PREPARATION AND CHARACTERIZATION OF POLYMER FIBRE AND CELLULOSE PAPER WITH POLYVINYL ALCOHOL

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Submitted By

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CERTIFICATE

This is certified that the thesis entitled **"Preparation and characterization of polymer fiber and cellulose composite paper with polyvinyl alcohol"** is an authentic record of my own work carried out as requirements for the award of the degree of Master of Engineering in CAD/CAM & Robotics at Thapar University, Patiala, under the guidance of **Dr. Rajeev Mehta** (Associate Professor & Head, CHED) and **Mr. Bikramjit Sharma** (Assistant Professor`,MED) during January to June 2013.

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Abstract

With growing capacities, an ever-increasing reliability of products in service is demanded of power transmission systems. The life of transformer depends upon the insulating material used. The most important insulating materials of optimum dielectric strength properties that have been used in large high-voltage transformers through almost a century are the oil impregnated, cellulose-based products: primarily paper and pressboard. The chief disadvantage of cellulosic material for electrical use is that it is hygroscopic in nature and needs to be processed and maintained dry. For power transformers the process is quite elaborate and time consuming. To overcome this limitation, a new area to look forward to is blending of cellulose fibers with synthetic fibers and binder. The most important property of these materials is their high thermal stability. Their dielectric strength is excellent, being above that of kraft paper, and they retain this property for a sustained period even at high temperature for short periods of time. The present study discusses the production of electrical grade paper from kraft pulp and synthetic fibers. The insulation paper produced by blending kraft pulp with synthetic fibers, viz, polyvinyl alcohol and recron fiber has higher tensile, tear, burst strengths as compared to normal kraft paper making it useful for electrical insulation in transformers.

Keywords: Insulation, electrical grade kraft paper, power transformers, cellulose fibers

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Abbreviations

ASTM	American Standard of Testing and Materials
CD	Cross Direction
CMC	Carboxy Methyl Cellulose
DGA	Dissolved Gas Analysis
DMA	Dynamic Mechanical Analysis
DSC	Differential Scanning Calorimetry
EDXS	Energy Dispersive X-Ray Spectrometry
FTIR	Fourier Transform Infra-Red
MD	Machine Direction
pA	Pico Ampere
PVOH	Poly Vinyl Alcohol
SEM	Scanning Electron Microscope
TAPPI	Technical Association of Pulp and Paper Industry
TGA	Thermo Gravimetric Analysis
TMA	Thermal Mechanical Analysis
WDXS	Wave Dispersive X-Ray Spectrometry

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Chapter 1: Introduction

1.1 Transformer background

A transformer is a device that transfers electrical energy from one circuit to another through inductively coupled conductors. A transformer is used to bring electrical voltage up and down in an AC electrical circuit. Transformers are complex devices it consisting of an iron core around which insulating wires are wrapped, the tank is filled with insulating oil, along with connectors, bushings and various other small components. The design of transformers is based on the expected sustained and short-term power-frequency voltage stresses originating on the network and those caused by lightning and switching surges. Besides, the growing geometrical dimensions, disposal of heat losses and the determination of local hot spots resulting from stray magnetic fields are factors of increasing concern in the design.

Like other machines, transformer too has limited life. However, unlike most other machines, it does not have any moving parts, except tap changers or cooling fan or pump motors. The outages, therefore, is not due to wear out. The transformers die because of deterioration of insulation over time. The insulation system in most power transformers consists of oil/paper on the copper windings, and there are also several oil-impregnated pressboard barriers between the high and low voltage windings, and sometimes also between windings and the core [9]. The insulation is subjected to a variety of stresses, such as thermal, mechanical, electromagnetic, etc. Under the influence of the these stresses and in the presence of oxygen and moisture, the insulation deteriorates continuously over a period of time, eventually leading to failure.

Technological advances in recent decades have infancy the development engineer to rapid changes, a phenomenon that will have to be taken into account when considering the future of transformers. It seems that in near future, the transformer will still remain an important element of power systems. It is not easy to predict what new requirements will be raised in the years to come. In any case, the present state of the art is surely an important link in the chain leading into the future

1.2 Insulation developed in Transformer

Mixtures of cellulosic and synthetic materials are now used in many transformer insulation applications [15]. The insulation of transformer had developed concurrently with the transformer development, but it took a few decades before the paper-oil combination became reliable and well accepted. After 1930s, the transformer insulation was used kraft paper insulation in combination with insulating oil. This combination was used to satisfy the increasing insulation requirements as the voltage readings escalated. In the 1940s, kraft paper in combination with oil was the dielectric material of choice for high voltage transformers. Synthetic dielectric materials which slowly developed in the late 1950s, began to replace cellulosic insulation in power cables and capacitors.

1.3 Materials used for Insulating

Insulating materials are those materials which allow negligible current to flow when we apply voltage These materials are various in origin and properties. Insulating materials are essentially non-metallic, organic or inorganic; uniform or heterogeneous in composition; natural or synthetic. Plenty of them are of natural origin as, for example, paper, cloth, paraffin wax and natural resins. . Many of the insulating materials are man-made products manufactured in the form of resins, glass, ceramics, etc. Wide use is made of many inorganic insulating materials such as glass, ceramics and mica.. In the recent years wide use is made of new materials whose composition and properties place them in an intermediate position between inorganic and organic substances. These are the synthetic organo-silicon compounds, generally termed as silicones.

There are many properties, which characterize the insulating materials, e.g. resistivity, breakdown voltage, permittivity and dielectric loss, etc. An ideal insulating material should have:

1. Thermal stability upto high extent.
2. It has good dielectric strength which is continuous at elevated temperatures
3. High resistivity
4. Good thermal conductivity
5. High tensile and shear strength .

In addition to the above properties, the material should have other good mechanical properties such as ability to withstand moisture (it should be non-hygroscopic), vibration, abrasion and bending. Also, it should be able to withstand chemical attack, heat and other adverse conditions of service. The paper needs for insulation should be strong , elastic,uniform and free of holes and debries. This application is being replaced by plastic application.

1.4 Paper for insulation

Cellulose papers are used as electrical insulation in many application due to outstanding electrical properties of cellulose. Cellulose is a good isolator and is a polar, having dielectric constant significantly greater than one. Insulation based on cellulose is very good choice for the solid insulation in power transformers . This is due to that because it is available in plenty from natural renewable source like softwood.

Insulation grade paper is made by the delignification of wood pulp by the kraft process. The major constituent of paper is cellulose, which is a natural polymer of glucose. It has about 90% cellulose, 6 to 7% lignin and the balance is hemicelluloses. The natural water content of paper is 4 to 5% by weight and the insulation is dried after winding to less than 0.5%. The dried paper is impregnated with insulating oil, which increases its dielectric strength and also serves to cool the windings. Power transformer conductor windings are insulated by paper impregnated with insulating oil, which is expected to last the life of the transformer (25 years minimum at an operating temperature of 65 to 95 °C). A typical 600 MVA transformer contains 12 t of paper, 30-120 µm thick (density 0.7-0.8 g/cm^3), and 45 t (40,000 l) of oil.

1.5 Degradation of paper

It is common sense that paper loses most of its strength and stiffness when it is exposed to high humidity or soaked in water. Paper is layered mat with pore structure consisting of a network of cellulose fiber which are bonded together by hydrogen bonds .When the paper is subjected to high humidity, it absorb water and swells, hydrogen bonds are destroyed, and paper loses its mechanical strength Water is a product of ageing. Its presence in the insulation increases conductivity and the likelihood of gas bubble formation, reducing the thermal stability of the insulation system during overload conditions. Thermal ageing of transformer insulating materials is associated with the chemical reactions occurring within the materials. These chemical reactions are caused by pyrolysis, oxidation and hydrolysis, and are accelerated by increased levels of temperature and of the oxygen and moisture contents. Apart from chemical reactions, there is a reduction in the mechanical properties of cellulose paper.

