6.4	31	75
5	after 1hr	25	0.091	0.015	6.066667	31	75
6	after 1hr	23	0.085	0.015	5.666667	30	76
7	after 1hr	21	0.081	0.015	5.4	30	75
8	after 1hr	19	0.075	0.016	4.6875	31	74
9	after 1hr	17	0.071	0.016	4.4375	32	76
10	after 1hr	15	0.069	0.016	4.3125	32	76
11	12 hr	12	0.065	0.016	4.0625	32	76

Table 5.7: 2% Saline effect of Relative humidity, Moisture content and Temperature of 5mm thick Sundari wood slice

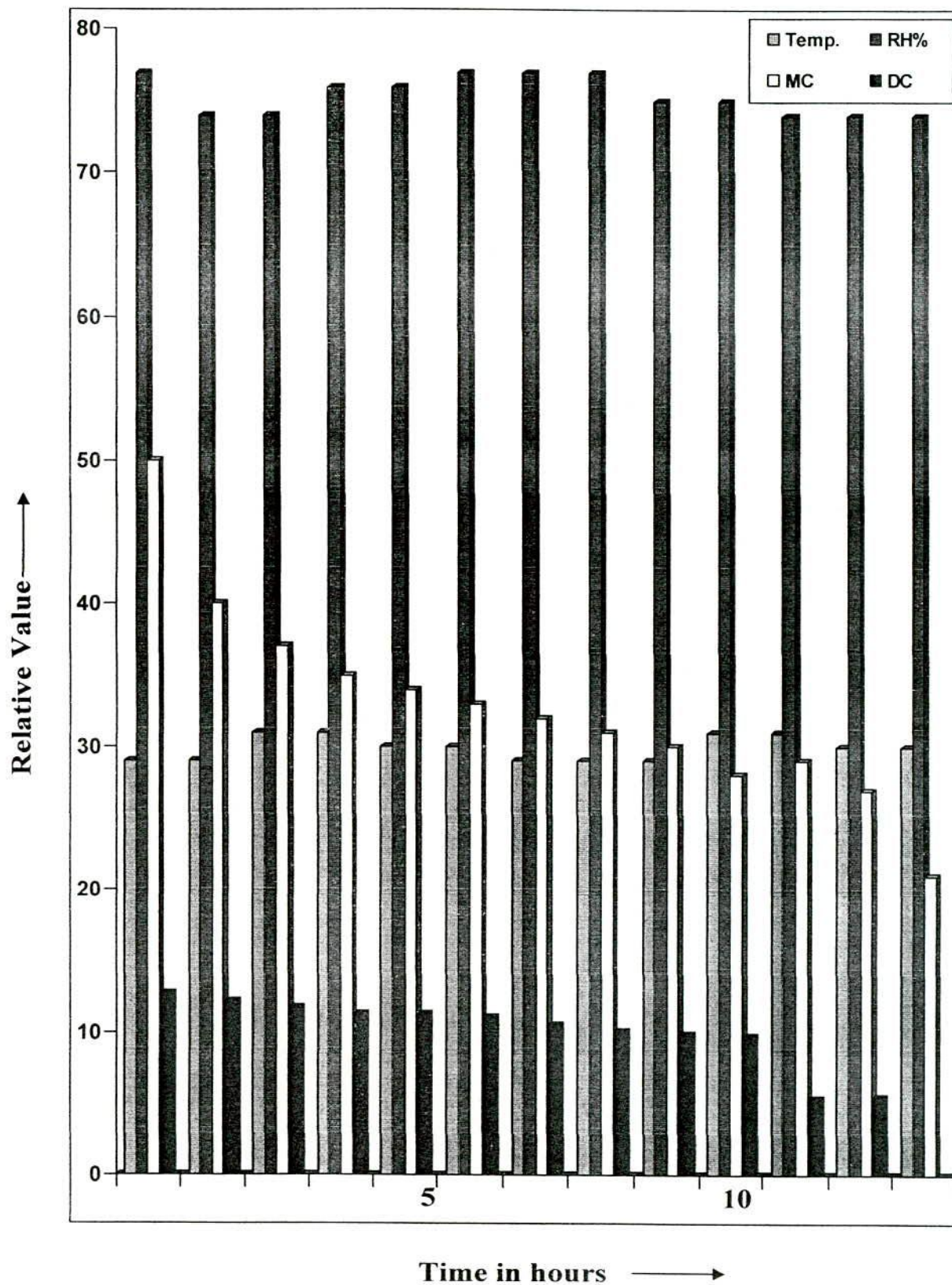
S.NO	Time	M.C	C(nF)	Co(nF)	D.C	Temp.	R%
1	after 1hr	50	0.113	0.0111	10.18018	30	81
2	after 1hr	50	0.105	0.0112	9.375	30	81
3	after 1hr	50	0.099	0.0113	8.761062	31	80
4	after 1hr	47	0.093	0.0114	8.157895	31	80
5	after 1hr	46	0.089	0.0115	7.73913	32	81
6	after 1hr	45	0.085	0.0116	7.327586	31	82
7	after 1hr	43	0.079	0.0117	6.752137	31	82
8	after 1hr	41	0.075	0.0118	6.355932	31	80
9	after 1hr	40	0.071	0.0118	6.016949	30	80
10	after 1hr	38	0.078	0.0117	6.666667	30	80
11	12 hr	36	0.062	0.0117	5.299145	29	80
12	12hr	35	0.059	0.0118	5	30	79

Fig- 5.7 to Fig-5.11 show the increasing relative humidity with increasing content of air the amount of water within the wood matrix increase to respond dielectric constant. Accurately identifying values of moisture content and relative humidity for individual sensors by multipoint calibrations is difficult. These results are particularly true for the temperature. Above 30<sup>0</sup>C the averages of wet Sundari wood slice were higher than at 50% moisture content but lower than at 12% In connection with the internal drying process the question arises of relative humidities in the specimen responded to changing temperatures. As equilibrium moisture content of Sundari wood slice at constant relative humidity decreases when temperature rises, relative humidity must have increased with increasing moisture contents. Fig-5.7 to Fig- 5.11 show moisture content to change at nearly 31<sup>0</sup>C and then gradually decreases with decreasing. The explanation of dielectric constant is that when wet specimen wood has been cooled water diffused out of cell walls as soon as free water froze in the cell cavities at 30<sup>0</sup>C. The dielectric Constant of Sundari wood slice increases with increasing NaCl salt concentration but does not remarkable effect on relative humidity and moisture content.

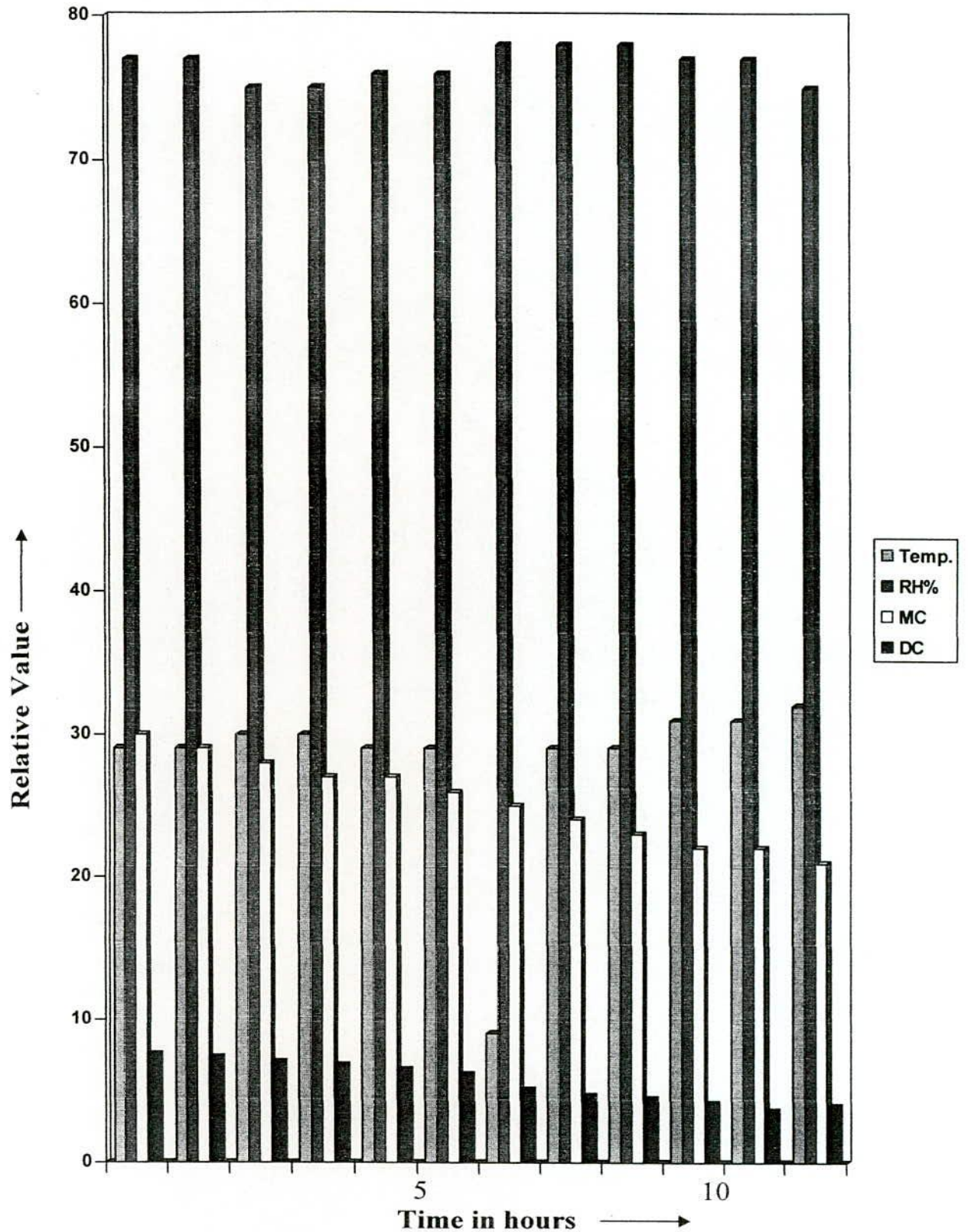


**Fig-5.7 :** Bar diagram for external factors affects the moisture content (MC) such as the relative humidity (RH%), the temperature (Temp) and the dielectric constant (DC) at 2mm thick Sundari wood slice.

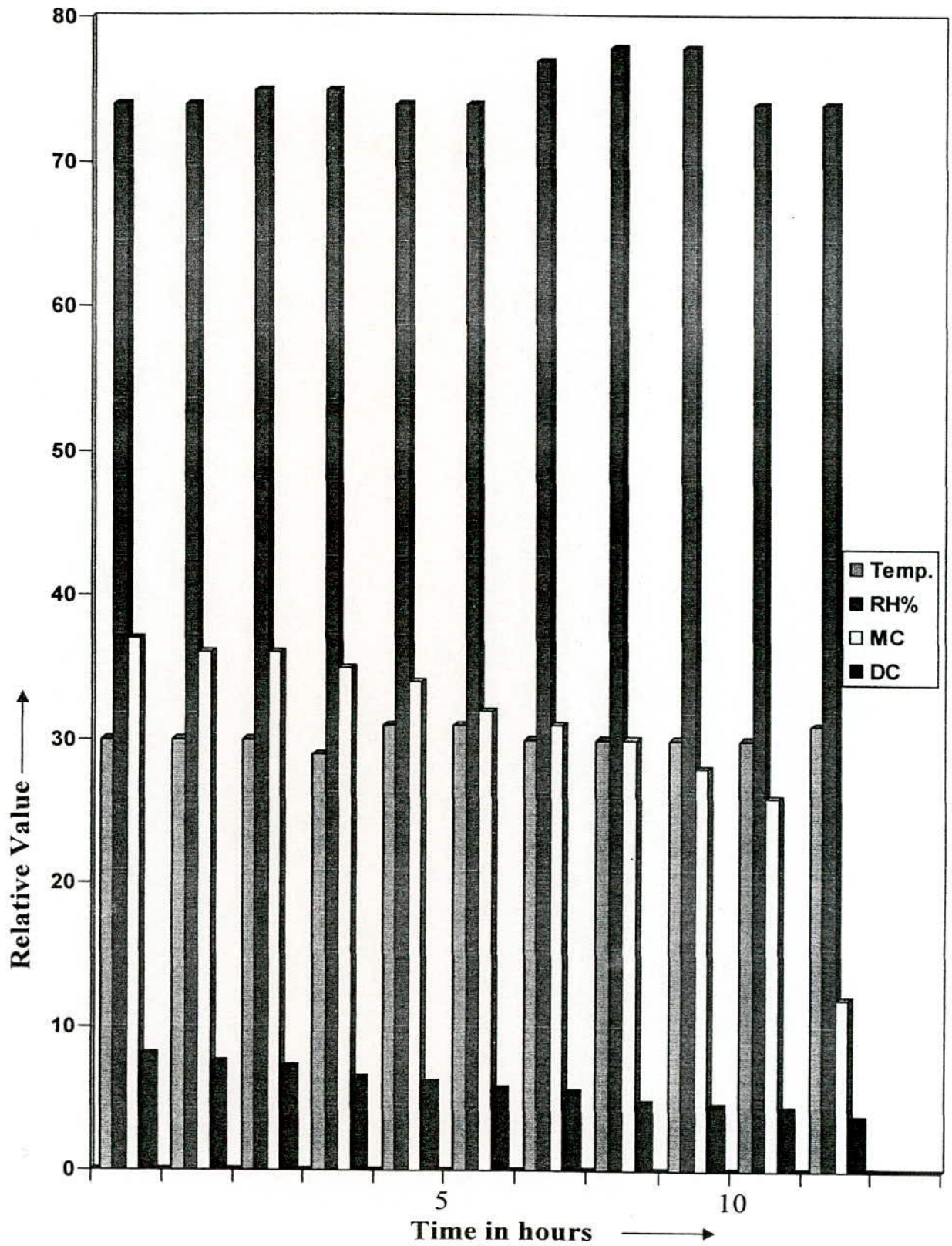




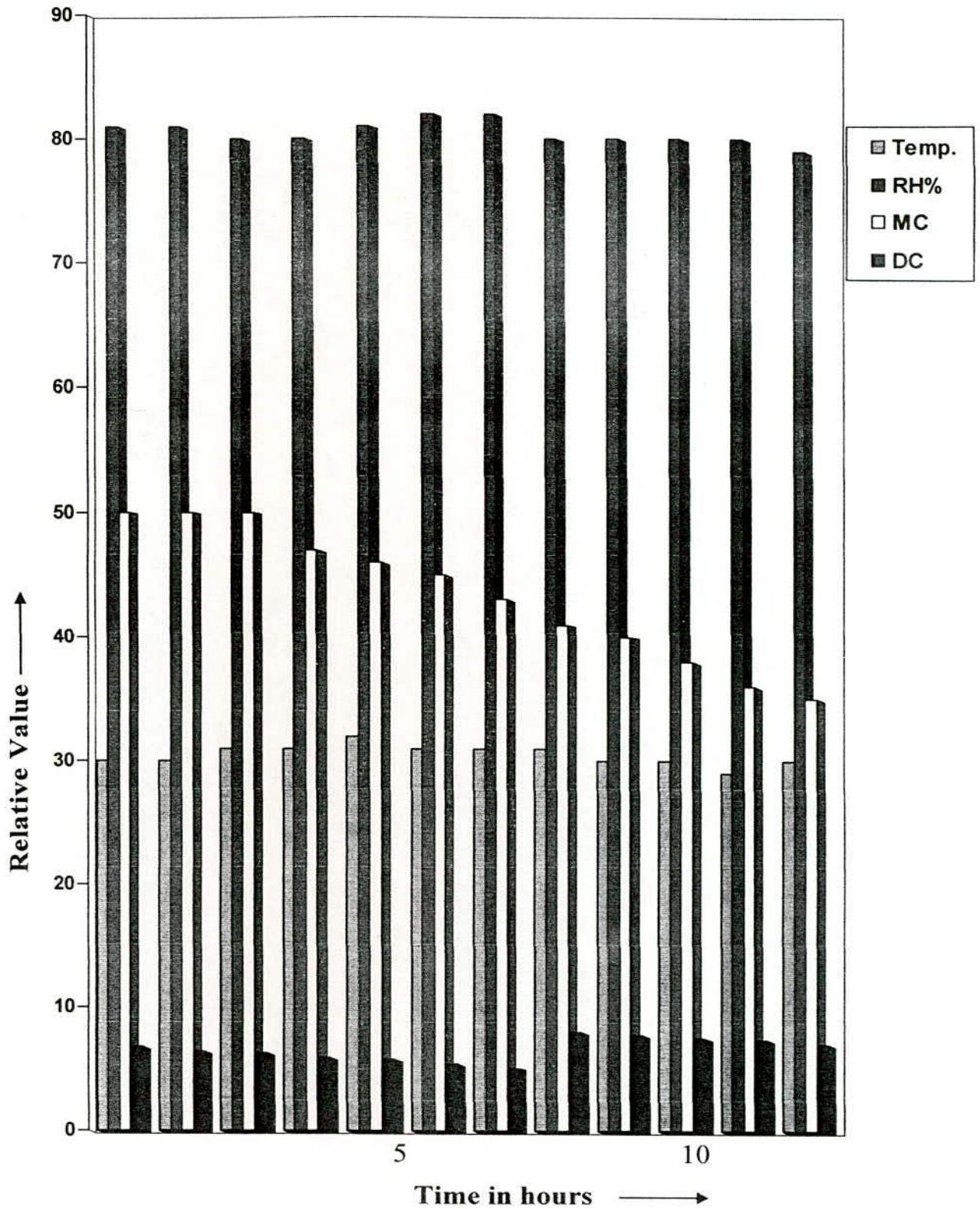
**Fig-5.8:** 0.5% saline effect of bar diagram for external factors affects the moisture content (MC) such as the relative humidity (RH%), the temperature (Temp) and the dielectric constant (DC) at 2mm thick Sundari wood slice.



**Fig-5.9 :** 1% saline effect of bar diagram for external factors affects the moisture content (MC) such as the relative humidity (RH%), the temperature (Temp) and the dielectric constant (DC) at 3mm thick Sundari wood slice



**Fig-5.10 :** 1.5% saline effect of bar diagram for external factors affects the moisture content (MC) such as the relative humidity (RH%), the temperature (Temp) and the dielectric constant (DC) at 4mm thick Sundari wood slice



**Fig-5.11:** 2% saline effect of bar diagram for external factors affects the moisture content (MC) such as the relative humidity (RH%), the temperature (Temp) and the dielectric constant (DC) at 5mm thick Sundari wood slice.

### 5.3 Measurements of Dynamic Dielectric Permittivity of Sundari wood slice and its Saline effects

The dielectric properties of Sundari wood slice over the frequency range 1kHz to 13MHz using an LCR Bridge (Agilent 4192A LF) at room temperature. The capacitance and loss tangent were directly noted as a function of frequency. The obtained data have been used to drive the dielectric permittivity  $\epsilon'(\omega)$  and loss tangent ( $\tan\delta$ ) from the eq<sup>n</sup> (4.3) and eq<sup>n</sup> (4.4). All the measurements have been made in air at room temperature. Similar behavior has been observed in the various thickness of all the Sundari wood slice specimens and their various saline effects. The frequency dependence of  $\epsilon'(\omega)$  of specimens of different thicknesses are shown in fig.5.12. It is clear from these graphs that the frequency dependence of the dielectric permittivity decreases abruptly with increasing frequency. The  $\epsilon'(\omega)$  has been found from 2.69 to 0.8652. The values of  $\epsilon'(\omega)$  is increased with increase of thickness of the sample. Similarly frequency dependence of  $\epsilon'(\omega)$  of various thicknesses and different saline effects are shown in fig.- 5.13 to fig-5.15. From the data it is seen that the dielectric constant increases with the increase of saline concentration.