The paper insulation becomes brittle to the point of almost falling apart, but it still retains an acceptable level of dielectric strength. Once in the transformer, the insulation begins to age over many years. Its water content increases because of the degradation of the molecular chain by thermal stresses and oxidative processes. Depolymerisation of the cellulose chain lowers the chain length and mechanical strength. The insulation finally becomes brittle and carbonaceous with no short circuit withstand capability. This stage is termed as an absolute end of life. Thus the combined action of temperature, oxygen and moisture cause the insulation to lose mechanical strength and become weak and brittle [1]. There are two main sources of moisture inside the transformer. One is ingress of atmospheric air into the tank. The amount of water into the transformer's tank strongly depends on the design of the transformer. The rate of water contamination in transformers with membrane-sealed conservator preservation systems is about 40.03 to 0.06% of water in cellulosic materials per year. But the rate of water contamination of transformers with an open-breathing conservator is even up to 0.2% per year [8,12]. The second source of moisture in the transformer is the aging processes of insulation [13,15,4].

The temperature of a transformer has a major impact on the life of the insulation. The best technique for evaluating the ageing of such thermally resistant papers is the determination of the degree of polymerization (DP) of the constituting cellulose chains. However, the technique turns out to be impractical due to the difficulty in retrieving paper samples in the field [11]. Continuous on-line monitoring of the transformer oil temperature along with a thermal model of the transformer can give an estimate of the loss of life of the transformer due to overheating. Current industry standards limit maximum allowable hot spot temperatures in transformers to 140 °C with conventional oil/paper insulation. The accelerated electric stress is an important factor considered in the oxidation of the oil. The weight and dimension restrictions of the transformer lead to a decrease in insulation clearances. Consequently, the oil ducts also become narrower and hence the strength of the electrical field increases which exerts a great effect on the oxidation process. Essentially, the electric stress supplies the energy (approximately 4 eV) required for the cleavage of a covalent bond. The mechanism by which the high voltage field interacts with the chemistry of insulating oil. The hidden source of energy capable of breaking covalent bonds, consists of the electrons that escape from the conduction band and manage to leave the surface of the metal conductor, especially during very short but frequent communication voltage surges.

1.5.1 Kraft paper

The quality insulation kraft papers offered by us are appreciated for features such as good insulation properties, high temperature tolerance, non toxic, bio-degradable and easy to use. The time when electrical grade paper was introduced, it was known that such papers were used for capacitors and cables extensively before becoming the primary insulation in transformers. The use of resin impregnated paper for transformer was introduced at the turn of 20th century [15]. The introduction of oil impregnation of paper led to the discontinuation of resin impregnated paper. By the late 1920s transformer board (now called pressboard) form kraft pulp could be easily fabricated into formed items. The calendered press board is ideal for washers and tubes used in power transformers.

Kraft paper is produced by kraft process which is a process for conversion of wood into wood pulp consisting of almost pure cellulose fiber. The pulp produced by the craft process is stronger than the other pulping process.

1.5.2 Creped paper

Crepe paper is used as electrical insulation purpose like in motors, transformer, switch gears and many more application. There are some features of crepe paper i.e.

- Light weight
- Superior thermal resistance.
- Enhanced tear resistance.
- It has much elongation.

The introduction of the creped paper was a few years after thermal upgrading agents were put into paper so the creped paper could be thermally upgraded at the same time from non upgraded paper [15]. Insulating crepe paper is one of the most important solid insulation materials used in transformer. This crepe paper is used as an insulation material used in transformers. This crepe paper has 300% more strength in mechanical and cross mechanical directions and hence is more resistance to breakage. Crepe paper also has greater surface area which help to retain more oil and hence lowers the working temperature of the transformer. It is also used to cover copper conductors having various cross sectional shape. As a result this insulation will not break or tear or crack compared to plain kraft paper.

1.5.3 Thermal upgrading of paper

As the rating of transformers climbed, the transformers would occasionally became overloaded; the concern for transformer life, or rather, paper insulation life was raised. Thermal upgrading of paper insulation was considered as one remedy. The purpose of upgrading is to increase the insulation life [6]. Accelerated ageing studies confirmed that cellulose degradation is considerably slowed by upgrading agents. Westinghouse studies on insulating paper showed that upgraded paper could take a temperature rise of 20 to 30°C greater as compared with non upgraded paper [1.2]

1.5.4 Hygroscopic nature of polymer

Hygroscopic is the ability of the substance to attract the water molecules from the surrounding environment. Insulation resistance is reduced if material absorbs moisture, so insulation material should be non hygroscopic. Cellulose insulation paper is widely used in power transformer and other high voltage devices but require intensive drying out to remove all moisture.

Oommen, T.V. and Andrady, T.L. modify cellulose to reduce its hygroscopicity ,of which graft polymerization was the most successful method.

1.6 Important characteristics of insulation materials used in transformer

The important characteristics for paper material used in oil-immersed transformers are their dielectric breakdown voltage, electrically speaking, and their tensile strength mechanically speaking. Although these characteristics will decline with aging, The dielectric breakdown voltage of the insulation paper is not observed to decline greatly, and it is tensile strength of the winding insulation paper that has traditionally been held to be the factor determining the service life of the transformer. For evaluation of the degradation of mechanical strength in insulation paper, the average degree of polymerization which generally correlates with tensile strength, has been widely used as a basic yardstick. As, however it is problematic to measure directly the average degree of polymerization of insulation paper in a transformer in the operating state, a method has been put forward whereby the insulator’s degradation is inferred indirectly from the amount of degradation products generated during degradation of the paper. By measuring the degradation by-product contents in the insulation oil, the insulator’s tensile strength and average degree of polymerization can be indirectly inferred and used for external diagnosis of the transformer’s aging degradation.

1.6.1 Mechanical analysis

1.6.1.1 Flexural properties of electrical insulating materials (ASTM D790): ASTM D790 3 point flexural strength test method differs from ASTM 06272 four point flexural property test method. The three point loading creates a shear stress concentration at the center loading position. The shear stress concentration affects the sample stress state, therefore, 3 point loading does not create pure flexural loading. Four point bending eliminates the shear load concentration in the test span, thus, pure flexural strength and modulus measurements are obtained for test spans greater than or equal to 16 times the sample thickness.

1.6.1.2 Compressive properties of rigid plastics (ASTM D695): ASTM D695 tests materials with compressive loading to determine compressive strength, strain to failure and compressive modulus. An ideal compressive failure for rigid, elastic materials would have the sample fail with 45° degree prism pieces.

1.6.1.3 Tensile properties of plastics (ASTM D638): Tensile strength, modulus and strain to failure can be determined by ASTM D638.

1.6.1.4 Shear properties of insulating materials (ASTM D5379): The shear strength, shear modulus and shear strain to failure for rigid laminates and structural composites can be determined using ASTM D5379.

1.6.2 Chemical analysis

There are many methods for determining the chemistry of electrical insulating materials. The constituent atomic elements of solid materials can be determined by Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray Spectrometry (EDXS) or Wave Dispersive X-ray Spectrometry (WDXS). The energy of the electron beam excites electrons in each atom impacted. The excited electrons in each atom will return to a lower energy level, a photon of unique wavelength is released from the material. Each atomic element will emit a unique x-ray photon for each possible electrical transition within the atom. These characteristic photon wavelengths have been determined for all common atomic elements; hence, identification of the various elements present can readily be determined.

1.6.2.1 Fourier Transform Infra-Red (FTIR) spectroscopy (ASTM E1252): FTIR spectrometry is often used to determine the identity of polymers present in solid or liquid materials with insulating properties. The sample is exposed to a range of infra-red light energy. Each polymer molecule bond within the molecule absorbs photons with a specific wavelength. Analytical FTIR spectrometers are equipped with a reference library with common characteristic waves for polymer materials for faster identification. It's also possible to store the test results for future comparisons.