The values of the complex number of Sundari wood slice at different thickness and various saline concentrations over a wide range of frequencies are shown in fig- 5.16 to fig- 5.19, as  $\log \epsilon'(\omega)$  verses  $\log f$ . The results are shown in table-5.8. The results show that  $\epsilon'(\omega)$  for both types of materials decreases with the increase of frequency and follows the universal law according to  $\epsilon'(\omega) \propto \omega^{n-1}$ . The complex number of all samples has been calculated following the relation:

$$n = \frac{\ln[\epsilon'(\omega)]}{\ln(\omega)} + 1 \quad (5.1)$$

Where  $n=1.02$  in the low frequency range as 1 to 900kHz and  $n=0.97$  to  $0.99$  in the high frequency range 1 to 13MHz for without saline effect.

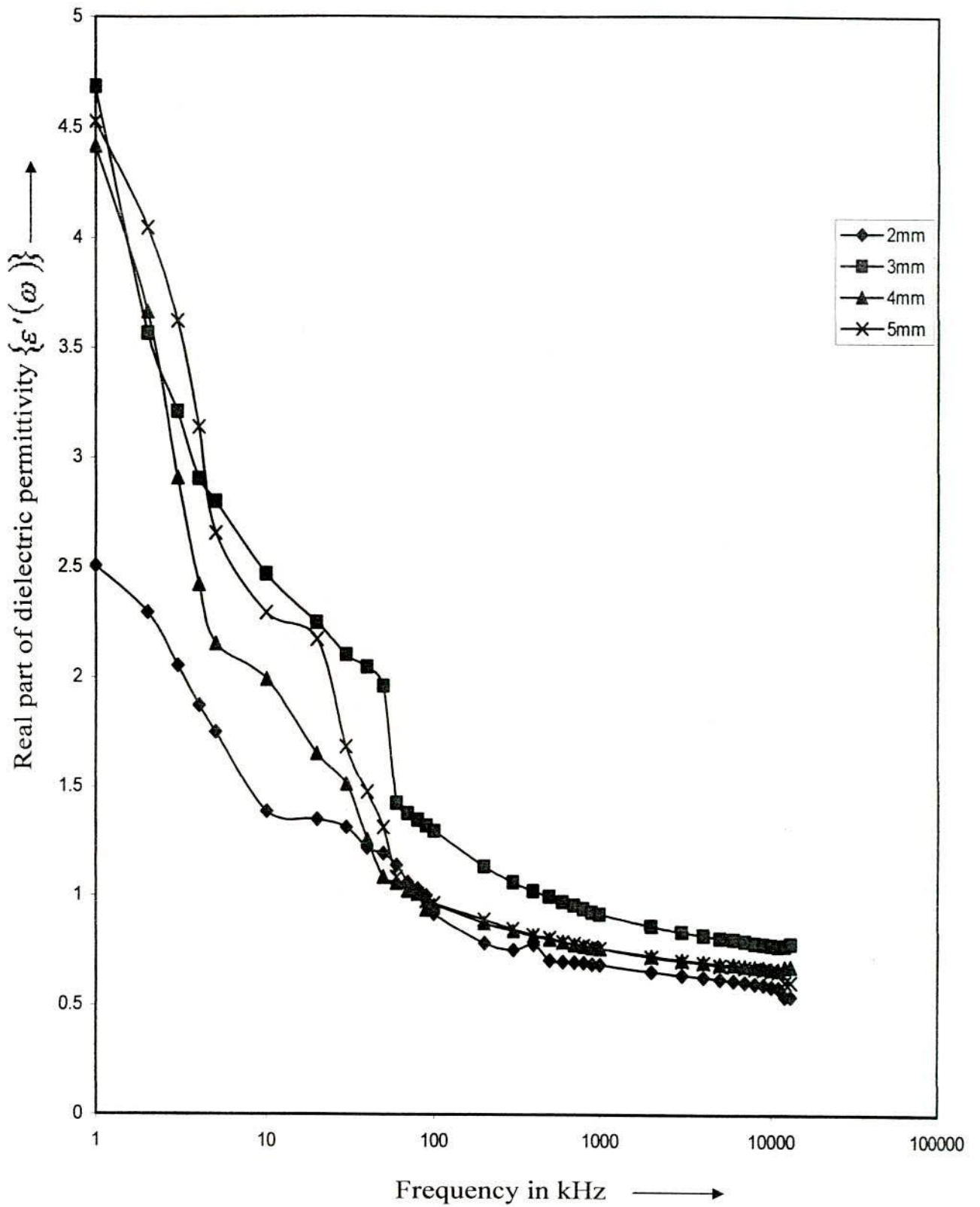


Fig-5.12. The frequency dependence of the real part of the dielectric permittivity of various thicknesses of Sundari wood slice at room temperature.

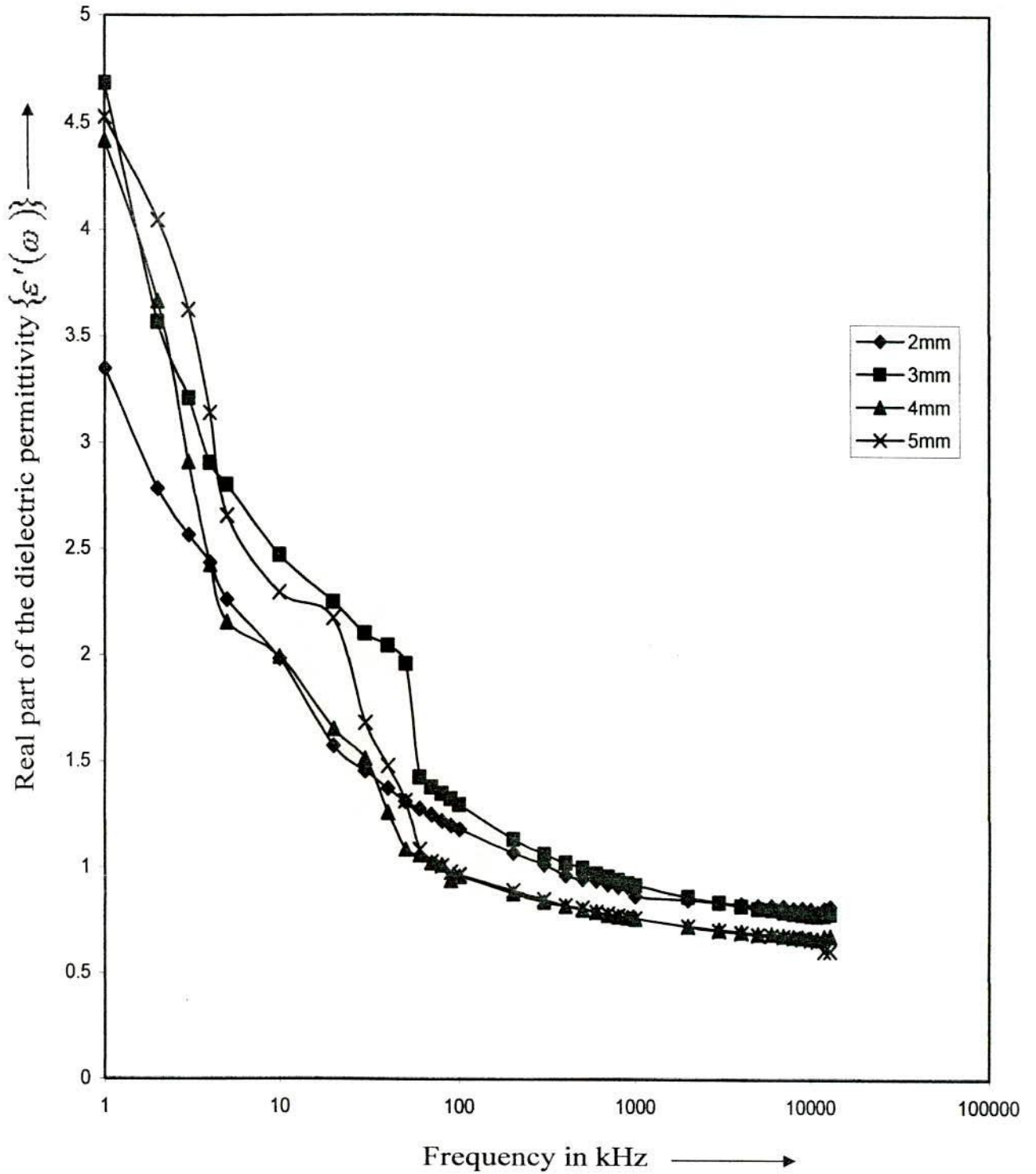


Fig-5.13: 0.5% saline effects on frequency dependence of the real part of the dielectric permittivity of various thicknesses of Sundari wood slice at room temperature

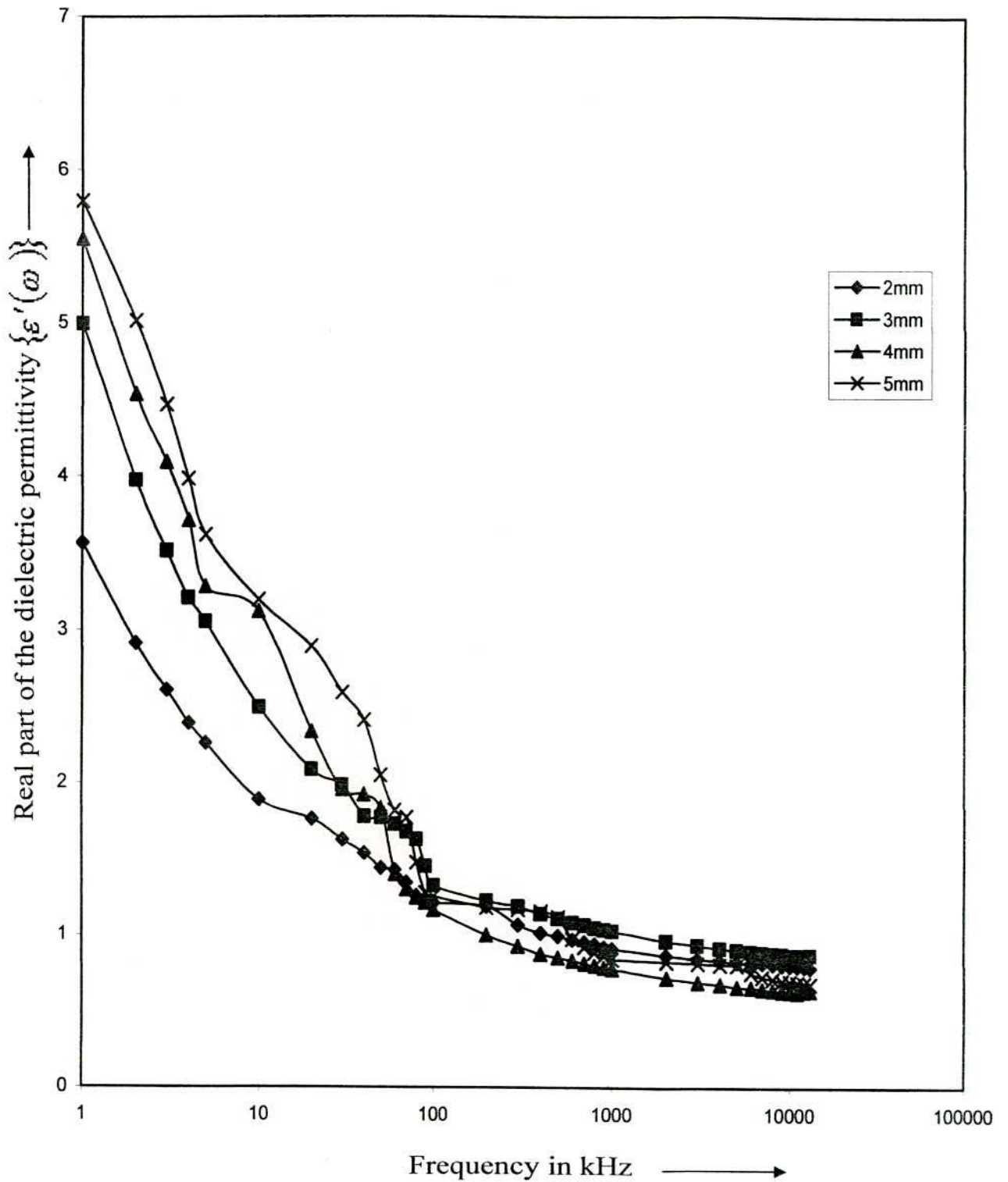


Fig-5.14: 1.5% saline effect on frequency dependence of the real part of the dielectric permittivity of various thicknesses of Sundari wood slice at room temperature



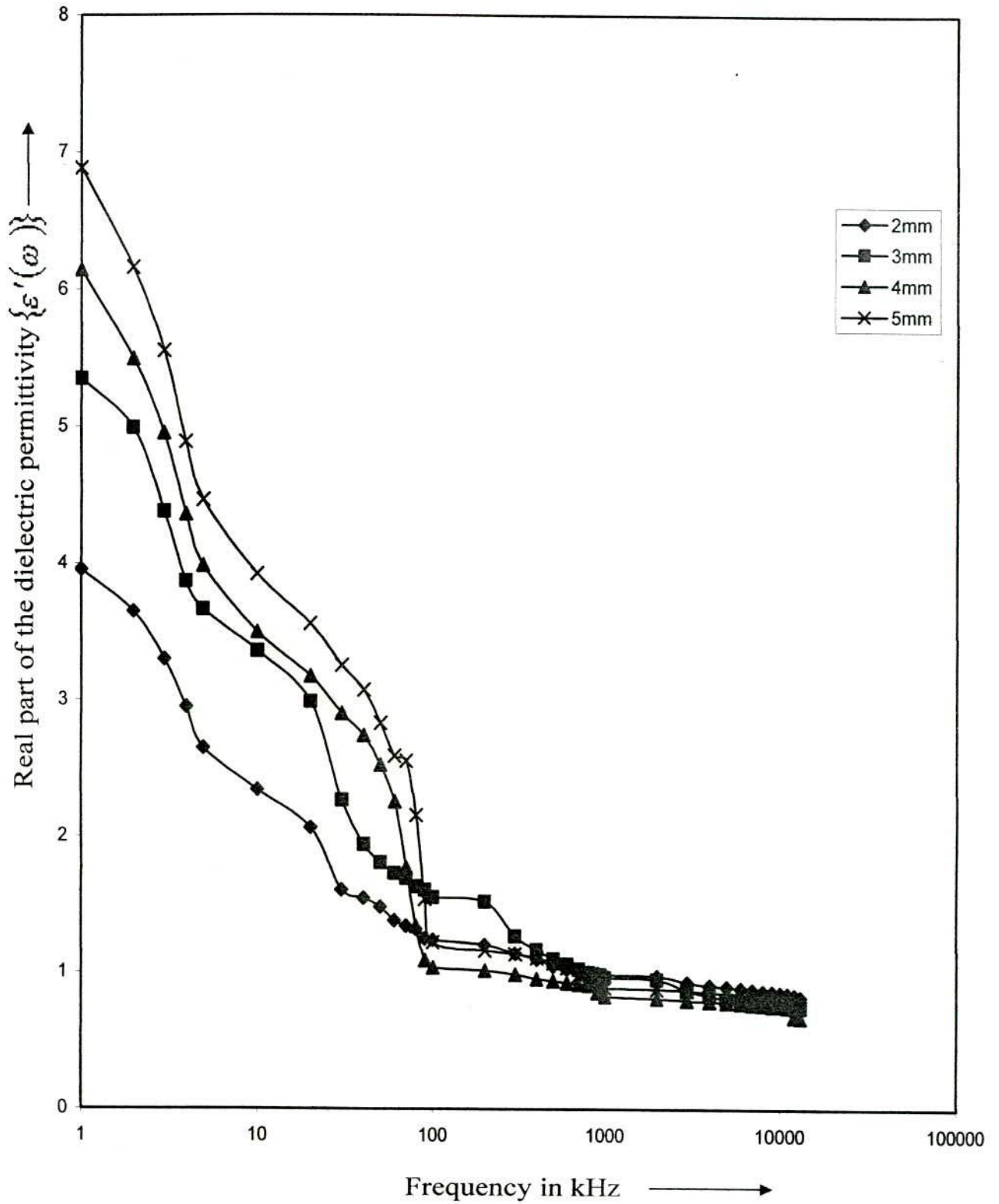


Fig-5.15: 3% saline effect on frequency dependence of the real part of the dielectric permittivity of various thicknesses of Sundari wood slice at room temperature

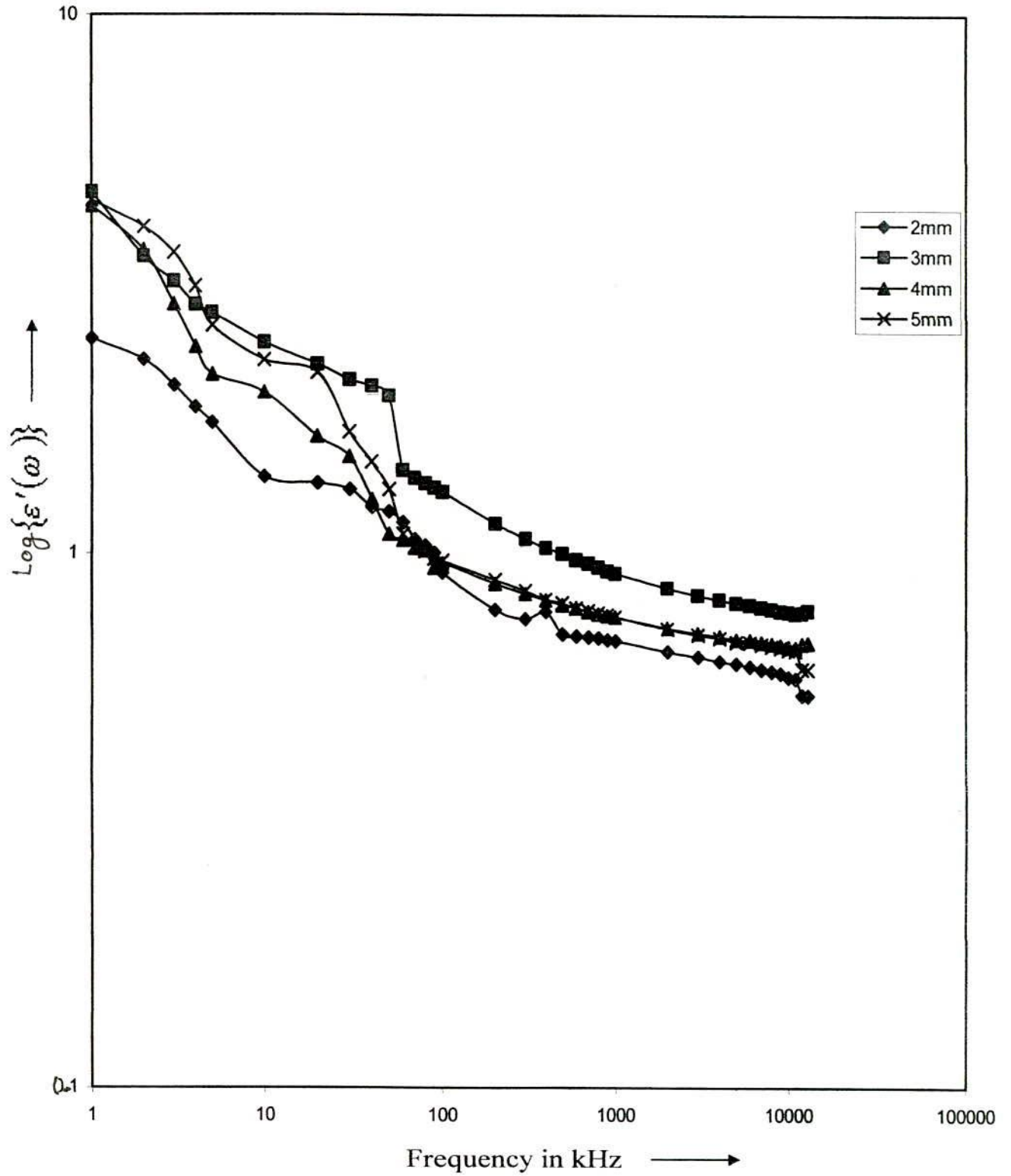


Fig-5.16: The frequency dependence on  $\log \{\epsilon'(\omega)\}$  of various thicknesses of the Sundari wood slice at room temperature

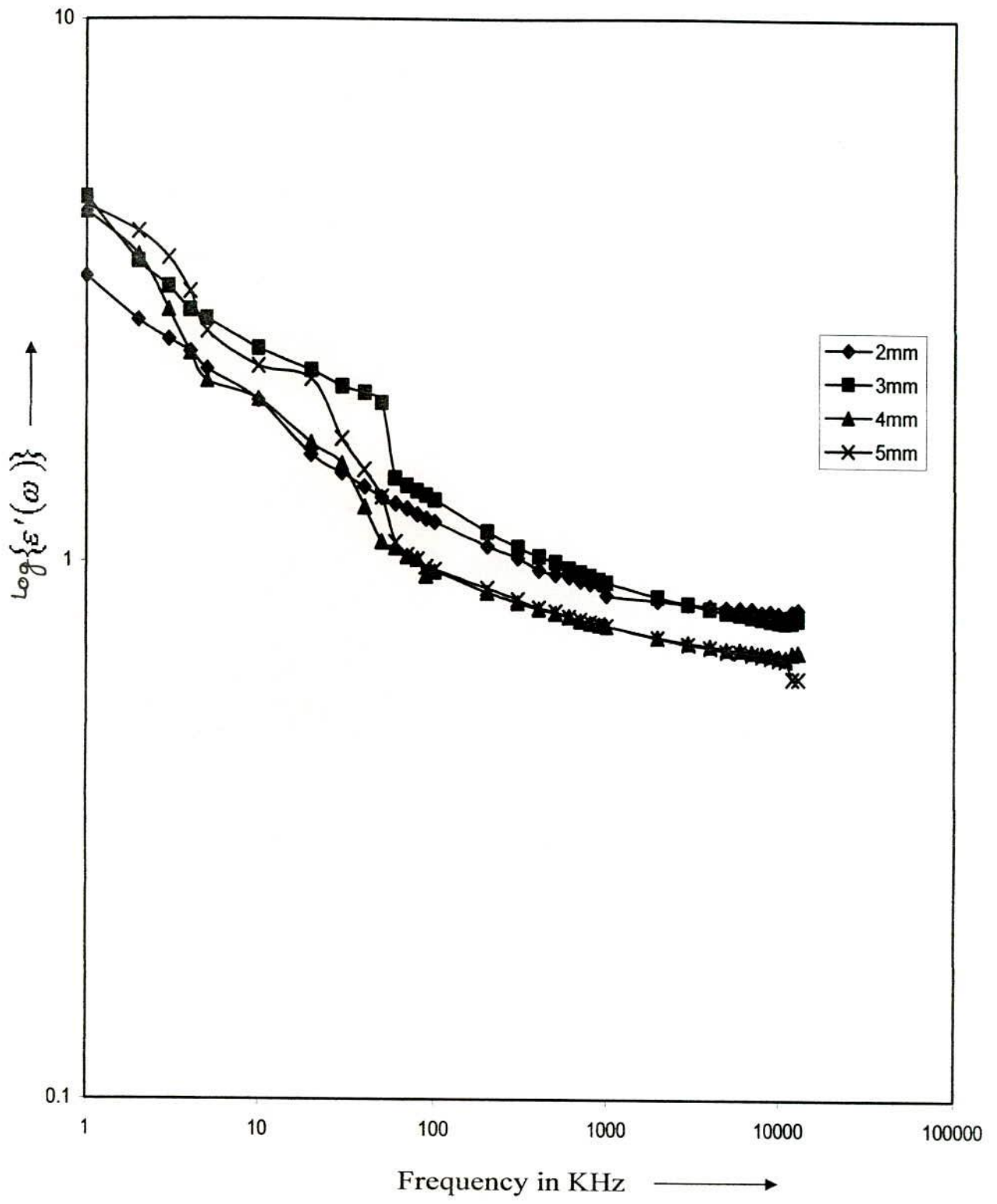


Fig-5.17: 0.5% Saline effect on frequency dependence of  $\log \{\epsilon'(\omega)\}$  of various thicknesses of Sundari wood slice at room temperature

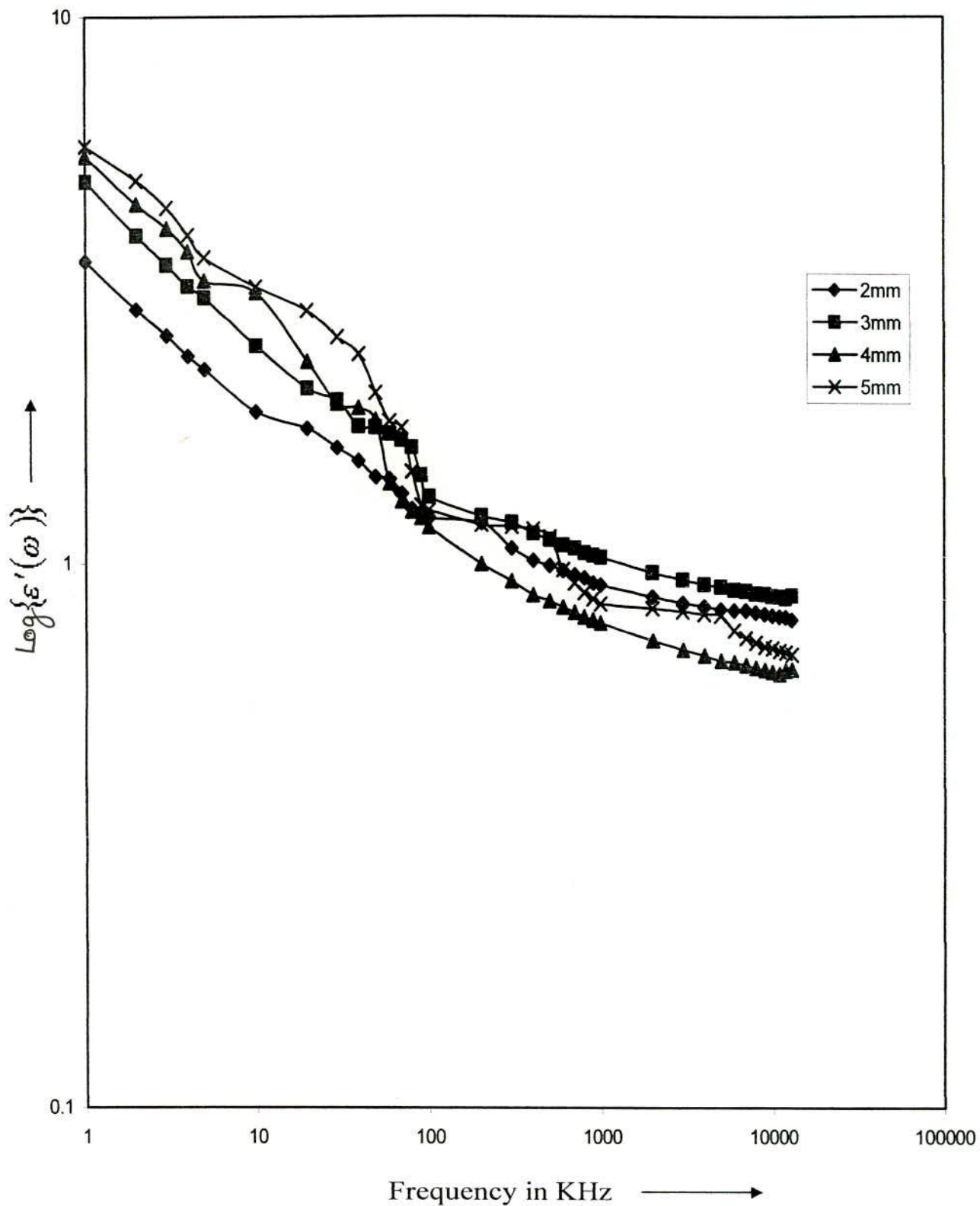


Fig-5.18: 1.5% Saline effect on frequency dependence of  $\log [\epsilon'(\omega)]$  of various thickness of Sundari wood slice at room temperature

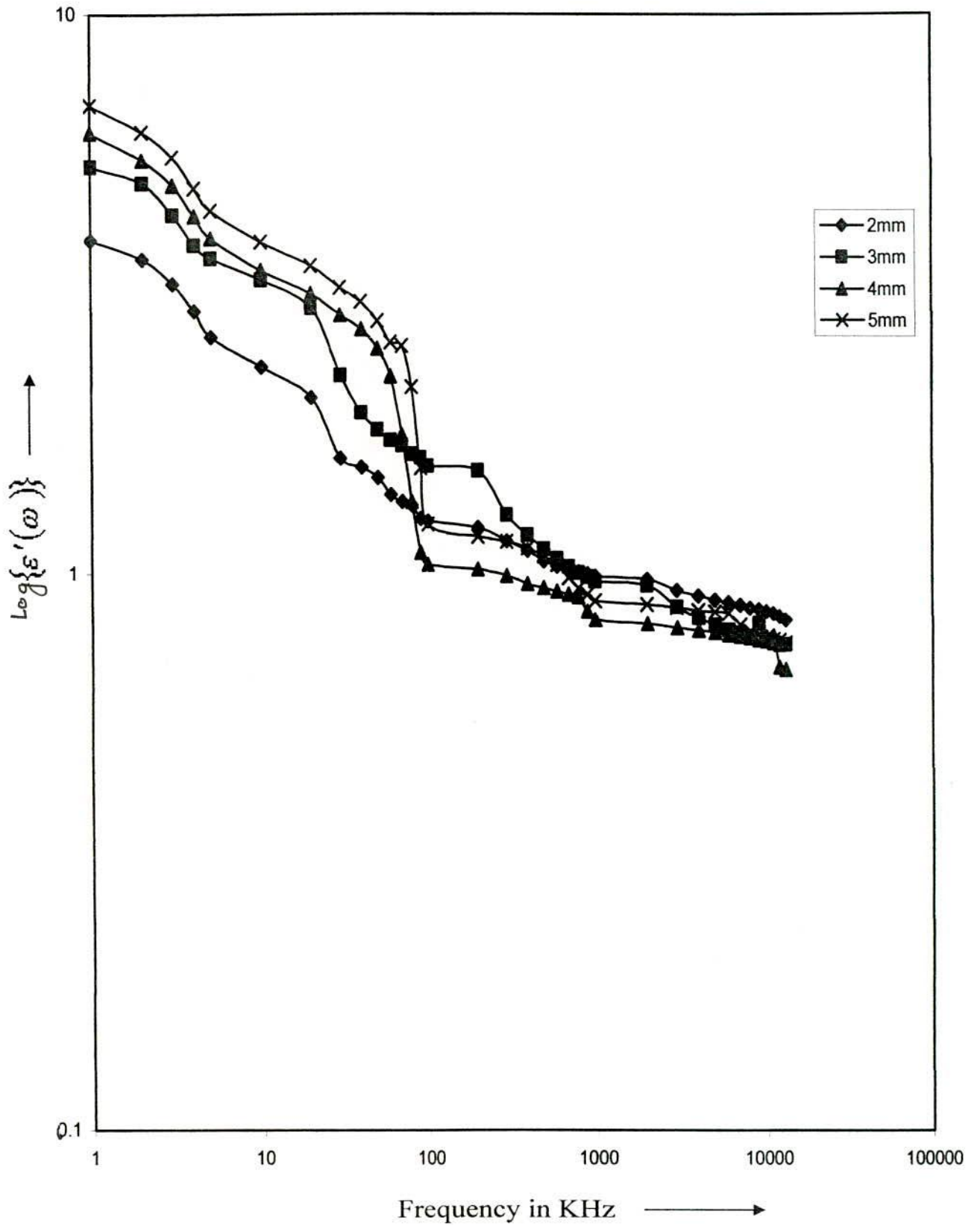


Fig-5.19: 3% Saline effect on frequency dependence of  $\log [\epsilon'(\omega)]$  of various thicknesses of Sundari wood slice at room temperature

Table-5.8: Saline effects on Sundari wood slice (the value of conductivity, dielectric permittivity and complex tangent

Thickness	Saline Concentration	RANGE			RANGE		
		(1-----900)K			(1000--13000)K		
		n(Con)	n(dc)	n(Lf)	n(Con)	n(dc)	n(Lf)
2mm	Normal	0.5427996	1.024947877	0.943384	0.6350996	0.9872502	0.821367
	0.50%	0.5573602	1.039508518	0.964797	0.6366698	0.988820428	0.792223
	1.50%	0.5619788	1.044127089	0.982459	0.6389144	0.991065045	0.851557
	3%	0.5707653	1.052913642	0.972835	0.6455322	0.997682792	0.842964
3mm	Normal	0.5426533	1.024801595	0.924074	0.6314919	0.983642316	0.8072258
	0.50%	0.5746065	1.056754813	1.00092	0.638381	0.990531578	0.868003
	1.50%	0.581137	1.063285273	1.000763	0.6463074	0.998458014	0.855345
	3%	0.5916268	1.073775116	1.026889	0.6429517	0.995102316	0.895175
4mm	Normal	0.5350553	1.017203595	0.958852	0.6183443	0.970494891	0.823217
	0.50%	0.5517816	1.033929864	0.969294	0.6262375	0.978388163	0.824922
	1.50%	0.5756888	1.057837068	1.015128	0.6263135	0.97846412	0.870963
	3%	0.5913874	1.073535736	1.017606	0.6335136	0.985664255	0.852603
5mm	Normal	0.534111	1.018259313	0.961079	0.6181551	0.971305697	0.82975
	0.50%	0.5603136	1.042461899	0.974333	0.6260338	0.97814421	0.824439
	1.50%	0.5895572	1.071705514	1.020719	0.6350249	0.987175533	0.866653
	3%	0.6055331	1.087681394	1.032818	0.639136	0.991286674	0.84906

Similar procedures are calculated the various saline effects on complex number of these samples and their various thicknesses. Complex number increases with increasing saline concentration for low frequency range as shown in table 5.8. Complex number almost same as values nearly 0.98 for all the samples and with saline effects shown in table- 5.8.

### 5.3.1 Measurements of dynamic loss factor of Sundari Wood slice and its saline effects

The loss factor  $\epsilon'' = \epsilon' \tan \delta$ , which measures the proportion of electric field energy converted into thermal energy within a volume of Sundari wood. The loss factor of wood also depends strongly on the properties of the free water salinity and thickness of the specimen. Which can vary significantly with frequency. The frequency variation of dielectric loss of Sundari wood of different thicknesses are shown in fig-5.20. The dielectric loss factor decreases sharply with a increase in frequency. This is due to conductive loss, which is dominating at these lower frequencies.

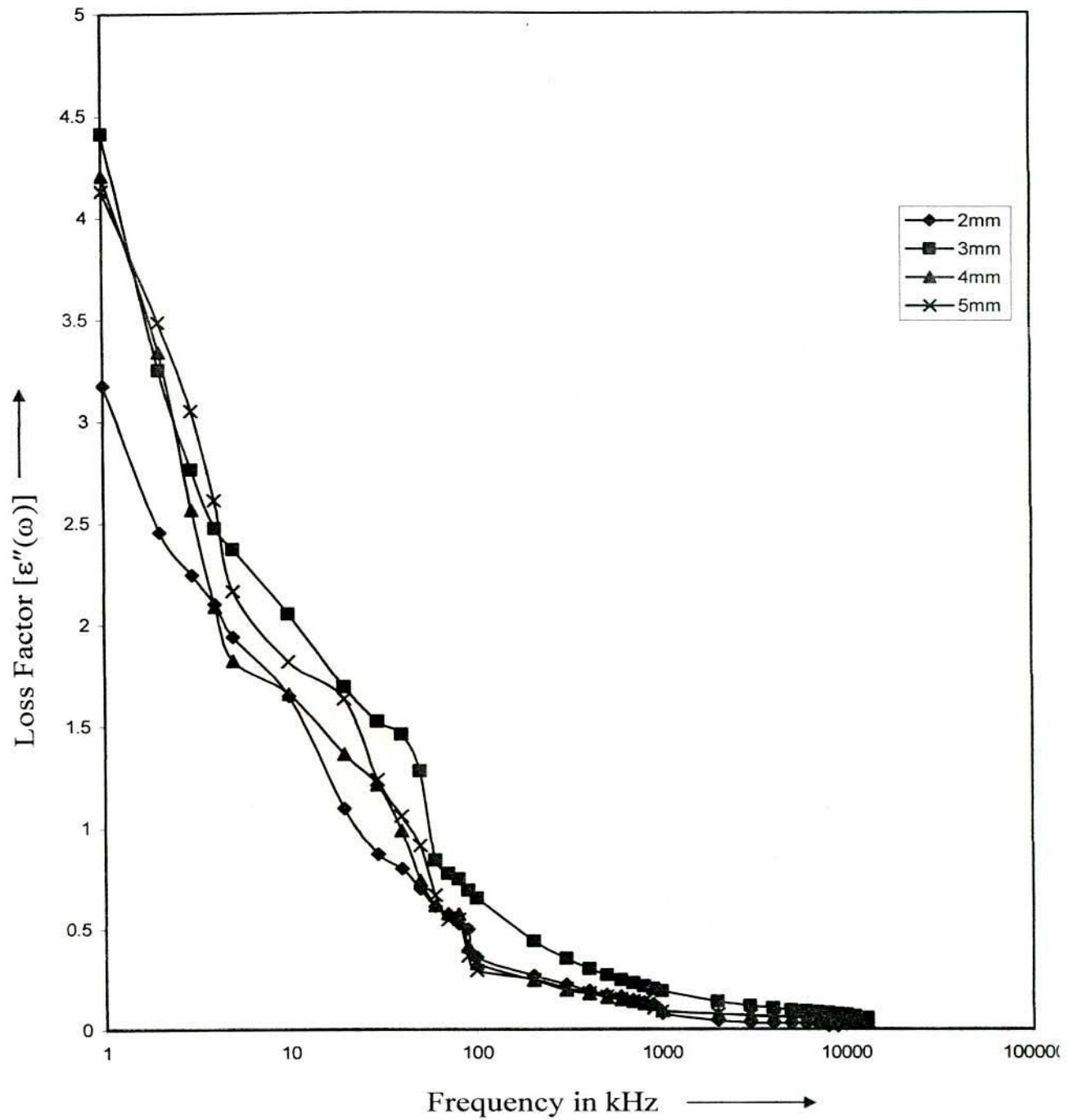


Fig-5.20: The frequency dependence of loss factor  $\epsilon''(\omega)$  of various thicknesses of the Sundari wood slice at room temperature.