1.6.2.2 Gas chromatography (GC) (ASTM 01428): It is used to determine the types of small sized organic molecules present in materials. The low molecular weight polymeric molecules are extracted by solvent based distillation and then vaporized into a gas vapor where a chromatograph records the absorbance time on the detector. The absorbance time measured corresponds to known molecules. The extractable ions are dissolved in a water solution and detected using ion chromatography.

1.6.3 Thermal analysis

1.6.3.1 Thermal expansion by TMA (ASTM E831): This is a common test procedure for measuring the coefficient of thermal expansion (CTE) using thermal mechanical analysis (TMA) equipment. Most material designs for electrical insulation use polymer materials that have a T_g temperature above the intended operating temperature. There is a significant drop in mechanical properties above the T_g temperature.

1.6.3.2 Glass transition method by DMA (ASTM El640): This is an excellent method to determine the glass transition temperature, T_g, for thermoset materials. The test procedure uses Dynamic Mechanical Analysis (DMA) methods. T_g by DMA plots shows the change in apparent modulus versus temperature. Most thermoset and thermoplastic materials lose a significant amount of physical strength above the T_g temperature.

1.6.3.3 Glass transition method by DSC (ASTM E1356): This method is frequently used to determine thermal transitions in polymeric materials using a Differential Scanning Calorimeter (DSC) techniques.

1.6.3.4Resistance to thermal transmission of materials by guided heat flow (ASTM E1530):

The heat dissipation of electrical insulating materials is critical to machine efficiency in electrical generator applications. The amount of heat that can be conducted per unit area through a known thickness is typically measured using ASTM E1530 thermal conductivity method.

1.6.3.5Rapid thermal degradation of solid insulating material by TGA (ASTM D3850):

Thermal limits related to material temperature stability or thermal decomposition can be determined by ASTM D3850 method for rapid thermal degradation of solid electrical insulating materials by Thermo Gravimetric Analysis (TGA). The procedure determines precise weight loss of a material when heated in inert gas environment. Heating can also be done in an air environment to measure the effects on thermal stability.

Since reliability of high voltage equipments and systems depend on the quality and proper choice of the insulation, it is not only desirable but also mandatory to acquire a sound knowledge of the behavior of insulating materials that are used. Thus, process of testing and evaluation of insulating materials plays a vital role in quality assurance and maintenance of high voltage equipments and systems.

Thus the topic preparation and characterization of polymer fiber and cellulose composite paper for electrical insulation covers the process of production of paper from kraft pulp and synthetic fibers viz Recron 3s$^{©}$ (Polyethylene terepthalate (PET) fibers, a product of Reliance industries Limited, India), Polyimide P84$^{©}$ (Polyimide fibers, a product of Evonik Iindustries, Austria). The paper thus produced has high thermal, mechanical and electrical resistance making it suitable for use in high power transformers.

Chapter 2: Literature Review

The demand of electric power is increased now so there is need of high voltage transformer. To develop high voltage we required high quality insulating paper. In the studies of literature we develop better cellulose paper composites used in transformer.

2.1 Material used for insulation.

John D. Albert and Donald R. Mcgivern in their study described the electrical insulation materials and methods of making and using same [1]. Electrical insulation material comparising a fiber component, a binder element. A method of making electrical insulation material, comprising preparing an aqueous slurry comprising a fiber component, forming a slurry into sheet, saturating the sheet with a saturant, wherein the saturant comprises a binder and a dielectric additives, and drying the saturated sheet. A method comprising preparing an aqueous slurry comprising a fibrillated acrylic fiber, dilution hydroforming the slurry into the sheet, saturated the sheet with saturant, wherein the saturated comprises a carboxylated styrene-acrylate copolymer and a fluoropolymer, drying the sheet, and providing the sheet for use as insilation on an electrical insulation on an electrical conductor. So method of making electrical insulation material, comprising:

- Preparing an aqueous slurry comprising a fiber component.
- Adding the binder
- Forming the slurry into sheets.
- Drying the sheets.

2.2 Aramid fiber used with cellulose.

Homan B. Kinsley, jr in their study high temperature paper containing aramid component [2]. In their study provided a paper structure comprised of cellulose pulp fiber, a polymeric binder, and an armid component comprised of armid fiber and/or fibrid. The paper structure can also comprise multiple layer of different composition, but at least one layer must comprise the armid component and polymeric binder. In accordance with the present invention, provided is a paper structure comprised of an armid fiber, a polymeric binder, such as poly vinyl alcohol, and cellulosic pulp fiber. In a preferred embodiment, the paper structure is comprised of two outside layers and at least one inside layer. The two outside layers are preferably comprised of substantially cellulolsic pulp fiber, the armid fiber and polymeric binder. The resulting paper structure provides a paper quit useful as E-board in transformer due to enhanced thermal resistance. Glass papers were made by the wet-forming papermaking process. A process for making a uniform dispersion of aramid fibers and polymers has also been studied [25]. Short aramid fibers were continuously combined with extrudable polymers to yield substantially uniform composition paper which comprised of 15 to 99 weight percent polymer and 1 to 85 weight percent aramid fibers. The aramid fibers were continuously introduced in the extruder simultaneously heat was applied in the extruder so as to evaporate the water from fibers. The fibers were then subjected to shear force in the extruder. The polymer was blended with the fibers so as to form a uniform dispersion.

Kinsley [26] and Cornbower [27] in their studies varied: (a) the composition of cellulosic pulp fiber from 50-80% by weight, (b) the aramid component from 5 to 25% by weight and

(c) the polymeric binder (polyvinyl alcohol) from 10 to 25% by weight to produce E board paper. The E board paper produced comprised of three layers. The outer two layers were comprised of cellulosic pulp fibers and the inner layer is comprised of polymeric binder, a synthetic fiber and cellulosic pulp fiber. E board paper could be used as an insulator in transformers because of its excellent dielectric properties, good mechanical strength, high thermal stability, good heat resistance, good oil impregnation and its ability to withstand temperatures upto 220ºC.

2.3 Synthetic fiber experiments.

SJ Ferrito RL Stegehuis in their study thermal endurance of high temperature fiber reinforced cellulose insulation [5]. In this there is advancements have been made in the thermal endurance of cellulose-based insulating papers by reinforcing the cellulose matrix with a high temperature synthetic fiber. This new insulating material is made by adding synthetic fibers to the cellulose pulp along with a binder material that bonds the synthetic fiber into the cellulose matrix. The high temperature fibers form a reinforcing backbone that gives the paper mechanical integrity, even after the cellulose component has thermally degraded. This new material has been used to improve the thermal durability of liquid-filled transformers.

The synthetic fiber added alone to a cellulose matrix would actually destroy some of the paper’s mechanical properties. This happens because the synthetic fibers interfere with the hydrogen bonding that takes place between the cellulose fibers. To determine the best types and combination of binders and synthetic fibers for this application, laboratory hand sheets were fabricated and tested. Mixture of cellulose pulp with numerous fiber and binder combination were evaluated in order to determine the optimum blend of materials. Hand sheet made from 100 percent cellulose pulp used as the experiment control.

2.4 Polyvinyl alcohol and cellulose

Polyvinyl alcohol can be used in fiber form or even in powder form. Poly vinyl alcohol fiber with low solubilisation temperature should be used for medium basis weight paper. For high basis weight papers polyvinyl alcohol with high solubilisation temperature can be used. Polyvinyl alcohol when used in powder form should be fully hydrolysed (99% or higher) and the polymer should be ground to a particle size of 100 mesh or smaller. The powder can be added to wood fiber prior to refining or it can be added to the system after refining. It should also be noted that the process water used to dissolve polyvinyl alcohol fiber or powder should not be more than 60°C as hot water will dissolve the polymer and most bonding characteristics will be lost.