Alternatively  $\log \epsilon''(\omega)$  versus  $\log f$  similar plots of various thicknesses Sundari wood slice samples are shown in fig-5.21.

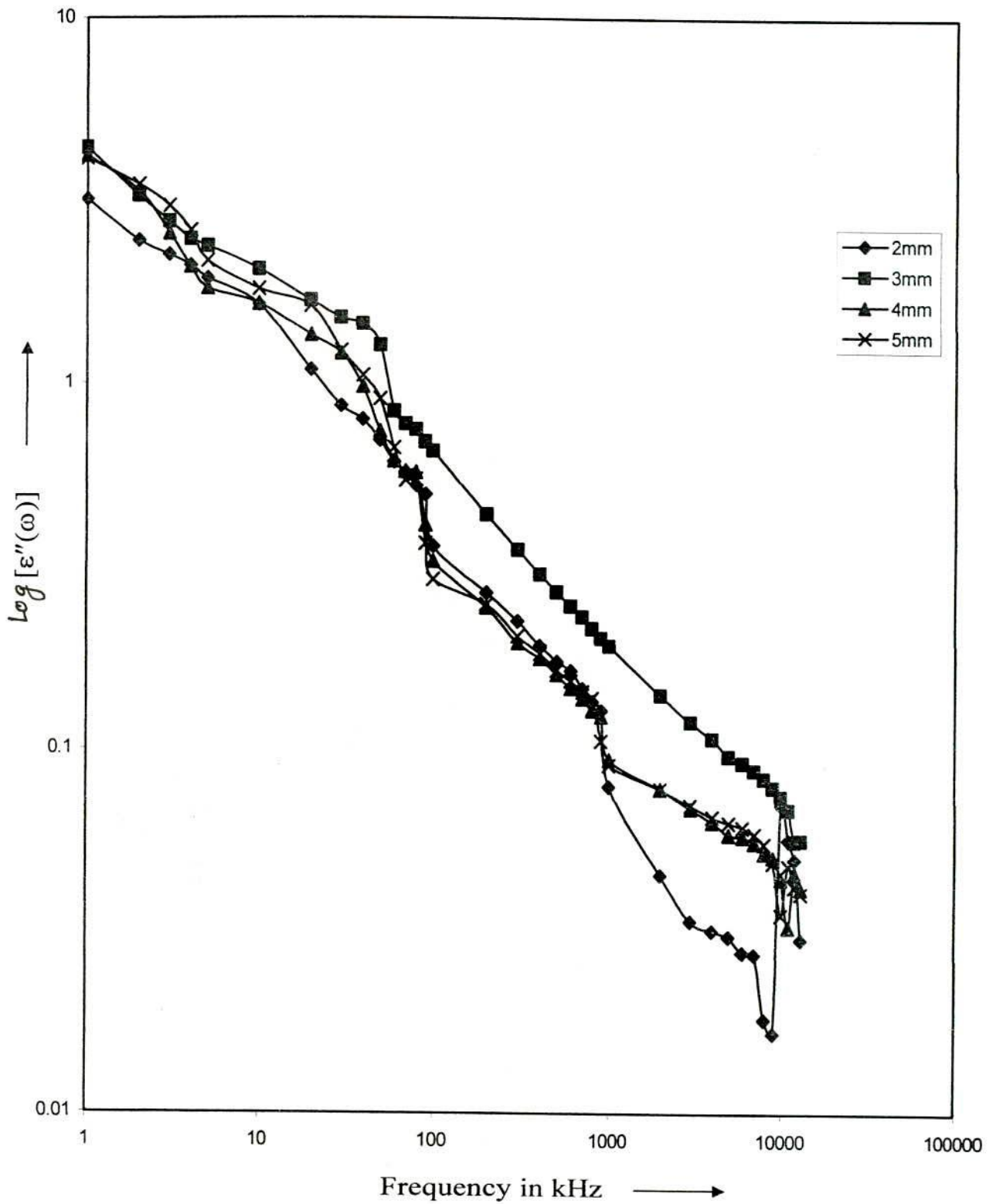


Fig-5.21: The frequency dependence on  $\log [\epsilon''(\omega)]$  of various thicknesses of Sundari wood slice at room temperature.



The data show that  $\epsilon''(\omega)$  decreases with increasing frequency. The value of  $\epsilon''(\omega)$  varies from 2.50 to 0.11 at low frequency range of 1 to 900kHz and 0.089 to 0.032 at high frequency range of 1 to 13 MHz. These results also varied with thickness of the specimens. Loss factor increases with increasing thickness of the specimen. Similarly frequency dependence of  $\epsilon''(\omega)$  of various thickness of different saline effect are shown in fig-5.22 to fig- 5.24.

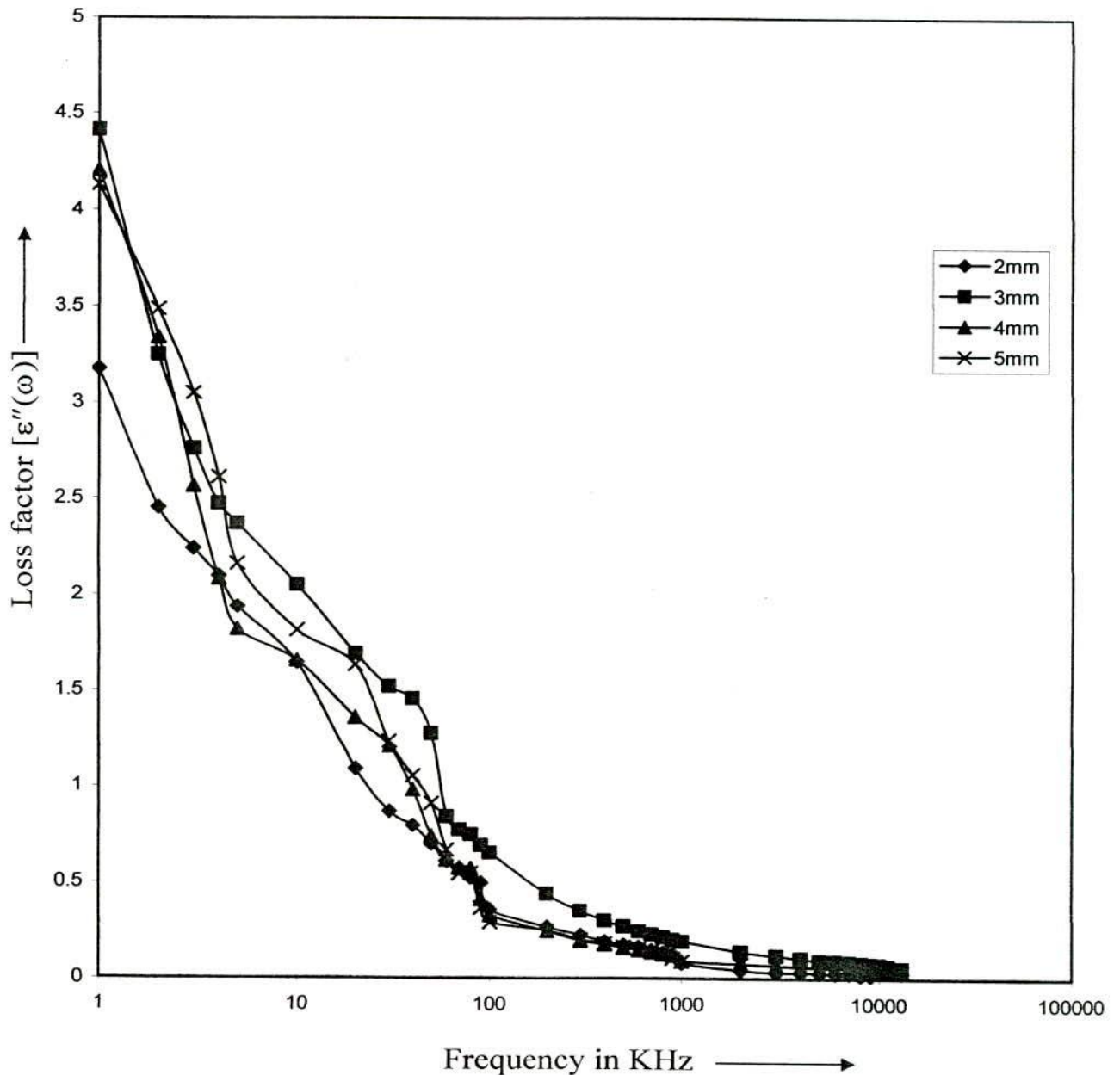


Fig-5.22: 0.5% Saline effects on the frequency dependence of  $\epsilon''(\omega)$  of various thickness of Sundari wood slice at room temperature

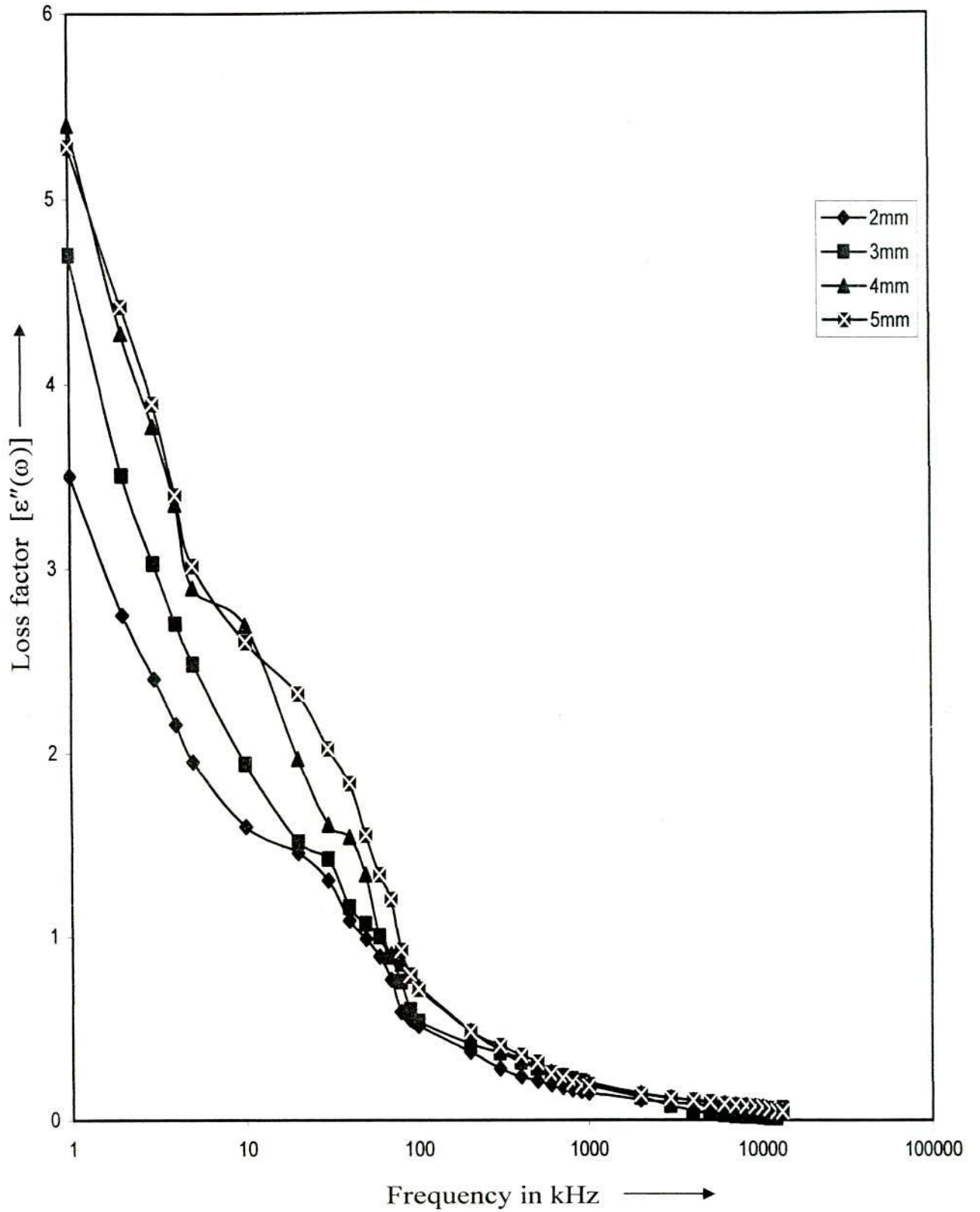
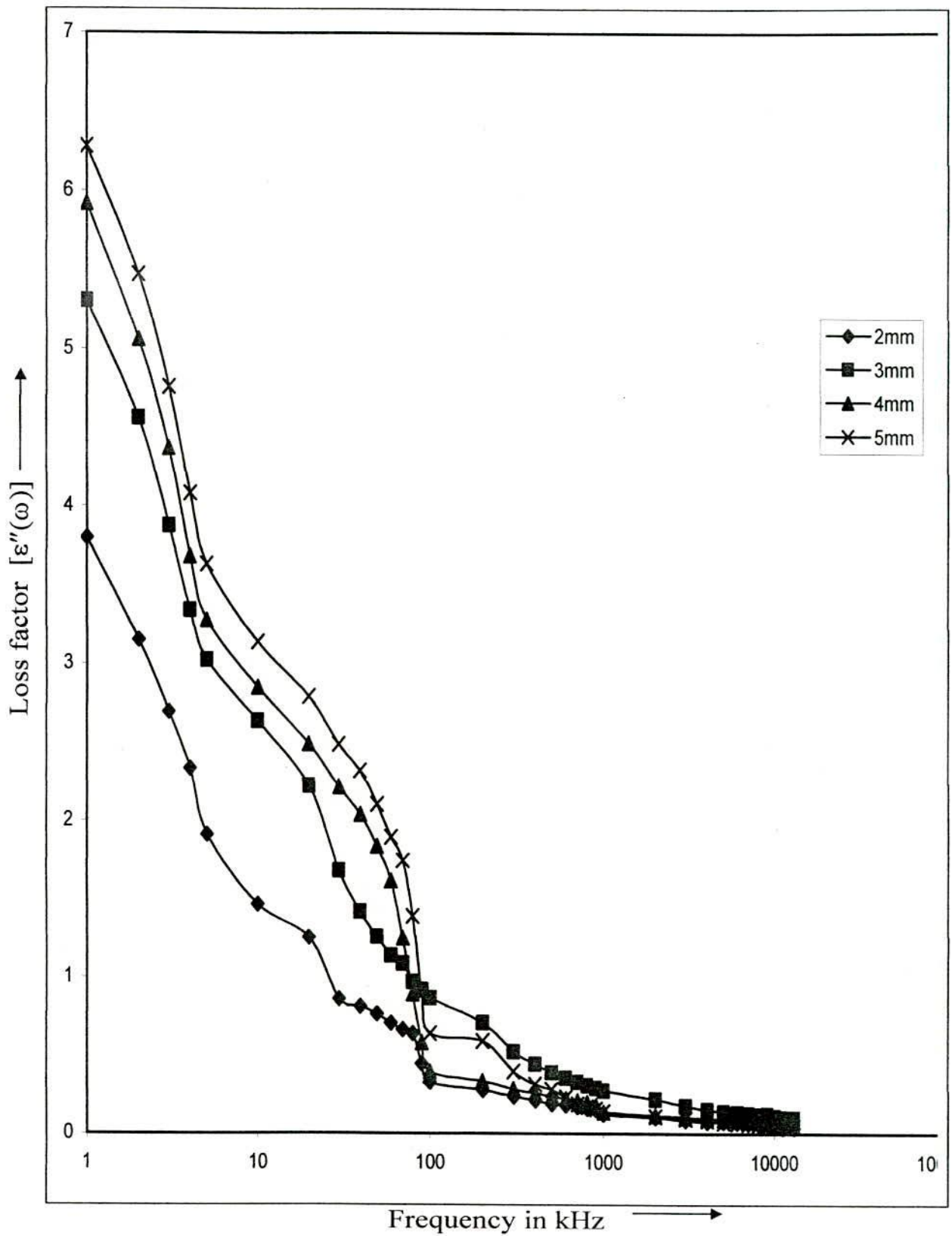


Fig-5.23: 1.5% Saline effects on frequency dependence of loss factor  $[\epsilon''(\omega)]$  of Sundari wood slice at room temperature



**Fig-5.24:** 3% Saline effects on frequency dependence of loss factor  $[\epsilon''(\omega)]$  of Sundari wood slice at room temperature

The data show that  $\epsilon''(\omega)$  increases slowly with increasing saline concentration. The loss factor complex number of all experimental specimens are followed according to the relation:

$$n = \frac{\ln[\epsilon''(\omega)]}{\ln(\omega)} + 1 \quad (5.2)$$

Detail results of loss factor complex number of experimental specimen and their various thickness and saline effects for low frequency range (1 to 900 kHz) and high frequency range (1 to 13 MHz) are shown in table- 5.8. The loss factor decreases at both higher and lower frequencies. These results dominate the loss factor complex number for thickness of specimen and also depending on the salt concentration. Thus the nature of Sundari wood may be said disordered.

### **5.3.2 Measurements of Dynamic Conductivity of Sundari Wood slice and its Saline effects**

The conductance (G) and loss tangent ( $\tan \delta$ ) have been directly noted as a function of frequency. The obtained data has been used to derive the real part of the conductivity from the eq<sup>n</sup> (4.6). All the measurements were made in air at room temperature. Similar behavior has been observed in all the experimental specimens. The frequency dependence of  $\text{Re}[\sigma(\omega)]$  of Sundari wood slice at different thicknesses are shown in fig 5.25.

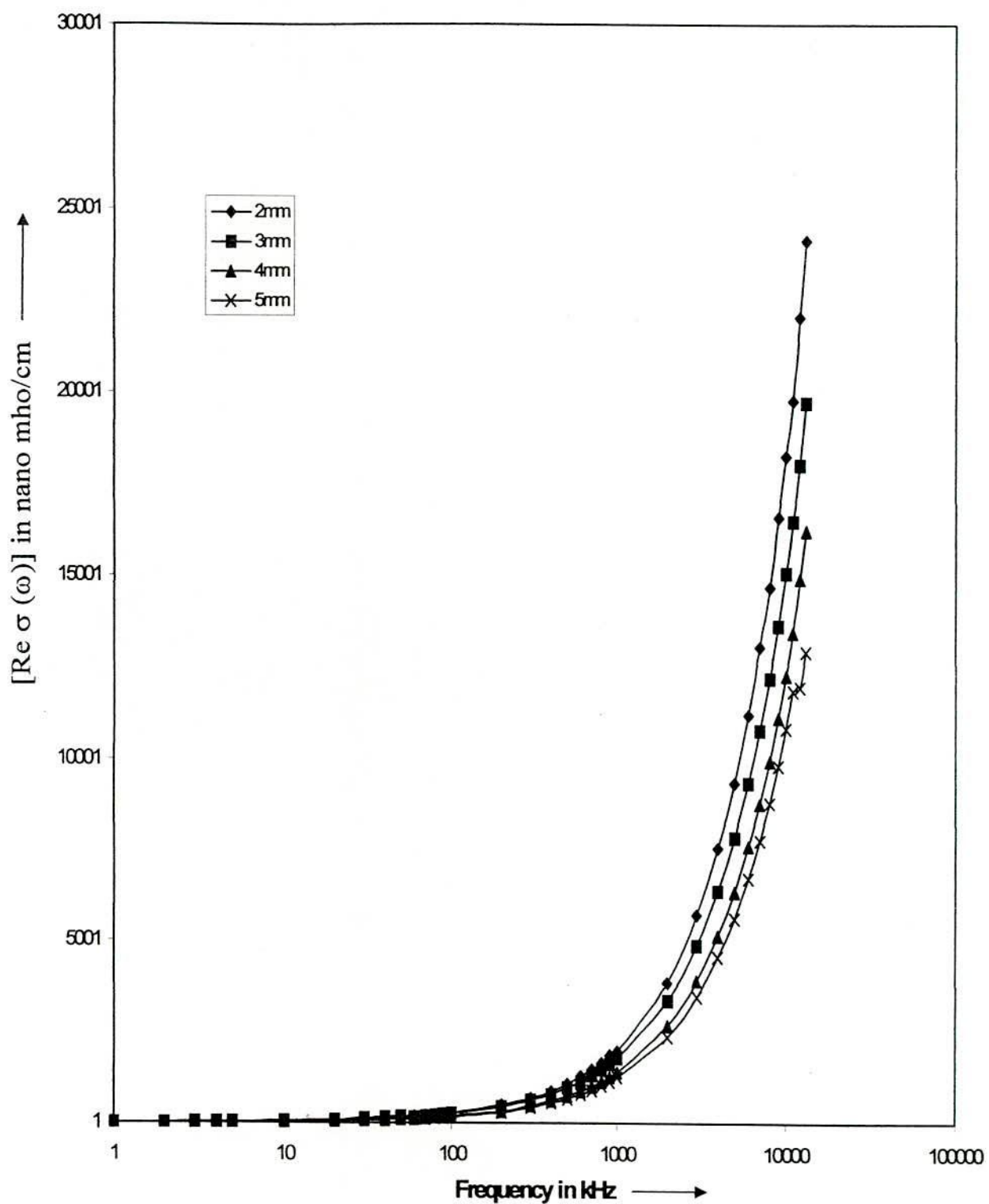


Fig-5.25. The frequency dependence of the real part of the conductivity  $\text{Re } \sigma(\omega)$  of various thicknesses of Sundari wood slice at room temperature

It can be observed that the room temperature conductivity enhances in the high frequency range (MHz). These frequency dependence of the real part of the conductivity follows a  $\text{Re}[\sigma(\omega)] \propto \omega^n$  law, where  $n < 1$ . Caution should be used there before interpreting all cases of rising conductivity with frequency as evidence of hopping conduction. The conductivity decreases with increasing thickness of the specimens. Similarly frequency dependence of  $\sigma(\omega)$  of various thickness of different saline effect are shown in fig-5.26 to fig-5.28.

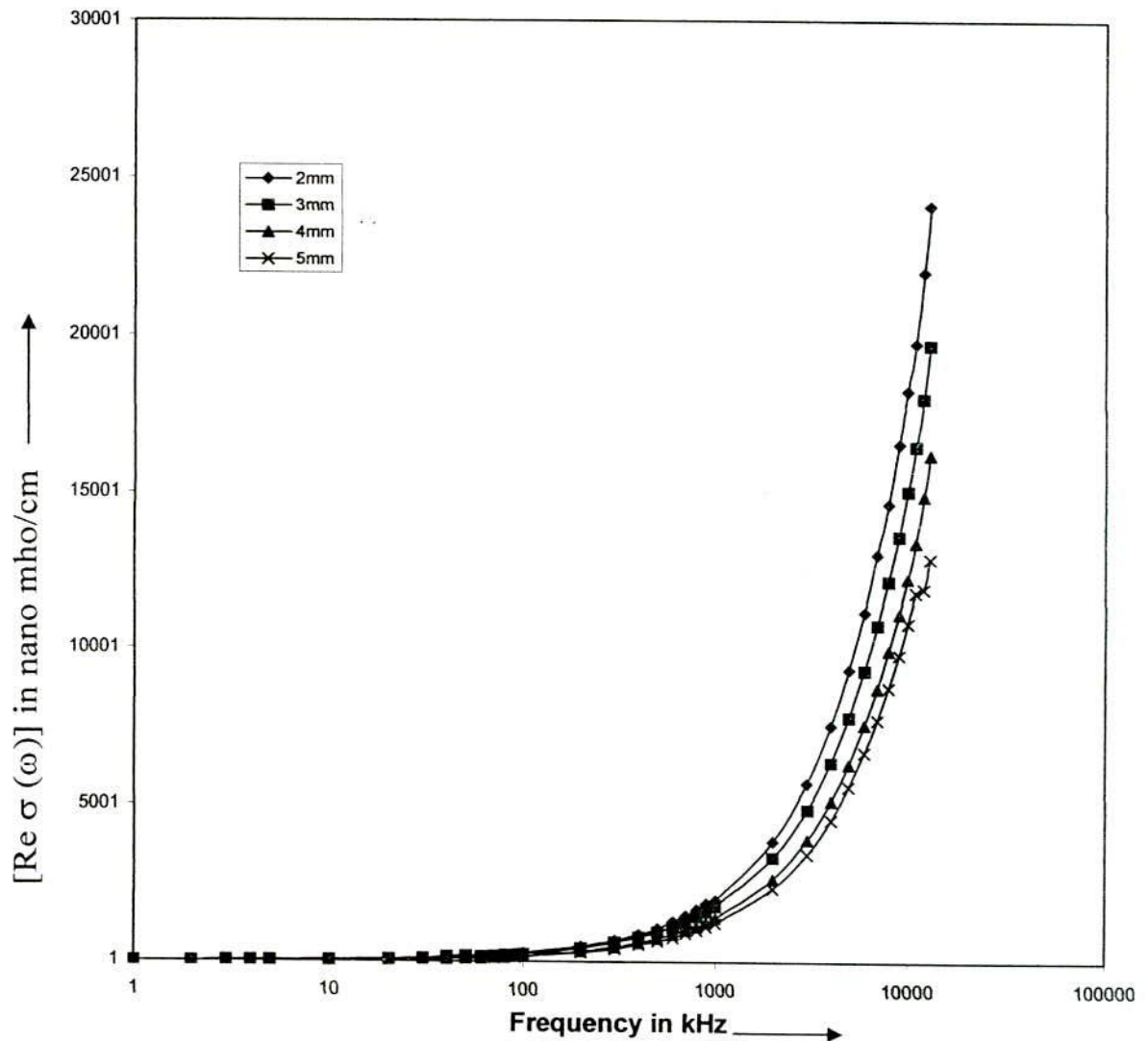


Fig-5.26. Frequency dependence of the real part of the conductivity  $\text{Re} \sigma(\omega)$  of various thickness of Sundari wood slice soaked in 0.5% NaCl at room temperature

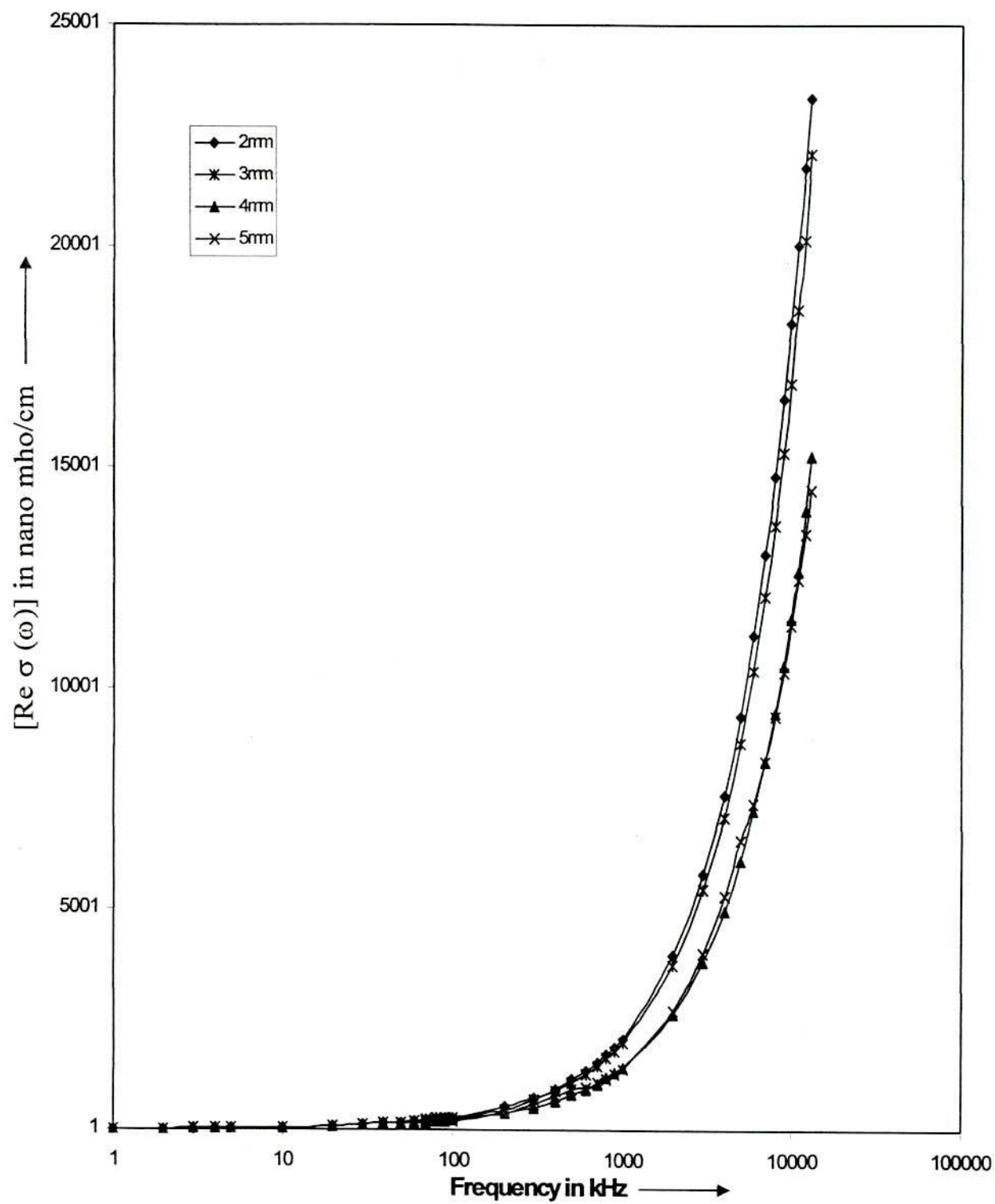


Fig-5.27. Frequency dependence of the real part of the conductivity  $\text{Re } \sigma(\omega)$  of various thicknesses of Sundari wood slice soaked 1.5% NaCl at room temperature

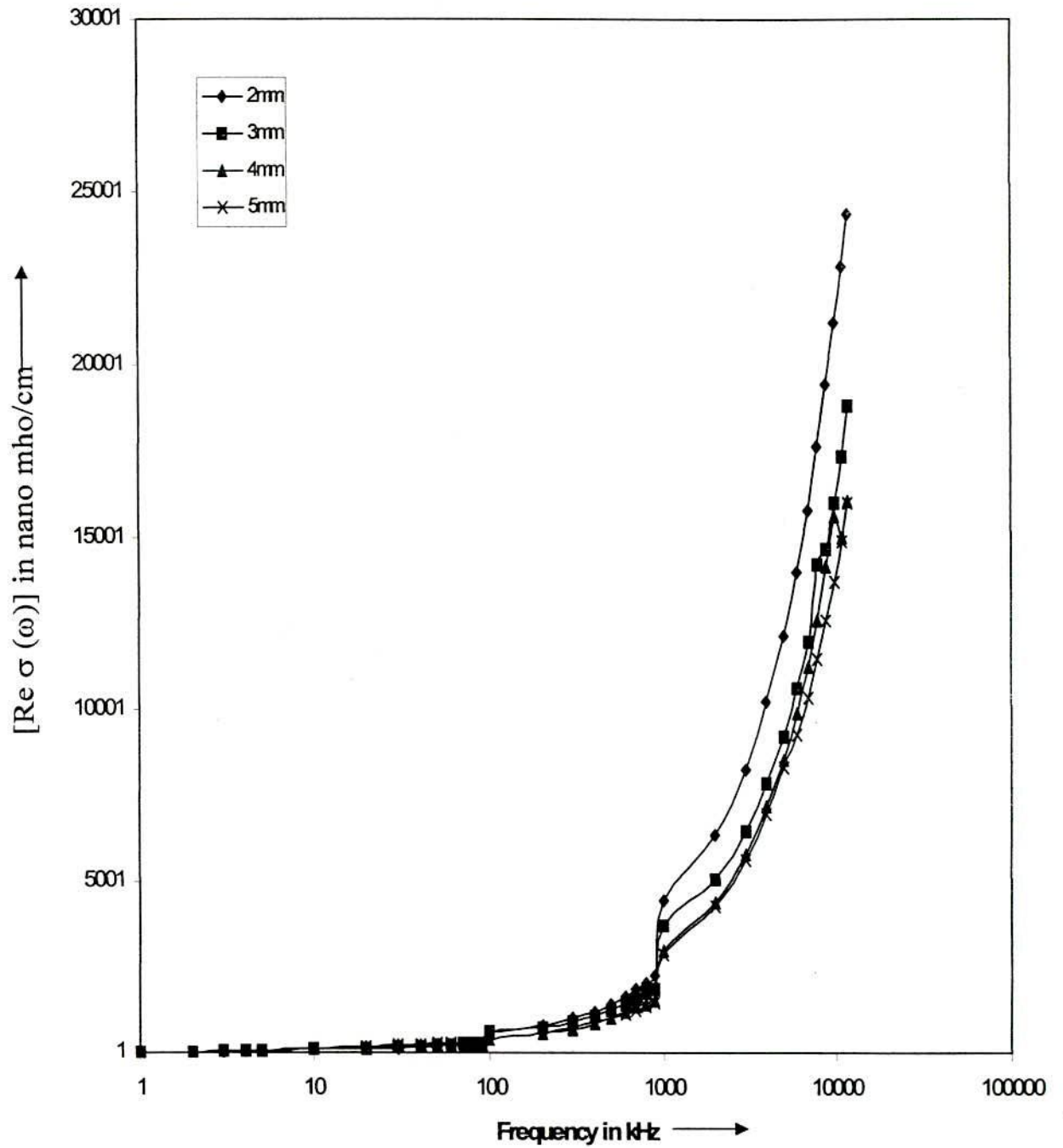


Fig-5.28: Frequency dependence of the real part of the conductivity  $\text{Re } \sigma(\omega)$  of various thicknesses of Sundari wood slice soaked 3% NaCl at room temperature



The conductivity increases with increasing saline concentration. The conductivity of a hopping process is an increasing nonlinear function of saline concentration this is in contrast to band conduction, which exhibits a slow decrease due to free movement of saline charge carriers through a periodic lattice. The frequency dependence of conductivity in a hopping system compensated Sundari wood cell in the impurity conduction range.

In fig-5.29 to fig-5.32 conductivity data of Sundari wood slice are plotted as  $\log [\sigma(\omega)]$  versus  $\log f$ .

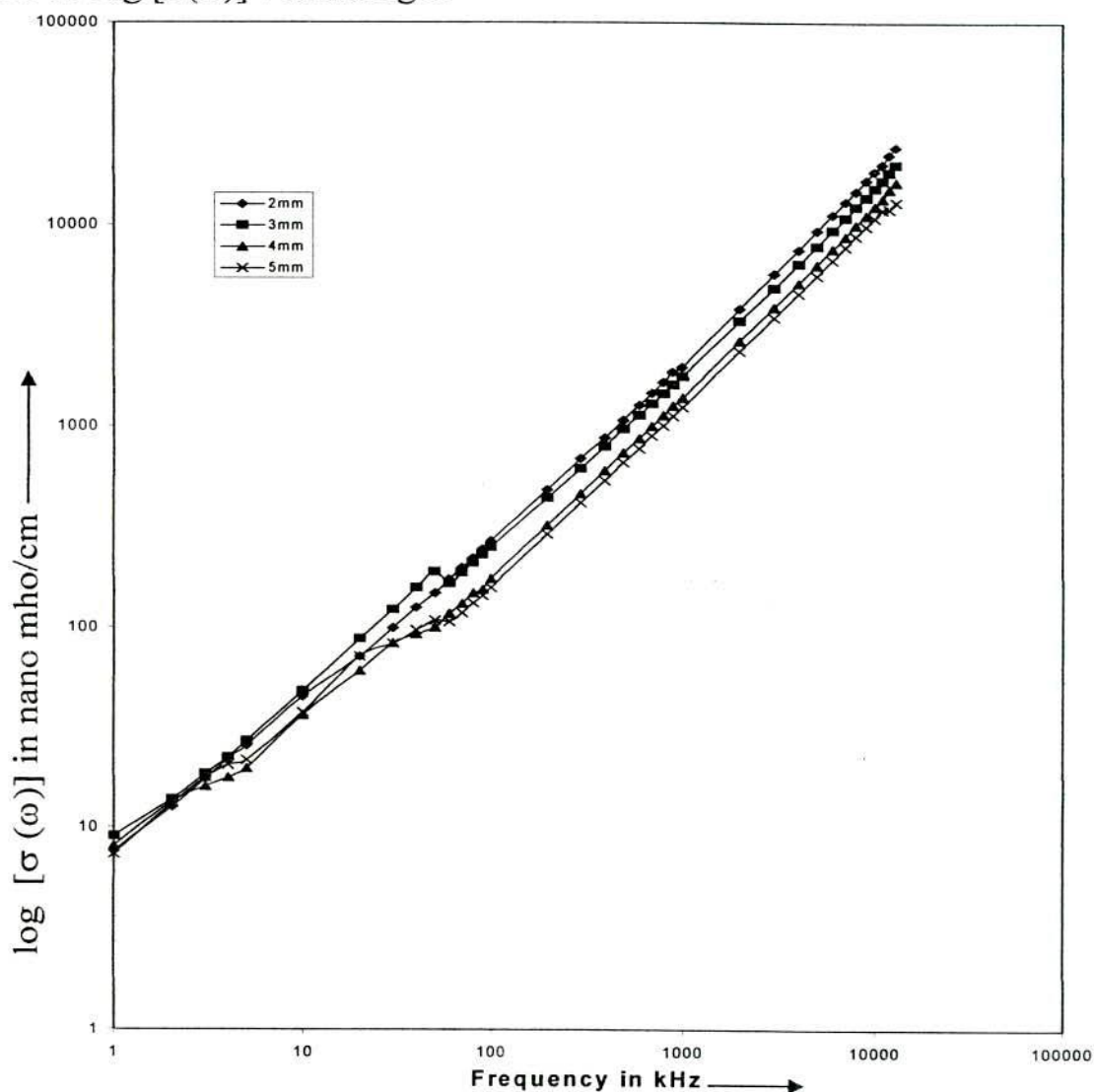


Fig-5.29. The frequency dependence of the  $\log [\sigma(\omega)]$  of various thicknesses of Sundari wood slice at room temperature