Suter et al. in their study described the coating of electrical grade paper with a material insoluble in liquid dielectrics and is substantially free of alkali metals (polyvinyl alcohol/starch) [18]. The coating material is present in 2-15% of total weight of coated paper. For a coating which increases coat weight per unit area by less than 4 % could increase the dielectric constant by 25%.

A process for internally strengthening the paper or board during their manufacture so that they can have enhanced strength properties have also been studied [19]. The cellulosic pulp fibers are blended with polyvinyl alcohol to increase strength properties. The composition of polyvinyl alcohol varied from 3-10% and the composition of cellulosic pulp fibers varied from 97-90%. The paper so formed had increased tear resistance and mechanical resistance.

Kinsley in his study described the production of paper which comprised of cellulosic pulp fiber, a particulate binder substantially insoluble in water and an emulsion comprised of lecithin and fatty acid [20]. The binder used was polyvinyl alcohol powder. The composition of cellulosic pulp fiber varied from 60 to 90%, the composition of binder which was insoluble in water varied from 10 to 20% and the composition of emulsion of lecithin and fatty acid varied from 1 to 10%. The invention dealt with improving the strength properties of paper like dry strength, wet strength and folding endurance of paper.

Kinsley in his study described the production of paper which comprised of cellulosic pulp fiber, a particulate binder substantially insoluble in water and an emulsion comprised of lecithin and fatty acid [21]. The binder used was AIRVOL 165SF (product of Air products and Chemicals Inc). The composition of cellulosic pulp fiber varied from 60 to 90%, the composition of binder which was insoluble in water varied from 10 to 20% and the composition of emulsion of lecithin and fatty acid varied from 1 to 10%. The invention dealt with improving the strength properties of paper like dry strength, wet strength and folding endurance of paper. This method was cost effective method of producing paper.

Additives were used to improve paper strength properties [22]. Additives may be added to paper pulp slurry prior to sheet formation or after sheet formation depending on the properties desired such as wet strength, dry strength, folding endurance, oil resistance and stain resistance. The invention dealt with improving the folding endurance of paper by treating paper with hydroxy containing polymer and multifunctional aldehyde in presence of catalyst. The composition of aldehyde was 100 to 800 weight percent of the polymer and the catalyst was present in the weight ratio of about 1:0.2 to 1:1 aldehyde: catalyst.

Table 2.1: Summary of polyvinyl alcohol and cellulose paper composites

Sr. No.	**Dimensions of fibers**	**Binders**	**Composition**	**Properties**	**References**
1	Not specified	No binder	The electrical insulating paper is coated with starch/polyvinyl alcohol/ protein in range of 2-15%	For a coating which increases coat weight per unit area less than 4 % can increase the dielectric constant by 25%	[18]
2	Not Specified	No binder	3-5% polyvinyl alcohol and rest cellulosic pulp Fibers	Increase in tear resistance, mechanical reistance and strength of paper	[19]
3	Length: 2-15 mm and dia: 10-15 µm, dia of microfiber 0.2-10µm	Polyvinyl Alcohol Powder	Cellulosic pulp fiber (60-90%), a binder insoluble in water (10-20%) and an emulsion of lecithin and fatty acid (1-10%)	Increase in dry strength of paper	[20]
4	Not specified	Airvol 165SF	Cellulosic pulp fiber (50-75%), a binder insoluble in water (15-25%) and an emulsion of lecithin and fatty acid (1-10%)	Cost effective method of paper making	[21]

2.5 Meta-Aramid and Cellulose insulation

O .M .Zodeh in thermal characteristics of a meta-aramid and cellulose insulating transformer [10]. In this there is advancement in meta-aramid a synthetic, aromatic polyamide in which the phenyl molecules are connected in the meta orientation-paper and pressboard technology has lead to production of a high temperature insulation system that can be used in transformer, replacing cellulose materials in the winding, thereby eliminating the cellulose temperature limitation. A medium-power mineral oil-immersed transformer was constructed, with a hybrid insulation system comprised of meta-aramid paper and pressboard insulated windings and cellulose bulk insulation. The core and coil of the hybrid transformer has a thermal capability that is inherently higher than that of the all-cellulose unit because of its higher permissible temperature.

2.6 Polyamide and cellulose composite paper

The electrical quality of cellulose material is highly dependent upon its moisture content. The presence of moisture in a transformer deteriorates cellulose transformer insulation by decreasing both electrical and mechanical strength. In general mechanical life of the insulation is reduced by half for each doubling in water content and the rate of thermal deteriorate of paper is proportional to its water content. The importance of moisture presence in paper and oil system has been recognized since the 1920's. To overcome the hygroscopic nature cellulose is blended with with synthetic polymer fiber i.e. polyamide fiber [18].

The wood pulp fiber composition generally varies from 60-80% by weight (length 0.5-1.4 inch, diameter 10-15 µm), synthetic fiber varying from 5-20% by weight (length 0.1-1 inch, diameter 10-15 µm) and polymeric binder 10-30% by weight. Ideally the binder and synthetic fiber have good long term aging properties and are compatible with common dielectric fluids [23].

Thinius in his study described the production of mixed structures, foils, filaments and films consisting of polyamide and cellulose pulp fibers [24]. The paper produced had good heat resistance, good water repellent properties and high thermal stability. Blending of cellulose and its derivatives with polyamide resulted in increased flexibility, higher stability on heating and better dyeing characteristics.

The electrical insulating material made wholly or in part of aliphatic polyamide and/or one or more copolymer and/or additives there of can be used in a film form or in a fibrous form as an insulator in liquid filled transformers. The film or fiber will contain a thermal/ chemical stabilizer. The term polyamide describe a family of polymers which are characterized by the presence of amide group. Many technically used synthetic polyamide are derived from monomers containing 6-12 carbon atoms, most prevalent are PA6 and PA66. The amide groups in the mostly semi crystalline polyamides are capable of forming strong electrostatic forces between the –NH and –CO- units(hydrogen bonds), producing high melting points, exceptional strength and stiffness, high barrier properties and excellent chemical resistance. Moreover, the amide units also form strong interations with water, causing the polyamides to absorb water. These water molecules are inserted into the hydrogen bonds, loosening the intermolecular attracting forces and acting as a plasticizer, resulting in the exceptional toughness and elasticity.

Electric insulation paper made from combination of polyamide and cellulose fibers have outstanding electrical, mechanical and thermo-chemical properties. However, the desired insulator shape must be stamped out of aramid paper sheets resulting in significant handling and labour costs and also resulting in considerable waste of material in the non-used trimmings which adds to transformer costs.

The above studies are summarised in Table 2.2

Table 2.2: Summary of polyamide and cellulose paper composite

Sr No.	Dimensions of fibers	Binders	Composition	Properties	References
1	Not specified	No binder	Cellulosic pulp fibers (60-80%) and polyamide fibers (20-40%)	Paper has good water repellent properties	[24]
2	Not specified	No binder	85%), extrudable polymer (20-30%)	dispersion gives dimensionally stable paper	[25]
3	Length: 5 mm to 25 mm	Polyvinyl Alcohol	Cellulose pulp (50-80%), polymeric binder (5-25%), aramid fiber (10-25%)	Increased thermal resistance of paper	[26]
4	Length of fiber : 0.25 to 0.75 inches, dia: 10-15 µm	Polyvinyl Alcohol	Wood pulp fiber (70%), synthetic fiber (20%), binder material (10%)	Binder used has good thermal aging properties,adding synthetic fiber to wood pulp fiber increases papers thermal stability	[23]

5	Length: 0.25 inch	Polyvinyl Alcohol	%), polyvinyl alcohol (20%), poly amide fiber (10 %)	thermal resistance of paper	[27]

2.7 Glass fiber with cellulose

The use of glass fibers and wood pulp to control dimensional stability has also been studied [19]. The composition of paper was 38-46% glass fibers, 24-32 % wood pulp, and around 22-38% binder. The pulp used was neutracel pulp which had following advantages over long fiber super soft pulp: a) it is less expensive and less required, b) since thickness is not critical, varying machine conditions have less of an effect on mat acceptability and c) short wood pulp fibers can also be obtained from recycled pulp which offers cost reduction properties without changes in mat structure.