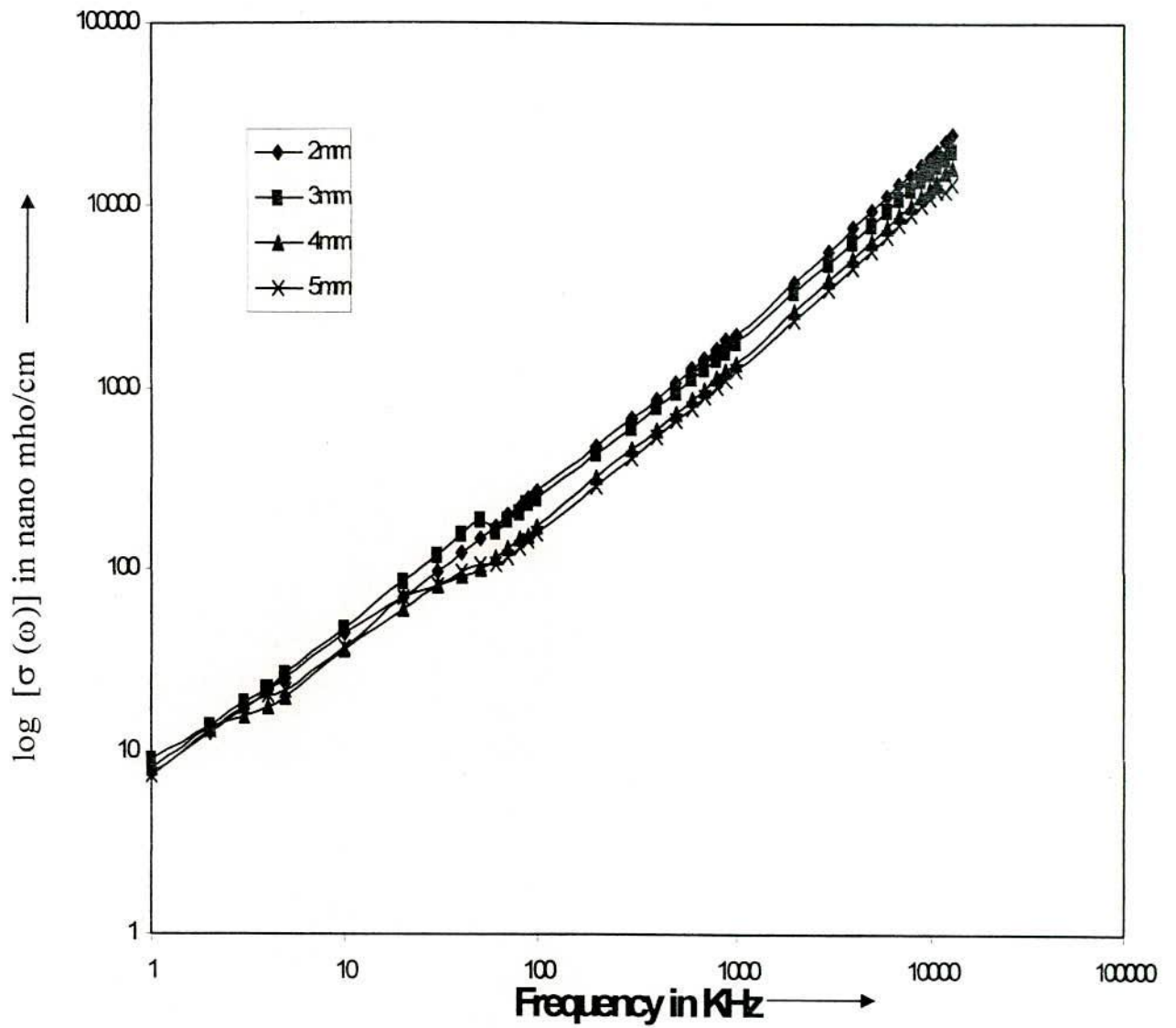


Fig-5.30. 0.5% Saline effects on the frequency dependence of the log  $[\sigma(\omega)]$  of various thicknesses of Sundari wood slice at room temperature

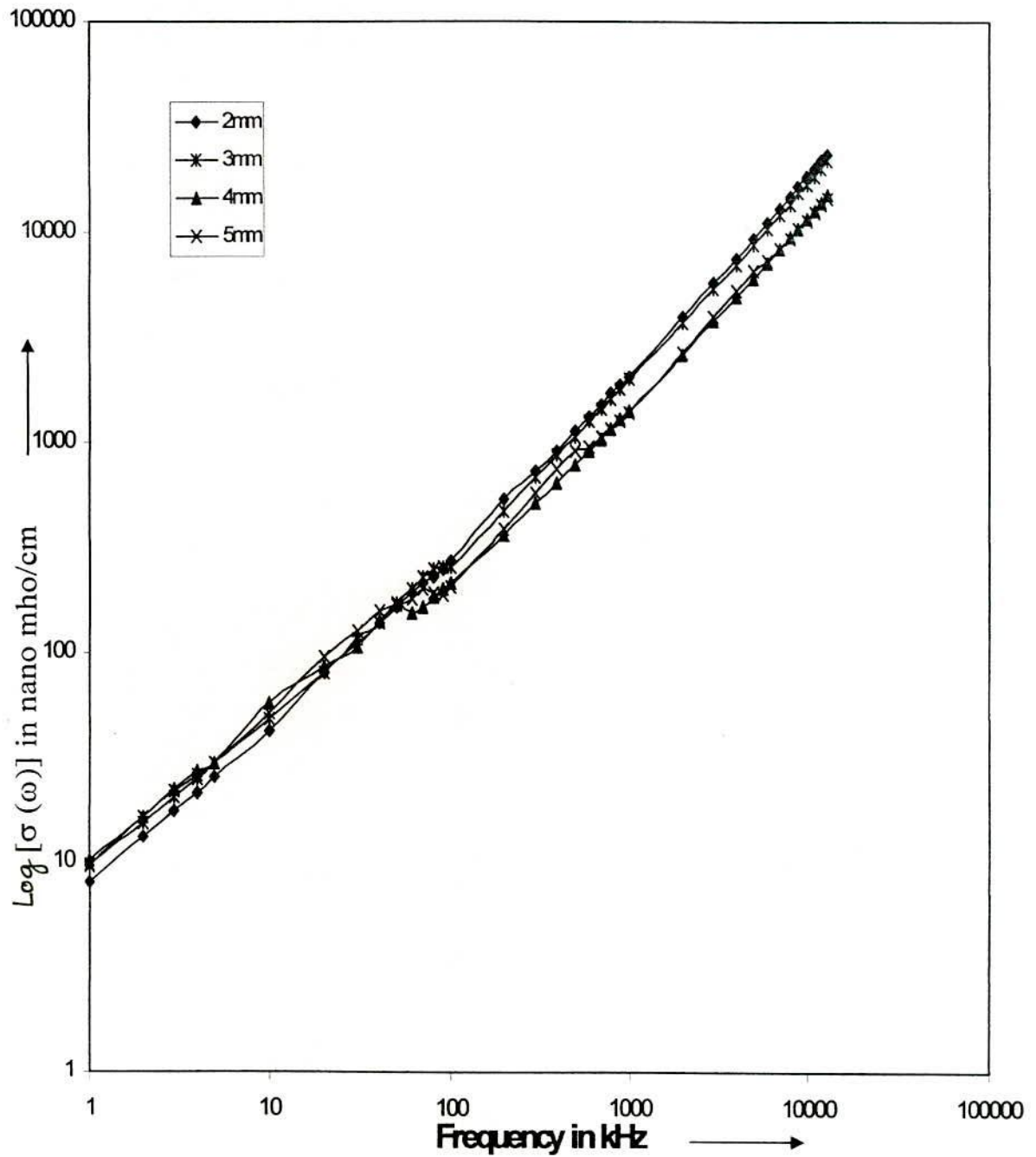


Fig-5.31. 1.5% Saline effects on the frequency dependence of the log  $[\sigma(\omega)]$  of various thicknesses of Sundari wood slice at room temperature

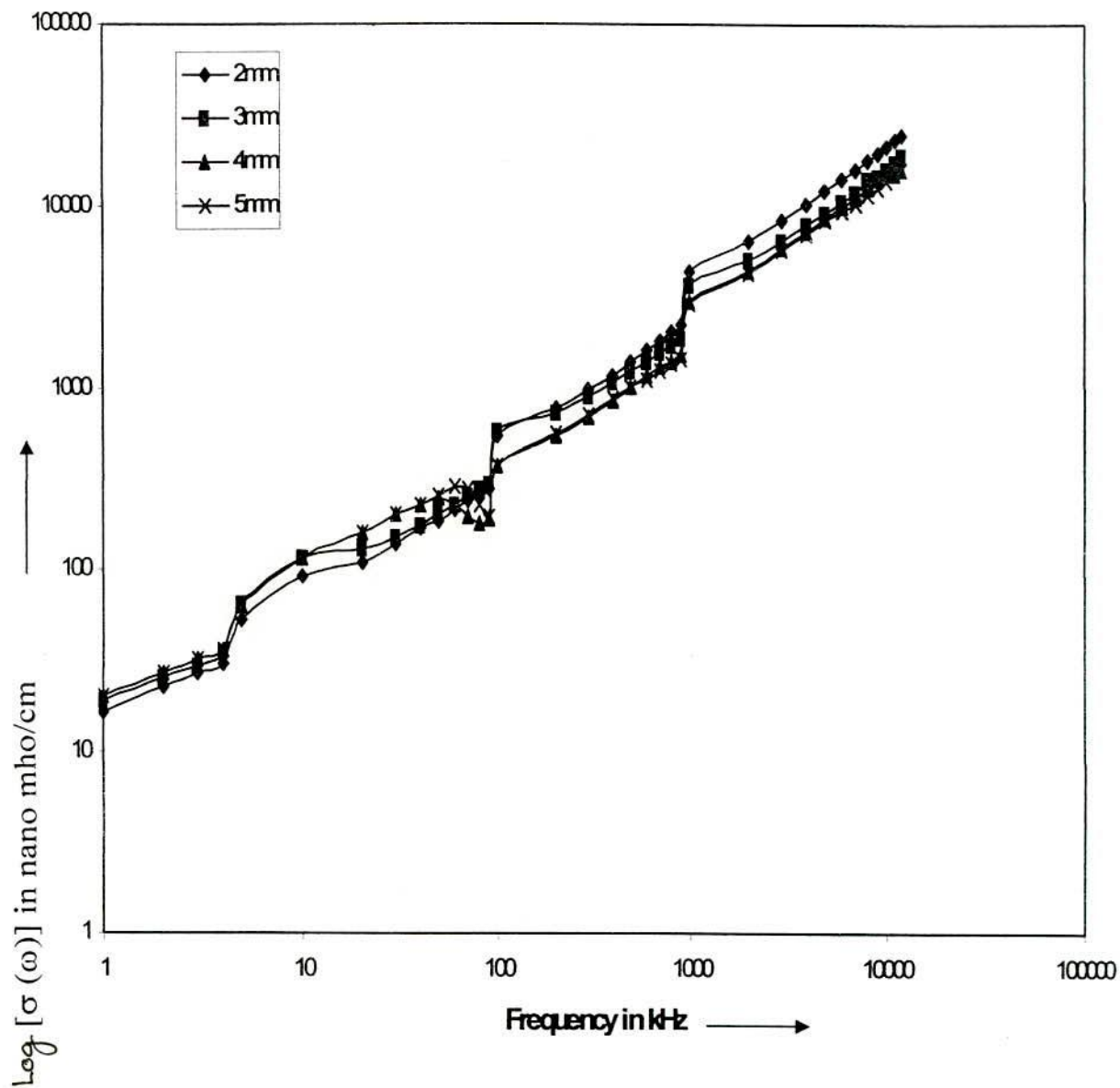


Fig-5.32. 3% Saline effects on the frequency dependence of the log  $[\sigma(\omega)]$  of various thicknesses of Sundari wood slice at room temperature

The conduction complex number of all specimens has been calculated from the following relation.

$$n = \frac{\log|\sigma(\omega)|}{\log(\omega)} + 1 \quad (5.3)$$

With  $n = 0.59$  for Sundari wood. It is significant to mention that  $n < 1$  that all the specimens showed similar behavior but the values of complex conduction number decreases slightly with the increase of thickness of the specimens. The result also show that the conduction complex number increases with the increase of applied frequency range (MHz range) and with typical values are shown in table- 5.8. The nature of the frequency variation of conductivity of all the samples showed similar behavior. Hence the value of conduction complex number increases with increasing saline concentration. The conduction lower frequency and tend to merge together at higher frequency range. In a wide range of Sundari wood material it is generally found that the frequency dependence of complex conduction number is less than unity.

#### **5.4 Salinity Effects on Thermal Conductivity of Sundari Wood**

Wood is a composite material. It is composed of cells. When wood contains just enough water to saturate the cell walls it is said to be at fiber saturation point. The water in the cell walls is known as hygroscopic water wood can absorb and retain within itself a certain amount of this type of moisture and can actually pick it up from the surrounding atmosphere. Therefore, the amount of water within to the cells, even of seasoned wood, depends to some extent on whether the wood is sapwood or heart wood.

When a slice of Sundari wood is exposed to air, evaporation takes place and continues until there is a balance between the water in the wood and the moisture in the air. The insulation value of wood varies with its

moisture content, density and temperature. The thermal conductivity (K) of wood is nearly linearly proportional to its density. Slight variations in conductivity may be disregarded for most purposes. Cell walls consist essentially of cellulose in the form of fiber, which are long spiral strands. Some lignin is also present. The cellulose itself is a good insulator and the conductivity of these specimens depends on the moisture content.

When Sundari wood is treated with concentrated salt solutions the salts enter the cell walls to give a concentration practically as great as the bulk concentration. The value of the thermal conductivity for these specimens soaked in NaCl solution has been found to conductivity increase with increasing saline concentration. The results are presented in Table- 5.9 to Table- 5.10. Fig-5.33 and fig-5.34 show at thermal conductivity increases with increasing saline concentration.

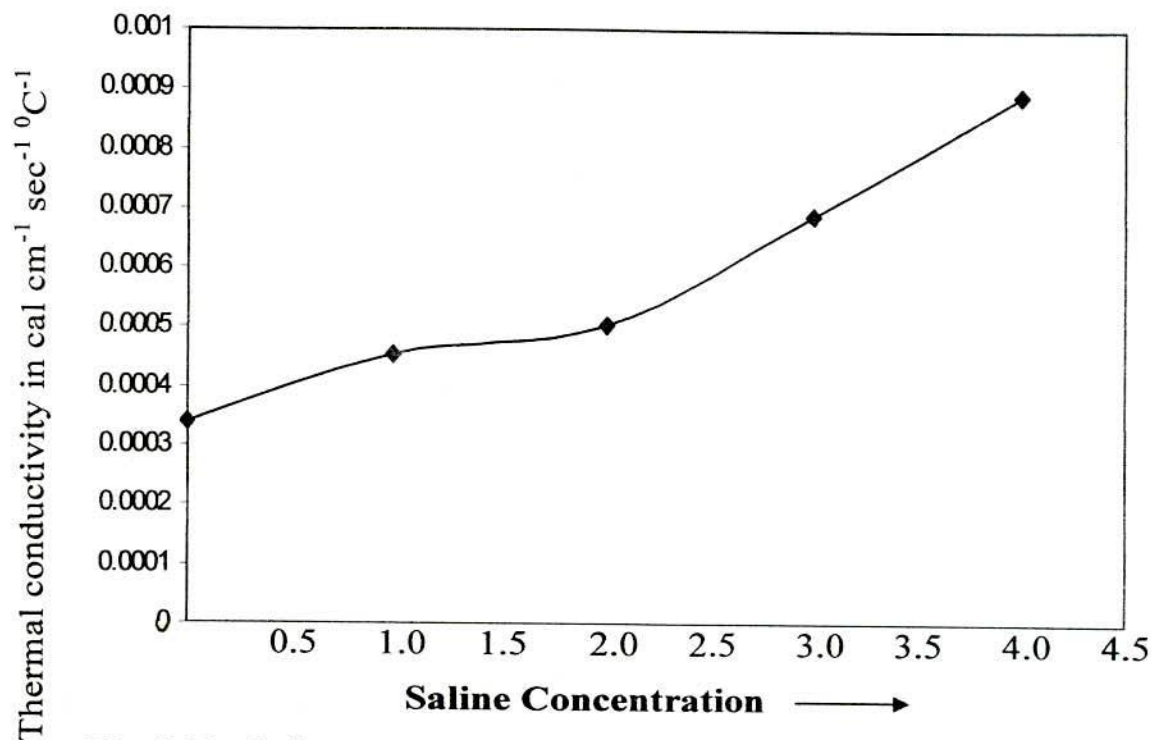
Thermal conductivity of Sundari wood increases with increasing thickness of the specimens. Some saline ions are formed in the covalently bound matrix of the Sundari wood, when one or more electrons from one atom may transfer to the other and the resulting positive and negative ions attract each other. An example, is NaCl, where the bond exists between  $\text{Na}^+$  and  $\text{Cl}^-$  ions. Most of the atoms of different elements do not have their outermost shells completely filled, i.e. they do not have eight electrons in their outer most orbit. The electrons occupying the outermost orbit or shell of an atoms are called valence electrons. They determine the chemical and electrical properties of element. Element deficient in valence electrons are highly active in the sense of increases of thermal conductivity. Those elements which have one or two valence electron are good conductors of electricity. Ionic bonds occur between two different atoms and are due to the permanent transfer of valence electrons from one atom to another. It is a very strong bond. Such bonds are formed between sodium and chlorine atoms during the formation of sodium chloride.

Table-5.9: Saline effects on thermal conductivity of 2mm thick Sundari wood slice

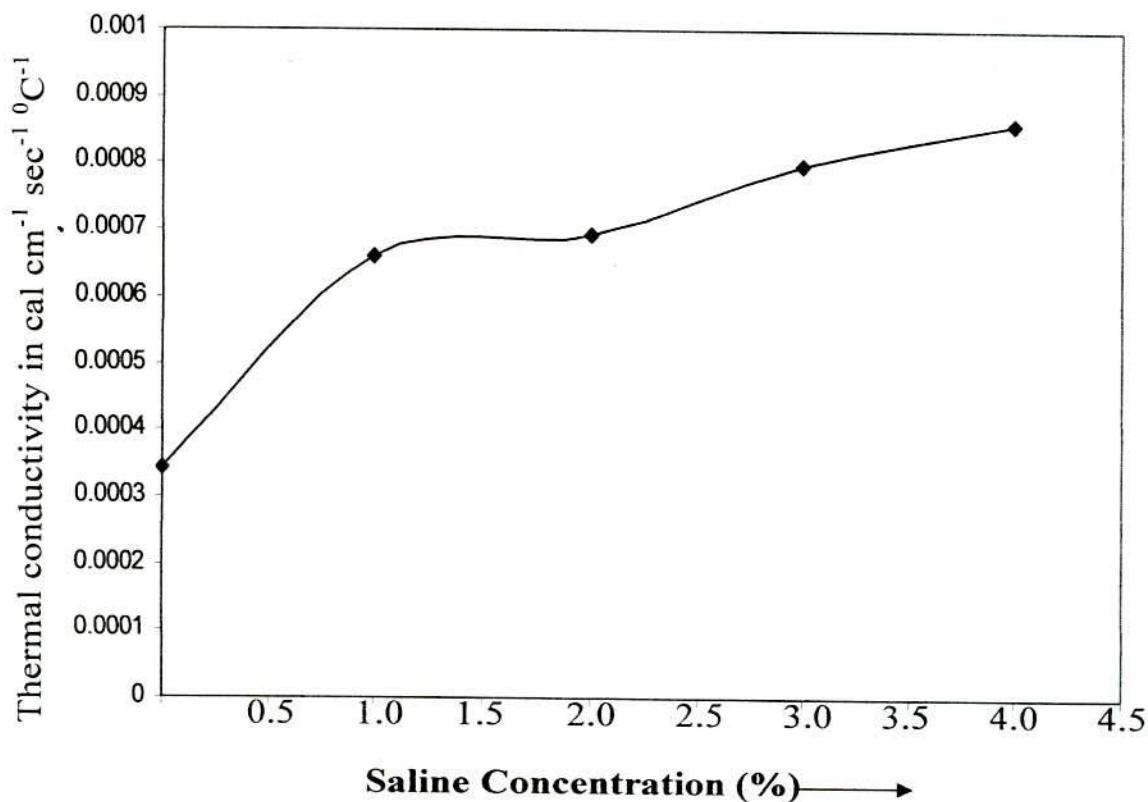
Saline concentration (%)	Mean temperature	( $\theta_1 - \theta_2$ )	$\frac{d\theta}{dt}$	$K = \frac{(0.839820 \times 0.0020617 + d_1)}{\theta_1 - \theta_2} \times \frac{d\theta}{dt}$ cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
dry	51	10	0.01667	0.0002828
1%	53.5	9	0.024111	0.0004546
2%	56.5	7	0.02111	0.0005117
3%	57	6	0.028333	0.0006868
4%	62.5	3	0.015778	0.0008924

Table-5.10: Saline effects on thermal conductivity of 3mm thick Sundari wood slice.

Saline concentration (%)	Mean temperature	( $\theta_1 - \theta_2$ )	$\frac{d\theta}{dt}$	$K = \frac{0.839820 \times 0.0020617 + d_1}{\theta_1 - \theta_2} \times \frac{d\theta}{dt}$ cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
dry	49.5	9	0.016111	0.0003037
1%	53.5	8	0.019444	0.0004564
2%	54	7	0.016444	0.0005950
3%	54.5	7	0.018889	0.0006798
4%	55.5	4	0.013556	0.0008590



**Fig-5.33:** Saline concentration versus thermal conductivity of 2mm thick Sundari wood slice.



**Fig-5.34** Saline concentration versus thermal conductivity of 3mm thick Sundari wood slice.



#### 5.4.1 Voltage dependence of Thermal Conductivity of Sundari Wood

The thermal conductivity of Sundari wood and cellulose does not follow ohm's law. Apparent resistance of cellulosic materials depends upon the applied voltage <sup>(75-77)</sup>. The direct temperature increases with increases in applied voltage from 10 to 14 volts. The value of thermal conductivity of Sundari wood slice has been determined under different voltage and saline concentrations are presented in table 5.11 to 5.18. These values are calculated using slopes obtained from fig-5.35 (a,b,c, & d) and fig 5.36 (e,f,g, & h). Fig 5.37 and fig 5.38 show that thermal conductivity increases with increasing saline concentration and increases applied voltage.

The saline electron in the outer most shell of an atom are called valence electron. They have least binding energy though their orbital energy is maximum. It is these electrons which are most affected when a number of atoms are brought very close together as during the formation of a solid. The energy band occupied by the valence electrons is called the valence band. It may be either completely filled or partially, filled with electrons but can never be empty.

The electron which have left the valence band are called conduction electrons. They practically leave the atoms or only weakly held to the nucleus. The band occupied by these electrons is called the conduction band. It may either be empty or partially filled with electrons. Current flow occurs in a given Sundari wood material, when a voltage of suitable magnitude is applied to it which cause the charge carrier within the material to move in a desired direction. This may be due to the process, i.e. electron motion and hole transfer. In electron motion, defect electron in the conduction band are moved under the influence of the electric field set up by the applied voltage.

But insulators are those experimental specimens in which valence electrons are bound very tightly to their parent atoms thus requiring very large electric field to remove them from the attraction of their nuclei. When the electron jump from the valence band to the conduction band then degrees of freedom is increased and then the thermal conductivity is also increased. Above this range, Sundari wood material affect the thermal conductivity result slightly increase with increasing applied voltage.

Table-5.11: The thermal conductivity of 2mm thick Sundari wood slice (Without saline)

Specimen thickness $d_1$ (cm)	Voltage (V)	$(\theta_1 - \theta_2)$	$\frac{d\theta}{dt}$	$K = \frac{0.839820 \times 0.0811915 + d_1}{\theta_1 - \theta_2} \times \frac{d\theta}{dt}$ cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
0.2	10	33	0.052083	0.000424
0.2	12	33	0.056259	0.000424
0.2	14	34	0.060660	0.000426

Table-5.12: 1% Saline solution effects on the thermal conductivity of 2mm thick Sundari wood slice

Specimen thickness $d_1$ (cm)	Voltage (V)	$(\theta_1 - \theta_2)$	$\frac{d\theta}{dt}$	$K = \frac{0.839820 \times 0.0811915 + d_1}{\theta_1 - \theta_2} \times \frac{d\theta}{dt}$ cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
0.2	10	18	0.041975	0.000542
0.2	12	19	0.049383	0.000585
0.2	14	19	0.051699	0.0005987

Table-5.13: 2% Saline concentration effects on the thermal conductivity of 2mm thick Sundari wood slice

Specimen thickness $d_1$ (cm)	Voltage (V)	$(\theta_1 - \theta_2)$	$\frac{d\theta}{dt}$	$K = \frac{0.839820 \times 0.0811915 + d_1}{\theta_1 - \theta_2} \times \frac{d\theta}{dt}$ cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
0.2	10	26	0.038085	0.000640
0.2	12	28	0.038095	0.000640
0.2	14	29	0.042857	0.000672

Table-5.14: 3% saline concentration effects on the thermal Conductivity of 2mm thick Sundari wood slice

Specimen thickness $d_1$ (cm)	Voltage (V)	$(\theta_1 - \theta_2)$	$\frac{d\theta}{dt}$	$K = \frac{0.839820 \times 0.0811915 + d_1}{\theta_1 - \theta_2} \times \frac{d\theta}{dt}$ cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
0.2	10	29	0.041379	0.000756
0.2	12	30	0.047190	0.000757
0.2	14	28	0.048275	0.000796

Table-5.15: The thermal conductivity of 4mm thick Sundari wood slice (dry sample)

Specimen thickness $d_1$ (cm)	Voltage (V)	$(\theta_1 - \theta_2)$	$\frac{d\theta}{dt}$	$K = \frac{0.839820 \times 0.0811915 + d_1}{\theta_1 - \theta_2} \times \frac{d\theta}{dt}$ cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
0.4	10	41	0.041975	0.000424
0.4	12	40	0.049383	0.000487
0.4	14	40	0.051699	0.000497

Table-5.16: 1% Saline concentration effects on the thermal conductivity of 4mm thick Sundari wood slice.

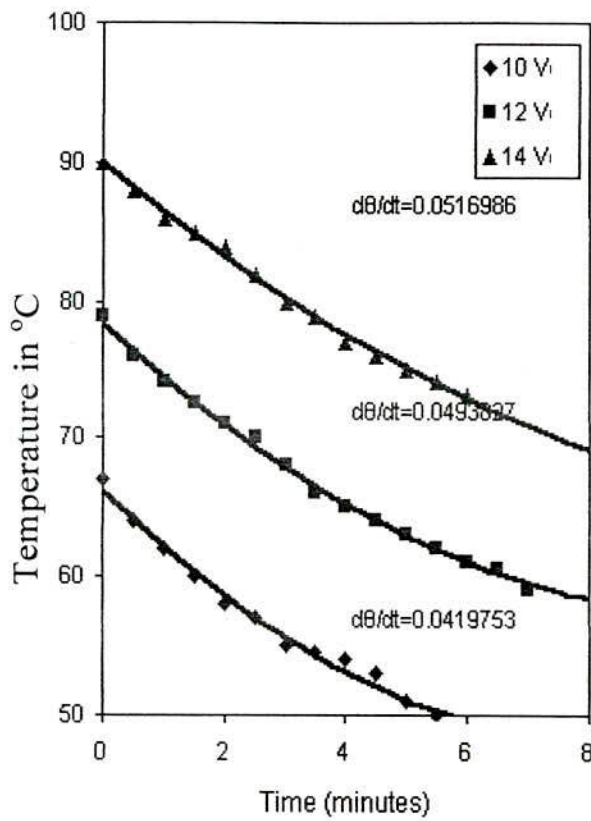
Specimen thickness $d_2$ (cm)	Voltage (V)	$(\theta_1 - \theta_2)$	$\frac{d\theta}{dt}$	$K = \frac{0.839820 \times 0.04811915 + d_1}{\theta_1 - \theta_2} \times \frac{d\theta}{dt}$ cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
0.4	10	28	0.040051	0.000591
0.4	12	29	0.041753	0.000601
0.4	14	30	0.049362	0.000605

Table-5.17: 2% Saline concentration effects on the thermal conductivity at 4mm thick Sundari wood slice

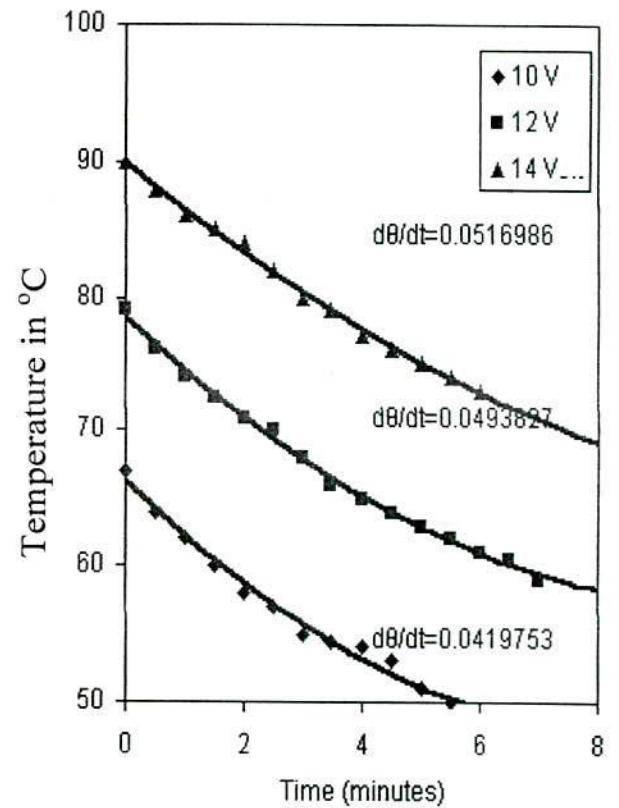
Specimen thickness $d_2$ (cm)	Voltage (V)	$(\theta_1 - \theta_2)$	$\frac{d\theta}{dt}$	$K = \frac{0.839820 \times 0.0811915 + d_1}{\theta_1 - \theta_2} \times \frac{d\theta}{dt}$ cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
0.4	10	35	0.035024	0.000643
0.4	12	34	0.037037	0.000650
0.4	14	35	0.037531	0.000674

Table-5.18: 3% Saline concentration effects on the thermal conductivity of 4mm thick Sundari wood slice

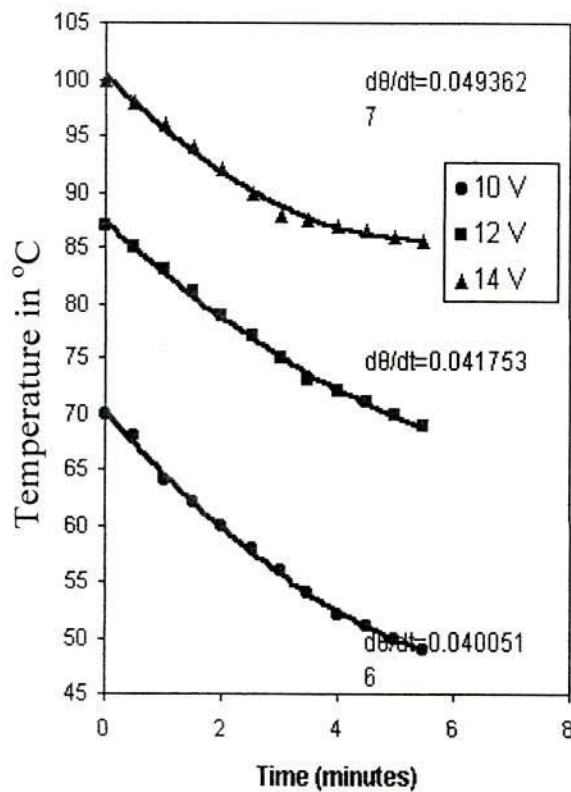
Specimen thickness $d_1$ (cm)	Voltage (V)	$(\theta_1 - \theta_2)$	$\frac{d\theta}{dt}$	$K = \frac{0.839820 \times 0.0811915 + d_1}{\theta_1 - \theta_2} \times \frac{d\theta}{dt}$ cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
0.4	10	33	0.039506	0.000898
0.4	12	35	0.041965	0.000920
0.4	14	36	0.041975	0.000989



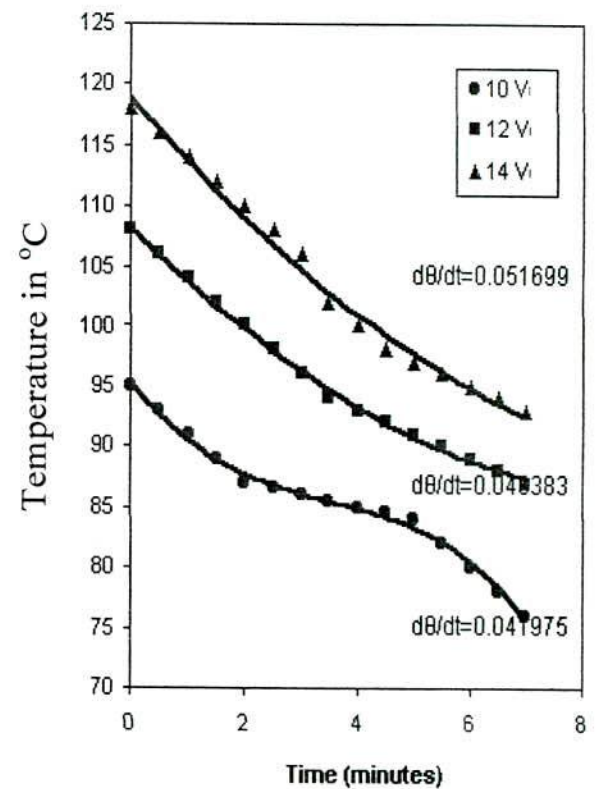
(a) 2mm thick dry Sundari wood specimen



(b) 4mm thick dry Sundari wood specimen

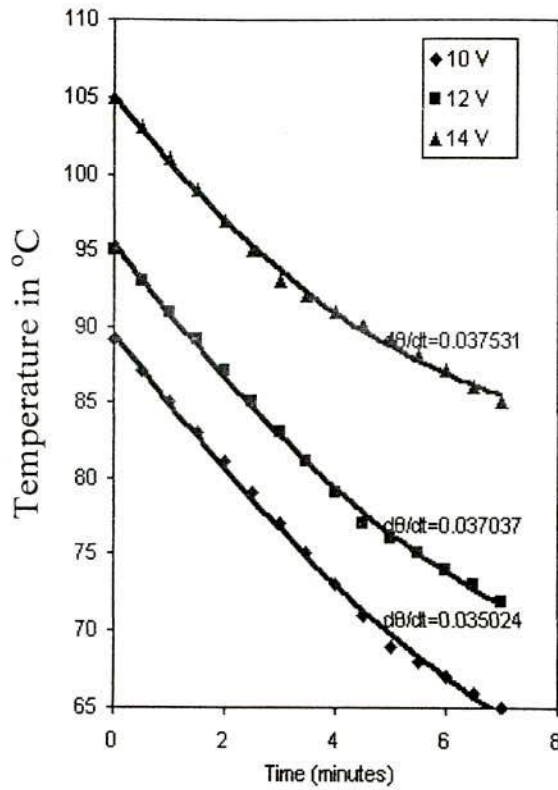


(c) 1% NaCl effects on 4mm thick Sundari wood specimen

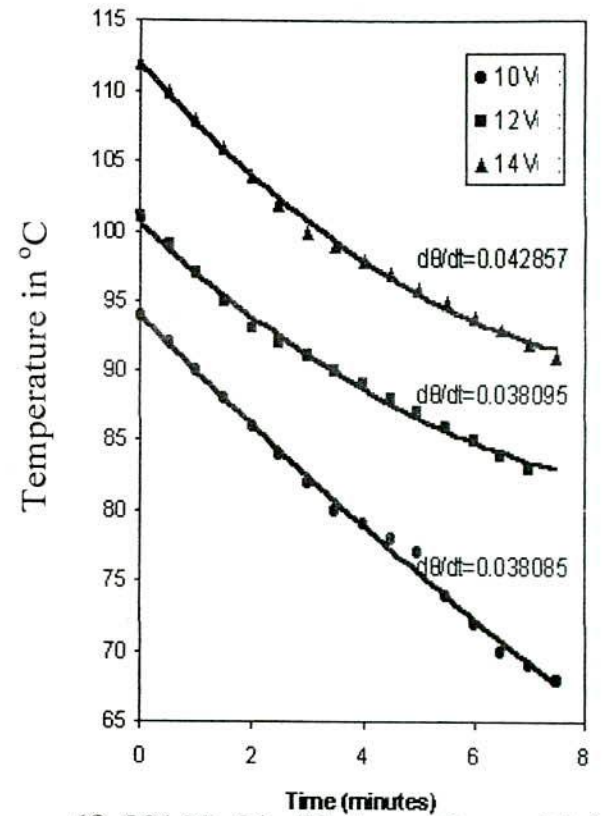


(d) 1% NaCl effects on 2mm thick Sundari wood specimen

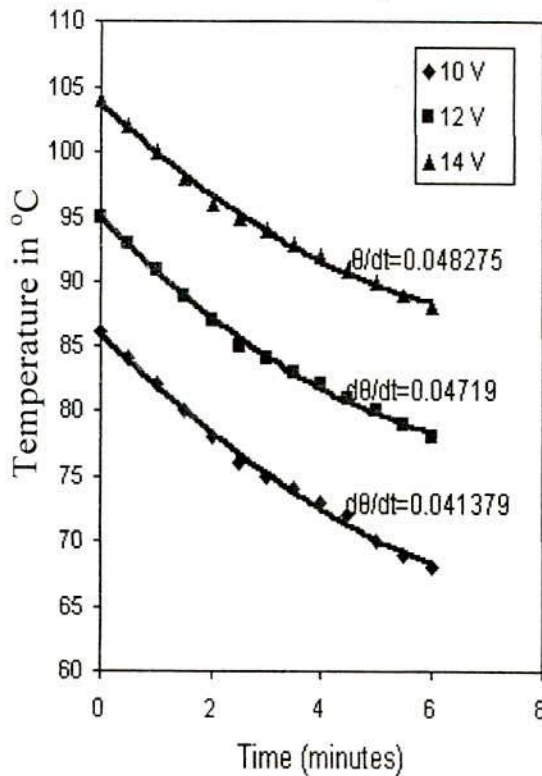
Fig-5.35 (a, b, c & d) Measurements of Temperature gradient ( $d\theta/dt$ ) graph.