Glass fiber paper have better temperature performance (up to 200°C) but the presence of glass fibers which is necessary to impart dimensional and structural stability, shortens the life of the insulator since it precipitates partial discharges which result in breakdown of transformers. Hence, glass fibers can only be used in dry type transformers.

The above studies are summarised in Table 2.1.

Table 2.3: Summary of glass fiber and cellulose paper

Sr No.	Dimensions of fibers	Binders	Composition	Properties	References
1	Length: 1/8 to 3/8 inch, dia: 0.45-1 µm	Liquid synthetic Resins	Glass fibers (80-99%) and liquid synthetic resin (20-1%)	Paper produced is smooth. Paper does not deteriorate at high temperature. The paper is non hygroscopic.	[28]
2	Length: 1 mm dia: 10-50 µm	B017A, B018B (Source not specified)	Cellulosic pulp fibers (38-46%), E glass fibers (24-32%), binder (22-38%)	Increased dimensional stability of paper	[29]

2.8 Treatment of fiber surface with Naoh

Thermoplastic poly(ethylene terepthalate) (PET) fibers have been used to toughen an intrinsically brittle epoxy resin with high glass transition temperature. The morphologies and chemical properties as-received and the surface modified PET fibers are comparatively investigated by scanning electron microscopy (SEM).

Strong fiber matrix adhesion is successfully achieved by optimizing surface modification of PET fiber with NaOH.

Compared with neat epoxy resin the fracture toughness of PET fibers filled epoxy composites is almost double when loading only 1% with chemically treated fiber.

The short fibers with an average diameter of 20 µm and an average length of 2-3 mm are hydrolyzed with alkali at (50 % w/v) at 80°C for different length of time (from 0-30 min). Then by washing with distilled water until all the sodium hydroxide was eliminated and the water used for washing the fiber no longer gave any alkalinity reaction. Subsequently the surface treated fibers would be dried at 60°C for 24 hrs in a vacuum oven.[30]

The following figure shows the difference between NaOH treated PET fiber and non treated PET fiber.

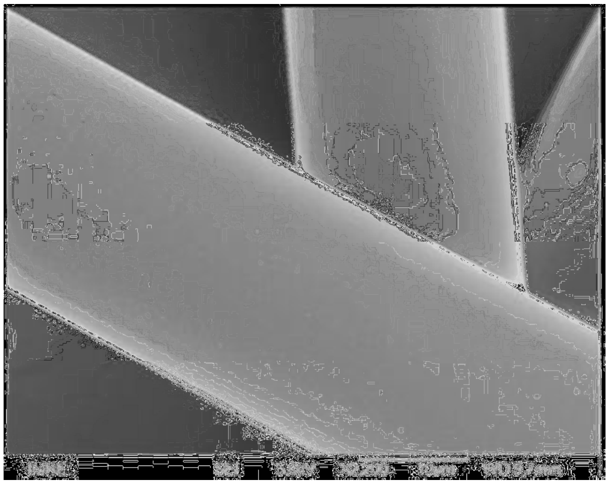

Fig: 2.1 PET FIBER SURFACE

Fig: 2.2 NaOH TREATED FIBER SURFACE

2.9 Pvoh fiber

Polyvinyl alcohol (PVOH) is commodity polymer which is used in wide variety of different applications. However PVOH is generally regarded as non thermoplastic. PVOH has a melting point of about 200 °C depending on degree of hydrolysis. PVOH is heated near its melting point, yellowing and discoloration occurs. Therefore, when using PVOH as a base material for thermoplastic applications, PVOH must usually be modified.

Modified PVOH is used in many different water- dispersible thermo formable articles, such as fibers, films and fabrics which maintain their integrity and strength when in use but dissolve and disperse when placed in contact with water. PVOH fibers are discontinuous and generally have a length ranging from 3 to 15mm and a diameter from 7 to 20 μm. [31]

Chapter 3: Experimental Procedure and Materials

3.1 Materials

3.1.1 Kraft paper

Name of product: PHOENIX AL-L-250

Name of the supplier: Kotlas pulp and paper, Russia

Basis weight: 60 gsm

Paper category: Non flammable paper

3.1.2 Polyimide fibers

Name of product: P84$^{©}$ polyimide fibers

Name of the supplier: Evonik Industries, Austria

Diameter: 16.9 µm

Length: 2.5 mm

Specific gravity: 1.25

Glass transition temperature (T_g): 310°C

3.1.3 Polyethylene terepthalate fibers

Name of product: Recron3s$^{©}$ fibers

Name of the supplier: Reliance Industries Limited, India.

Diameter: 15 µm

Length: 3 & 6 mm

Specific gravity: 1.36

Glass transition temperature (T_g): 180°C

Dispersion in water: Excellent

3.1.4 Polyvinyl alcohol

Name of the supplier: Loba Chemicals, Mumbai, India.

Degree of polymerization: 1700-1800.

pH (0.2% in water): 5-7

Hydrolysis (mole %): 98-99

Ash: 0.7%

3.2 Procedures

3.2.1 Preparation of fiber/pulp

Firstly we will take craft paper then it will torn into small pieces and soaked in water for minimum 16 hours. Then working in small batches, blend the paper with plenty of water .The longer the paper is blended, the finer the fiber will be.

3.2.2 Cooking of PVOH binder

We will take 100 ml water and heat this up to 85°C. Now we will take 20 gm PVOH and poured into the water and we will stir PVOH for 30 min at constant temperature 85^{o}C.

3.2.3. NaOH fiber Treatment

Take the PET fiber and treat it with NaOH for different time intervals then wash it with plenty of DM water so that all the NaOH washed out .after that put the treated fiber into vacuum oven for 24 Hrs.

3.2.4. Freeness of the pulp (TAPPI T 227)

Blending is followed by checking the freeness of pulp. The general standard accepted value for freeness is 425-500 CSF (25-30 °SR).

Fig 3.1: Freeness Tester

3.2.5 Pulp disintegration (TAPPI T 205)

A pulp sample is said to be completely disintegrated when it is subjected to mechanical treatment in water so that interlaced fibers, which were free in the pulp stock, are again separated from one another without appreciably changing their structural properties.

Figure 3.2 Pulp disintegrator

Addition of synthetic fibers: The fibers are first completely soaked in a solution containing a synthetic binder and the solution is made uniform by mixing it in a lab stirrer for 15 minutes. This solution is then added in the pulp disintegrator and blended for about 5000 revolutions.

3.2.6 Stock preparation

Water is added in a large bucket, to the blended fibers to make a consistency of 0.4%. A lab stirrer is then placed inside the bucket so that the pulp does not settle and it will also allow uniform mixing.

Figure 3.3 Stock preparation

3.2.7 Hand sheet preparation

Once a uniform dispersion is formed then hand sheets of paper are made on sheet maker. The sheet machine container is firmly placed in position, and firmly clamped by pulling the handles of clamping lever in upward direction. The drain valve and needle valve are closed and container is filled with water and pulp slurry is added. The perforated stirrer is then inserted, and moved steadily up and down six times and the stirrer is gently withdrawn. After a pause of 6 seconds when liquid becomes motionless, the drain valve is opened with a rapid movement. A sheet is then obtained which is transferred and air dried.