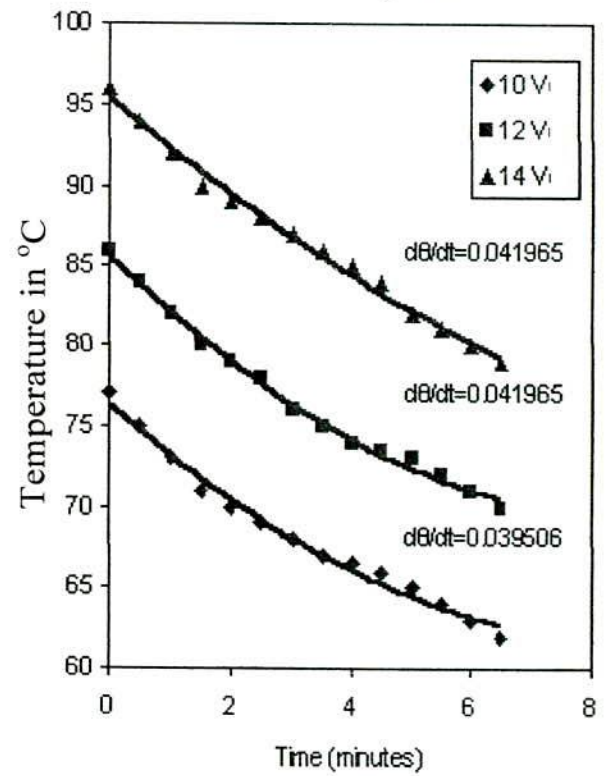
(e) 2% NaCl effects on 4mm thick Sundari wood specimen



(f) 2% NaCl effects on 2mm thick Sundari wood specimen



(g) 3% NaCl effects on 2mm thick Sundari wood specimen



(h) 3% NaCl effects on 4mm thick Sundari wood specimen

Fig-5.36 (e, f, g & h) Measurements of Temperature gradient ( $d\theta/dt$ ) graph.

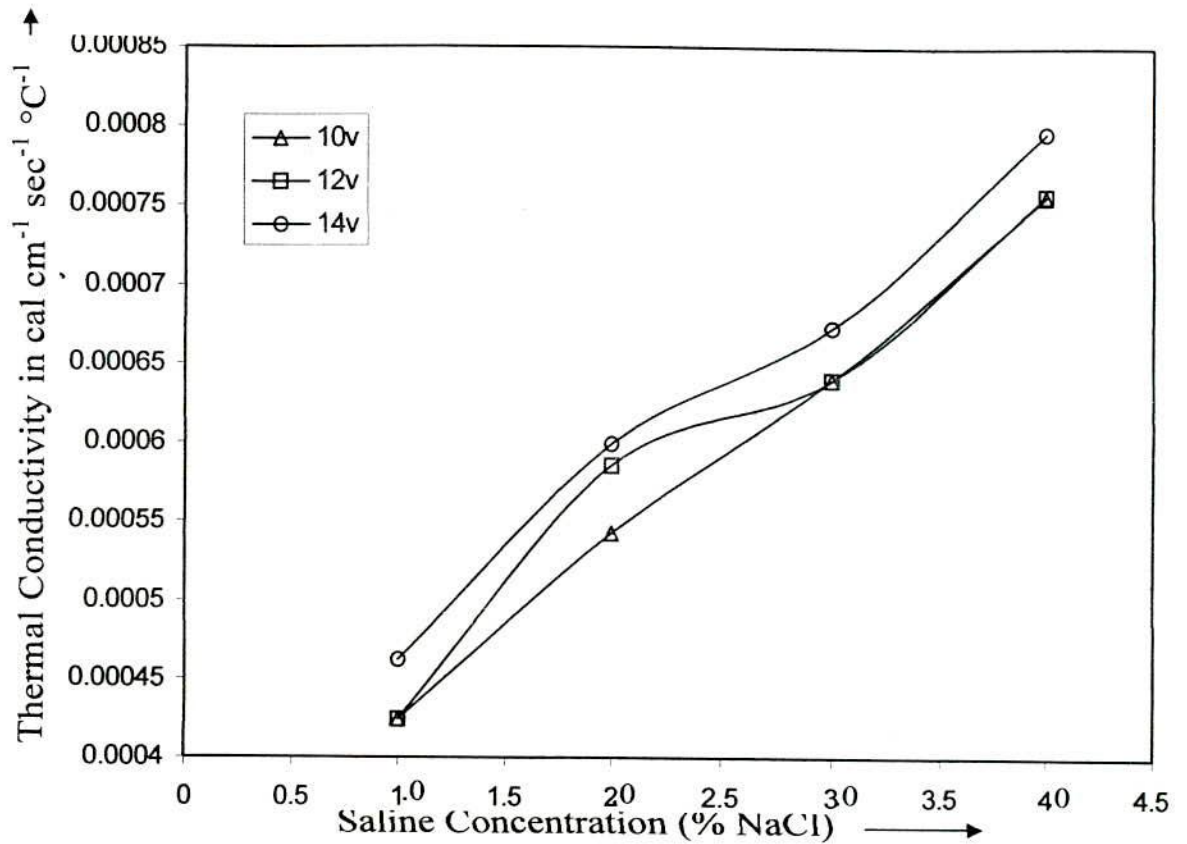


Fig-5.37, Effects on saline concentration of thermal conductivity of different applied voltages of 2mm thick Sundari wood slice.

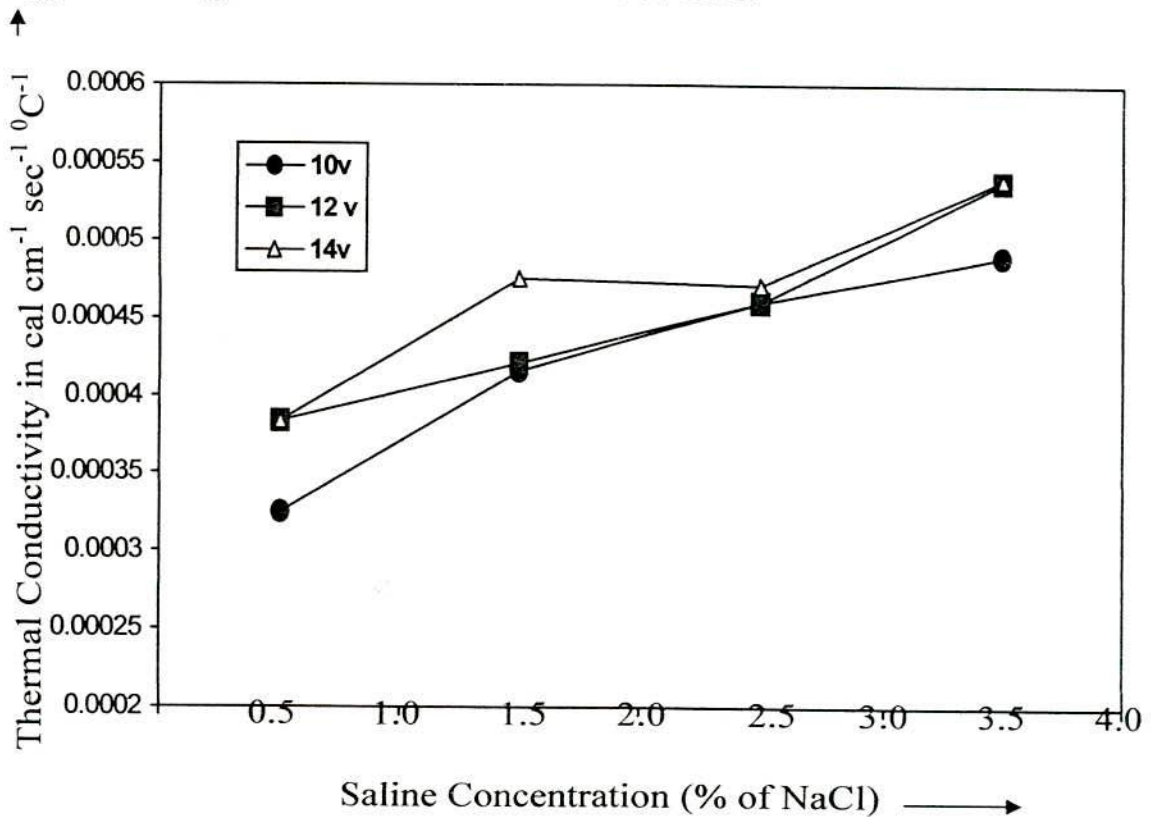


Fig-5.38, Effects on saline concentration of thermal conductivity at different applied voltages of 4mm thick Sundari wood slice.

#### **5.4.2 Effect of Mean Temperature and various Saline Concentration in the Thermal Conductivity of Sundari Wood**

The value of thermal conductivity of Sundari wood has been determined under different mean temperatures. The results are presented in Table-5.19 and Table-5.20 and these values are graphically plotted in fig 5.39 and fig-5.40. Sundari wood fiber saturation at all temperature and with wet above room temperature thermal conductivity generally increases with increasing level of temperature. These results show that thermal conductivity increases with increasing temperature. There are most free molecules in the interstitial space of the Sundari wood. These relatively free molecules can participate in the conduction of heat due to the increased number of degrees of freedom.

The presence of water molecules or salt molecules most likely alter the strength of the ionic bond that exists in materials like wood. This may effectively change the vibrational modes in the solid. In fact, there is some increase in the modes of vibration, which contribute to the increase of conductivity with increasing mean temperature. The relationship between thermal conductivity and temperature are similar at other hygroscopic moisture content. Thermal conductivity increased at the higher mean temperature levels and became more and more dominating over shrinkage from internal drying. Migration of water out of the wood cell walls and into the wood cell walls took some time; therefore the thermal conductivity changes lagged behind the changes in temperature.



Table - 5.19 Thermal conductivity dependence on mean temperature at various saline concentration of 2mm thick Sundari wood slice

Sample Sundari wood	Mean temperature °C	Thermal conductivity cal cm <sup>-1</sup> Sec <sup>-1</sup> °C <sup>-1</sup>
Dry	52.5	0.000424
	53.5	0.000424
	54.0	0.000426
Soaked in 1% NaCl solution for 48 hrs	70.0	0.000542
	70.5	0.000585
	75.5	0.000598
Soaked in 2% NaCl solution for 48 hrs	81.0	0.000640
	82.0	0.000640
	83.5	0.000672
Soaked in 3% NaCl solution for 48 hrs	92.5	0.000756
	93.0	0.000757
	94.0	0.000796

Table- 5.20 Thermal conductivity dependence on mean temperature at various saline concentration of 4mm thick Sundari wood slice

Sample Sundari wood	Mean temperature °C	Thermal conductivity cal cm <sup>-1</sup> sec <sup>-1</sup> °C <sup>-1</sup>
Dry	57.0	0.000424
	58.0	0.000487
	60.5	0.000497
Soaked in 1% NaCl solution for 48 hrs	76.0	0.000591
	76.5	0.000601
	79.0	0.000605
Soaked in 2% NaCl solution for 48 hrs	84.0	0.000643
	85.0	0.000650
	87.5	0.000674
Soaked in 3% NaCl solution for 48 hrs	95.5	0.000898
	96.5	0.000920
	99.0	0.000989

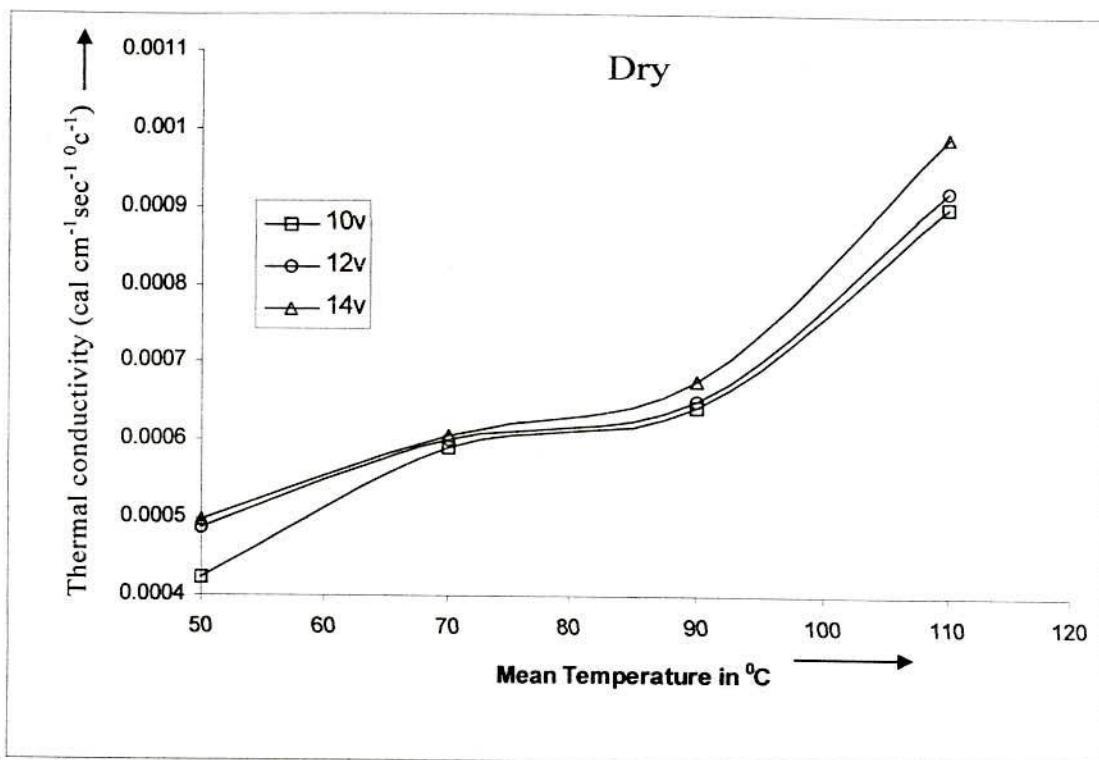


Fig- 5.39 Mean temperature versus thermal conductivity of various applied voltage of 2mm thick Sundari wood slice.

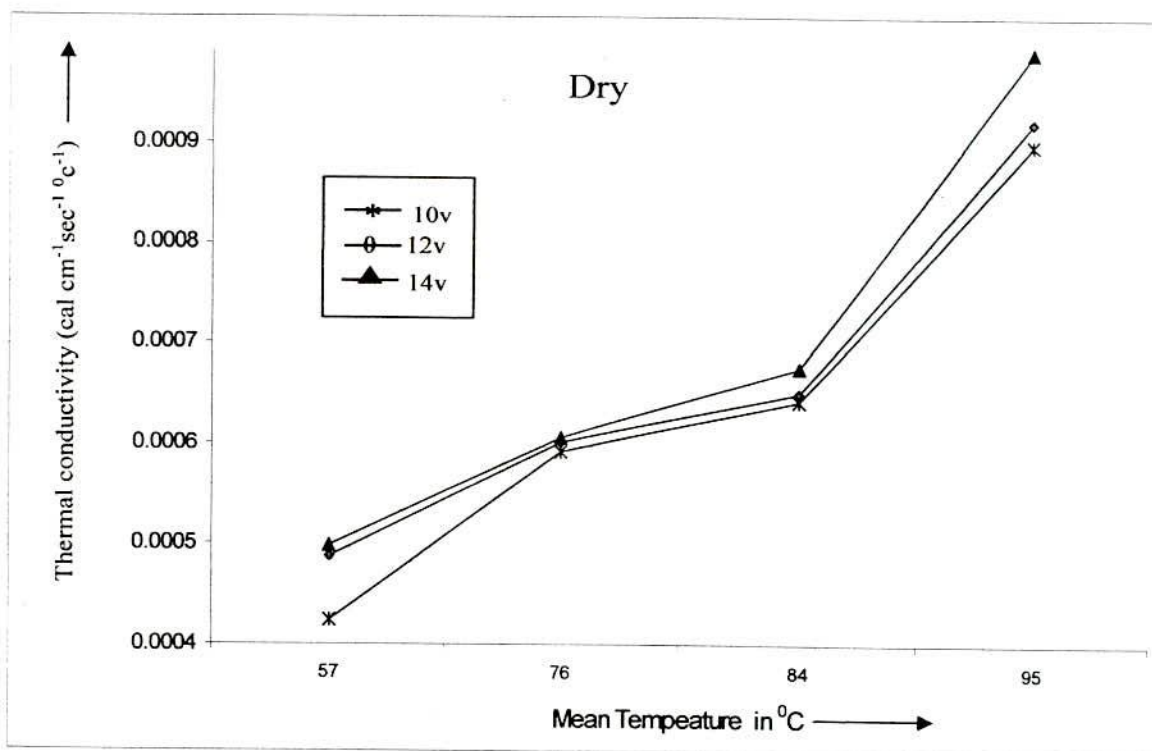


Fig- 5.40 Mean temperature versus thermal conductivity of various applied voltages of 4mm thick Sundari wood slice

## **Chapter-VI      CONCLUSIONS**

### **6.1    Conclusions**

## 6.1 Conclusions

Sundari wood is an important material with complex properties and variety of applications. But its physical properties are not very well studied. One reason for this is that wood has a complex and composite structure. The nature of the plant depends on source, age, processing of wood, relative humidity, moisture content, etc. Thus, it is important to know the thermal and electrical properties of wood especially for its use as a thermal and electrical insulator and as a dielectric. In the present work locally available Sundari wood has been selected for the investigations of thermal conductivity and dielectric permittivity, loss factor and also to calculate complex number as affected by moisture content and salinity.

Composite structure and physical properties vary from one kind of Sundari wood to another depending on the plant source, seasoning, moisture content and specially the indenter of salts as absorbed chemicals. Moisture and salinity can have far reaching effects on electrical properties of wood. Sundari wood as a construction material needs to be studied for its physical changes due to moisture and temperature variation. Moisture content and salinity affect dielectric constant. With increasing moisture content, the amount of water within the Sundari wood matrix increases which results high dielectric constant. On the other hand the polar components of the cell wall and the cellulose get more freedom of rotation at higher moisture content and this may also contribute to more pronounced dielectric behavior. Moisture content change in response to changes in relative humidity and or temperature. The relation between relative humidity and Sundari wood moisture content is not exponential. Relative humidity direct measured by cycling the sensor to be about 81% during the course of a week. These data point should not be taken after large increase or decrease in relative humidity. Moisture content is often the most important characteristics of wood products, because it determines

their suitability for harvest and for subsequent storage or processing. It often determines the selling price of the products for intended purposes.

Dielectric constant of Sundari wood measured at 500Hz has been found to vary from 3.03 to 3.33, and it increases by a factor of two on the introduction of salt ions into the wood matrix. This increase is quite expected due to the presence of additional ions.

The frequency dependence of real part of dielectric permittivity  $\epsilon'(\omega)$  of Sundari wood at different thicknesses and different saline concentrations over a wide range were investigated. The results show that  $\epsilon'(\omega)$  increases with the increase of thickness and salinity. The complex number of dielectric permittivity of Sundari wood followed the relation  $\epsilon'(\omega) \propto \omega^{n-1}$ .

The average value of complex number is 1.07. Dynamic conductivity data of these samples followed the relation  $\sigma(\omega) \propto \omega^n$  with  $n=0.53$  for Sundari wood. It is significant to mention that all the specimens showed similar behavior. The values of conductivity decreases slightly with the increase of thickness of the Sundari wood slice. Dielectric permittivity has been measured with a properly designed electronic sensor having reasonable accuracy.

The dielectric permittivity and conductivity of wood materials can be considered as either 'lossless' or a "Complex" or "lossy". Where the "lossless" case is of course a special case of complex case, but is of sufficient importance to be treated separately. The d.c. contribution has not been subtracted from the calculation of loss factor i.e.  $\sigma_0$  from  $\sigma(\omega)$ . Also the high frequency limit of dielectric constant  $\epsilon_\alpha$  was not calculated in the present investigation and has not subtracted from real part of dielectric permittivity. Further work is therefore needed to obtain a more complete

understanding of the mechanism involved in thermal, electrical and dynamic dielectric properties of wood.

The thermal conductivity of Sundari wood has been found to increase with salt content and their thickness, the temperature dependence of this specimen also shows an increase with increasing applied voltage. This study uses a technique of steady operation and emphasizes the saline influence on the thermal conductivity of the planes of cuts in wood and the moisture content.

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