Figure 3.4 Hand sheet maker

3.2.8 Hand sheet pressing and drying (TAPPI T 402)

The sheet is to be couched from the wire using blotters of suitable quality, using the couch roll. Then the sheet is laid, on the attached blotter, in the press on an initial pad of two blotters, a polished drying plate is centred over the sheet and add two more blotters. Repeat procedure for second sheet. The stack from top to bottom will then consist of two blotters, drying plate, test sheet, and two blotters. This process of assembling the blotters, plates, and test sheets has to be kept in the press until up to four sets have been accumulated. The top sheet is then covered with two blotters. Finally the cover of the press is put on and hand-tightened by two of the diagonally opposite, or all four, wing nuts. The pressure is then raised as indicated by the gage to 50 psig, on the sheet in 30 s from the time the needle begins to move and is maintained for 5 mins ± 15 secs. The stack of blotters, plates, and sheets is then removed from the press. A sheet of 185-mm filter paper is then laid on the test sheet with light hand pressure and the assembled plate, test sheet, and filter are fitted into a set of drying rings. The piles of rings are then clamped together. The test sheets are then dried in atmosphere in accordance with TAPPI T 402.

3.2.9 Hand sheet making calculations

4g in 1000ml = 0.4% consistency

Area of sheet = $0.02\ m^2$

For 60 gsm sheet

$60\ g \rightarrow 1\ m^2$

$X\ g \rightarrow 0.02\ m^2$

Therefore X = 1.2 g

4 g → 1000 ml

1.2 g → Y ml

Therefore Y = 300 ml

To prepare 60 gsm sheet 300 ml pulp slurry is required.

Prepare consistency sheet and weight it

Suppose its weight is 1.153 g

Then 1.153 g → 300

ml 1.2 g → Z ml

Z = 312.22 ml

So use 312.22 ml to prepare 60 gsm sheets.

Hand sheets were made by blending kraft pulp with synthetic fiber and binder. All hand sheets were made at 60 ± 1.5 gsm. The paper was conditioned as per TAPPI standards (paper sheet was conditioned in chamber in a temperature of 20-25 °C and relative humidity of 60-65% for four hours), the conditioning of sheets were followed by their mechanical testing which included measuring the thickness, air permeance, tear resistance, burst strength and tensile strength.

3.2.9.1 Air Permeance (TAPPI T 460)

Air permeance of paper is nothing but its ability to allow fluids (liquids and gases) to pass through it. A test which measures the time required for a given amount of air (100 ml) to flow through a sheet of paper; defines how open or tight the sheet of paper is with respect to the passage of air through the sheet.

3.2.9.2 Tearing resistance (TAPPI T 414)

Tearing resistance or tear strength of paper is the ability of the paper to withstand any tearing force when it is subjected to. It is measured in both machine direction (MD) and cross direction (CD), expressed in mN (milli newtons).

3.2.9.3 Tensile strength (TAPPI T 494)

Tensile strength of paper is nothing but the tensile force required to produce a rupture in a strip of paperboard, measured in MD & CD, expressed in MPa.

3.2.9.4 Burst Strength (TAPPI T 403)

Burst strength is the maximum hydrostatic pressure required to rupture the sample by constantly increasing the pressure applied through a rubber diaphram on 1.20 inch diameter sample.

Chapter 4: Results and Discussion

The difference in mechanical strength properties of paper made in machine and paper made from same material in hand sheet maker can be seen in Table 4.1 and Table 4.2. Tables 4.3 to 4.20 demonstrate mechanical properties of various formulations that have been tested and compared to normal kraft paper (Table 4.2). These tests were performed according to TAPPI standards.

When non-cellulosic synthetic fibers are incorporated with the kraft pulp fiber, an unusal phenomenon occurs. Synthetic fibers which are non-cellulosic in nature are generally stronger in tensile strength than are the wood fibers but are less bonded in a sheet than a cellulose fiber. When sheet is torn, the synthetic fibers do not rupture but pull out of the sheet structure. This requires more work than simple fiber rupture. This means that the tear strength will improve as the synthetic fiber content is increased (Table 4.3 to 4.20). At some point, however, the quantity of synthetic fibers will cause a loss in tensile strength (Fig 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.15, and 4.14). It is desirable therefore to add sufficient amount of synthetic fiber to increase the tear strength without disrupting the sheet structure to the point the tensile strength is decreased below the acceptable level. If the amount of synthetic fiber incorporated into the wood pulp/synthetic fiber sheet structure is constant, the tear strength will increase with the length of the fiber. It is important to note however that as length increases, the number of times synthetic fibers is contacted by wood fiber increases. Since each fiber contact as an area of bonding, the total amount of synthetic fiber bonding increases as length increases. At some point, however, the fibers become so bonded that they will break rather than pull out of the sheet during tear test. This phenomenon decreases the tear strength since it takes less energy to break a fiber than it does to pull it out of the sheet structure.

Binder is added to improve the bonding of wood pulp fiber and the synthetic fibers, since the synthetic fibers interfere with wood pulps bonding ability. The binder corrects for that interference so that wood pulp and synthetic fibers will bond. Even with a binder present, the addition of a synthetic fiber to cellulose fiber may not improve the tensile strength (Table 4.7 to4.12, 4.15 &4.17) to a great extent. The tensile strength of virgin Kraft paper was found to be 90 MPa. The same paper on being repulped had a tensile strength value of 19.56 MPa. There are two possible region for this:

1. The paper made via continuous process has much higher mechanical (tensile) properties as compared to the paper prepared in the lab (the setup similar to ours). This is due to the much higher alignment/orientation of the fibers structure.
2. Possible leaching out of some chemical into the water when the original Kraft paper is repulped. To ascertain this a simple experiment was performed when the specific gravity of water in which the original Kraft paper suspended overnight was compared with that of after water without any paper comparison was also done between the specific gravity of water suspension of original Kraft paper and water taken after the disintegration step during re pulping. The no difference in specific gravity was observed in both cases. This technique used a specific gravity bottle and weighing balance which is accurate to 0.1 ml. This we can conclude the drop in repulped Kraft paper tensile strength as compared to original Kraft paper due to the first reason i.e. higher properties of paper made by machine v/s by hand.

Table 4.1: Mechanical properties of original Kraft paper

		Test					
Sr.No	**Kraft Paper Original**	**Basis Weight (gsm)**	**Thickness (mm)**	**Air Permiance (sec/100 ml)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	100%	59.85	0.078	196	601	356	106.1
2		59.90	0.081	198	603	374	110.8
3		60.02	0.077	199	600	382	107.2
4		59.88	0.071	201	604	371	107.1
Average		**59.91**	**0.076**	**199**	**602**	**370**	**107.8**

Table 4.2: Mechanical properties of re-pulped Kraft paper (Base reading)

Base		**Test**					
Sr.No	**Kraft Paper Repulped**	**Basis Weight (gsm)**	**Thickness (mm)**	**Air Permeance (sec/100 ml)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	100%	61.20	0.11	11.5	776	164	19.00
2		61.10	0.12	12.0	820	163	19.80
3		61.10	0.12	11.8	838	158	20.00
4		59.97	0.11	12.5	919	155	19.50
Average		**60.80**	**0.115**	**11.95**	**838**	**160**	**19.57**

4.1: Effect of blending Kraft paper and PET fiber

Table 4.3: Mechanical properties of 95% Kraft pulp+5% Recron 3s, 3mm fibers +15 % PVOH granules of of2 5% of Recron 3s

ABPV4	**Test**				
Sr.No.	**Basis Weight (gsm)**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	61.12	0.125	1050	242	26.3
2	61.90	0.126	981	222	18.6
3	60.10	0.122	1045	258	22.7
4	60.25	0.124	1040	218	24.4
Average	**60.79**	**0.124**	**1029**	**235**	**23**

Table 4.4: Mechanical properties of 90% Kraft pulp+10% Recron 3s, 6mm fibers +10 % PVOH granules of 10% Recron 3s

ABPV1	**Test**				
Sr.No.	**Basis Weight (gsm)**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.10	0.112	1135	212	23.54
2	61.90	0.103	1128	213	20.98
3	60.12	0.110	1142	200	22.78
4	61.11	0.110	1075	215	23.42
Average	**60.80**	**0.108**	**1120**	**210**	**22.68**

Table 4.5: Mechanical properties of 90% Kraft pulp+15% Recron 3s, 6mm fibers +10 % PVOH granules of 5% Recron 3s

ABPV2	**Test**				
Sr.No.	**Basis Weight (gsm)**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	61.11	0.09	1227	187	18.68
2	61.90	0.10	1224	181	18.83
3	60.12	0.09	1230	187	17.20
4	60.10	0.083	1235	205	18.57
Average	**60.80**	**0.090**	**1229**	**190**	**18.32**

It can be seen from figure 6.10 that Recron 3s,6mm is compatible with cellulose when PVOH binder is used as binder moreover it is also clear that tear resistance and burst strength of paper increases by PVOH as binder .

It is also observed that addition of fiber decreases the tensile strength but increases the tear resistance.

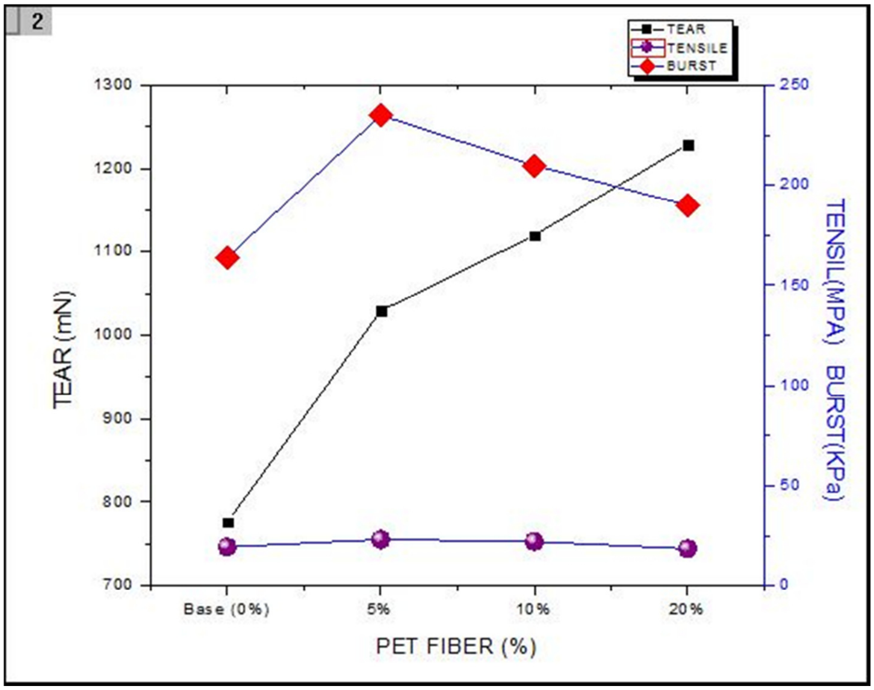

Fig4.1: Effect of (weight %) Recron 3s, 6mm loading on tear tensile and burst strength of paper in comparison to normal Kraft paper by using PVOH granules as a binder.

4.2: NaOH Treated PET Fiber

Table 4.6: Mechanical properties of 90% Kraft pulp+5% Recron 3s, 3mm fibers (2.5min treated) +5 % PVOH granules

AN11	**Test**				
Sr.No.	**Basis Weight (gsm)**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.10	0.07	964	192	24.83
2	60.12	0.08	956	187	25.78
3	61.10	0.08	958	178	25.32
4	61.10	0.09	954	163	26.07
Average	**60.78**	**0.08**	**958**	**180**	**25.5**

Table 4.7: Mechanical properties of 80% Kraft pulp+10% Recron 3s, 3mm fibers (2.5min treated) +10 % PVOH granules

AN8	**Test**				
Sr.No.	**Basis Weight (gsm)**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.10	0.12	1538	207	15.74
2	59.90	0.12	1532	208	16.28
3	61.20	0.13	1528	202	17.20
4	60.10	0.122	1530	199	14.98
Average	**60.33**	**0.123**	**1532**	**204**	**15.67**

Table 4.8: Mechanical properties of 70% Kraft pulp+15% Recron 3s, 3mm fibers (2.5min treated) +15 % PVOH granules

AN9	**Test**				
Sr.No.	**Basis Weight (gsm)**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	59.90	0.113	1092	204	14.60
2	61.20	0.10	1090	198	15.02
3	60.10	0.112	1089	200	14.98
4	69.84	0.107	1085	198	15.68
Average	**60.26**	**0.108**	**1089**	**200**	**15.07**

Table 4.9: Mechanical properties of 70% Kraft pulp+20% Recron 3s, 3mm fibers +10 % PVOH granules

AN10	**Test**				
Sr.No.	**Basis Weight (gsm)**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	61.20	0.136	1132	142	12.32
2	59.80	0.136	1128	139	12.20
3	59.84	0.14	1129	140	12.22
4	60.15	0.14	1127	139	12.38
Average	**60.24**	**0.138**	**1129**	**140**	**12.28**

It is observed from figure 6.2 that NaOH treated PET Recron 3s,3mm fiber and for same quantity of binder (PVOH granules)for different time interval have significant change on tensile strength with respect to base paper and burst strength increases not significantly with Naoh treated fiber as treatment time increases .Moreover we are getting better burst strength with respect to Base Kraft paper. While tear strength is increase very much with 2.5 min Naoh treated PET fiber.

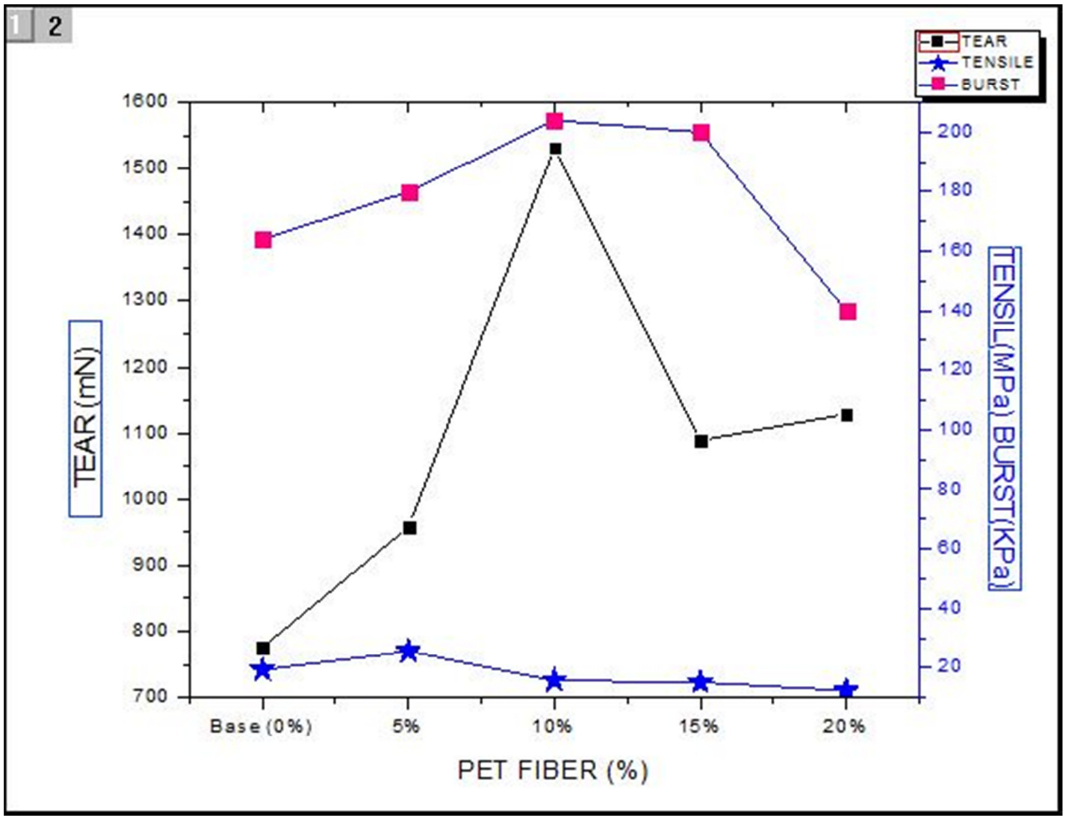

Fig 4.2: Effect of NaOH treated Recron 3s, 3mm loading for different time interval on tear, tensile and burst strength of paper in comparison to normal Kraft paper by using PVOH granules as a binder.

4.3: Effect of blending Kraft paper with higher percentage of binder (PVOH GRANULES) and PET fiber

Table 4.10: Mechanical properties of 75% Kraft pulp+15 % Recron fiber +20% PVOH granules of fiber

AN12		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	61.30	-	0.13	1276	149	17.62
2	59.80	-	0.136	1270	147	17.38
3	59.80	-	0.154	1272	148	17.46
4	60.15	-	0.14	1282	144	17.54
Average	**60.26**	**-**	**0.14**	**1275**	**147**	**17.50**

Table 4.11: Mechanical properties of 70% Kraft pulp+10% Recron 3s, 3mm fibers +20 % PVOH granules

ABPV5		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.15	-	0.156	1210	145	14.68
2	60.10	-	0.148	1195	138	14.28
3	59.80	-	0.140	1198	139	14.48
4	61.30	-	0.156	1197	138	14.30
Average	**60.33**	**-**	**0.15**	**1200**	**140**	**14.42**

Table 4.12: Mechanical properties of 60% Kraft pulp+20% Recron 3s, 3mm fibers +20 % PVOH granules

AN13		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	59.80	3.84	0.156	1130	125	10.20
2	60.10	4.05	0.16	1128	118	10.0
3	61.30	6.88	0.16	1137	119	9.84
4	60.20	1.25	0.188	1137	118	9.44
Average	**60.35**	**4.005**	**0.166**	**1133**	**120**	**9.87**

It is observed that with higher percentage of binder (cooked PVOH) there is some improvement in air permiance of the composite paper. From 6.3 the figure it is very clear that by adding sufficient amount of binder and keeping the lower percentage of Kraft paper (weight %) basis the air permiance increases.

Moreover the very high percentage (weight %) basis the air permiance and tensile properties of the composite paper get decreased a lot. It is desirable to add sufficient amount of binder (cooked PVOH) for the improvement of these properties but also keep the hygroscopic nature of PVOH in mind so that the moisture will not affect the paper quality

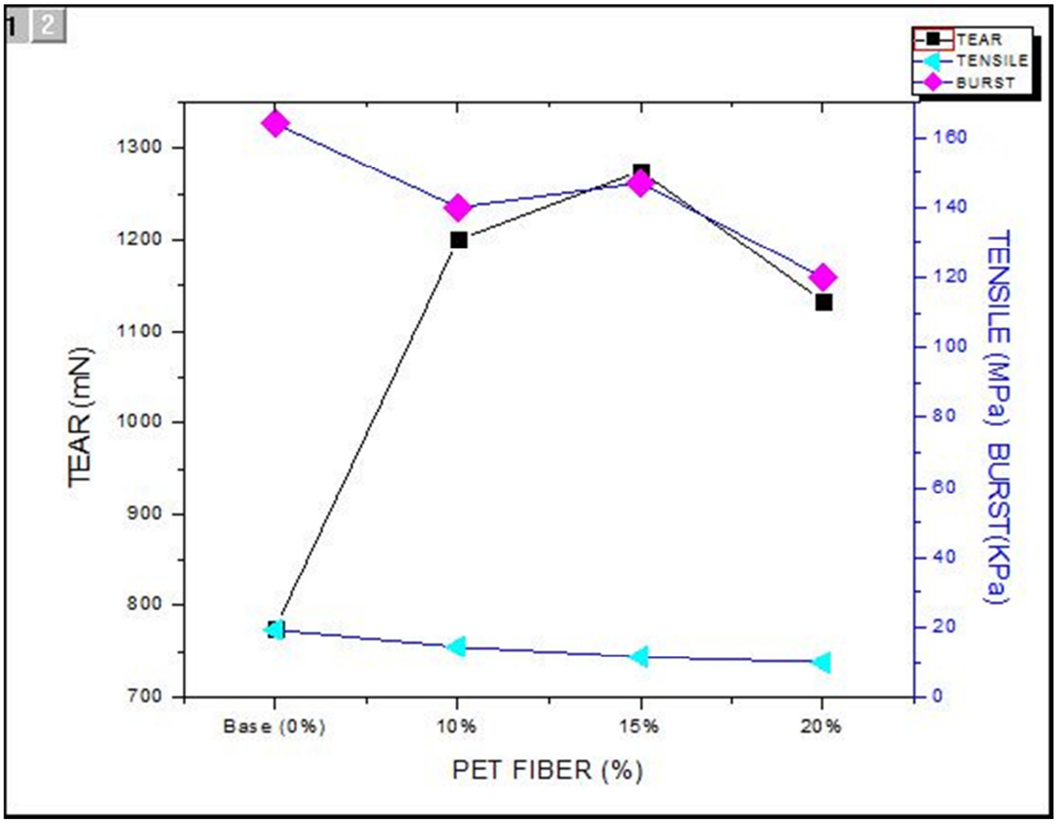

Fig 4.3: Effect of (weight %) PET fiber loading with higher percentage of binder (PVOH granule) with equal (weight %) percentage of PET fiber.

4.4: Experiment with PVOH fiber

Table 4.13: Mechanical properties of 95% Kraft pulp+5% PVOH fiber

AN17		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.20	3.64	0.11	1030	245	21.98
2	60.10	3.73	0.10	1020	238	22.57
3	61.30	3.44	0.10	1019	236	22.98
4	59.80	3.78	0.11	1023	241	23.19
Average	**60.35**	**3.64**	**0.105**	**1023**	**240**	**22.68**

Table 4.14: Mechanical properties of 90% Kraft pulp+10% PVOH fiber

AN15		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.20	5.57	0.10	1091	222	18.20
2	59.80	5.52	0.13	1084	213	17.30
3	61.30	5.92	0.12	1095	215	17.25
4	60.10	5.63	0.10	1086	222	18.81
Average	**60.35**	**5.62**	**0.112**	**1089**	**218**	**17.89**

Table 4.15: Mechanical properties of 85% Kraft pulp+15% PVOH fiber

AN16		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	61.30	1.27	0.12	1025	175	16.38
2	59.80	1.30	0.13	1018	168	16.32
3	60.20	1.53	0.12	1017	167	16.52
4	60.10	1.63	0.12	1024	170	16.38
Average	**60.35**	**1.431**	**0.112**	**1021**	**170**	**16.40**

Table 4.16: Mechanical properties of 80% Kraft pulp+20% PVOH fiber

AN14		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.10	3.37	0.12	1246	225	16.38
2	59.80	3.63	0.13	1238	218	16.32
3	60.20	3.73	0.12	1237	217	16.92
4	61.30	3.65	0.12	1243	220	16.38
Average	**60.35**	**3.59**	**0.112**	**1241**	**220**	**16.5**

Table 4.17: Mechanical properties of 60% Kraft pulp+40% PVOH fiber

AN18		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.10	1.27	0.12	1480	145	7.23
2	59.80	1.27	0.11	1468	150	7.90
3	60.20	1.30	0.11	1465	138	7.54
4	61.30	1.29	0.12	1475	135	8.81
Average	**60.35**	**1.28**	**0.117**	**1472**	**142**	**7.87**

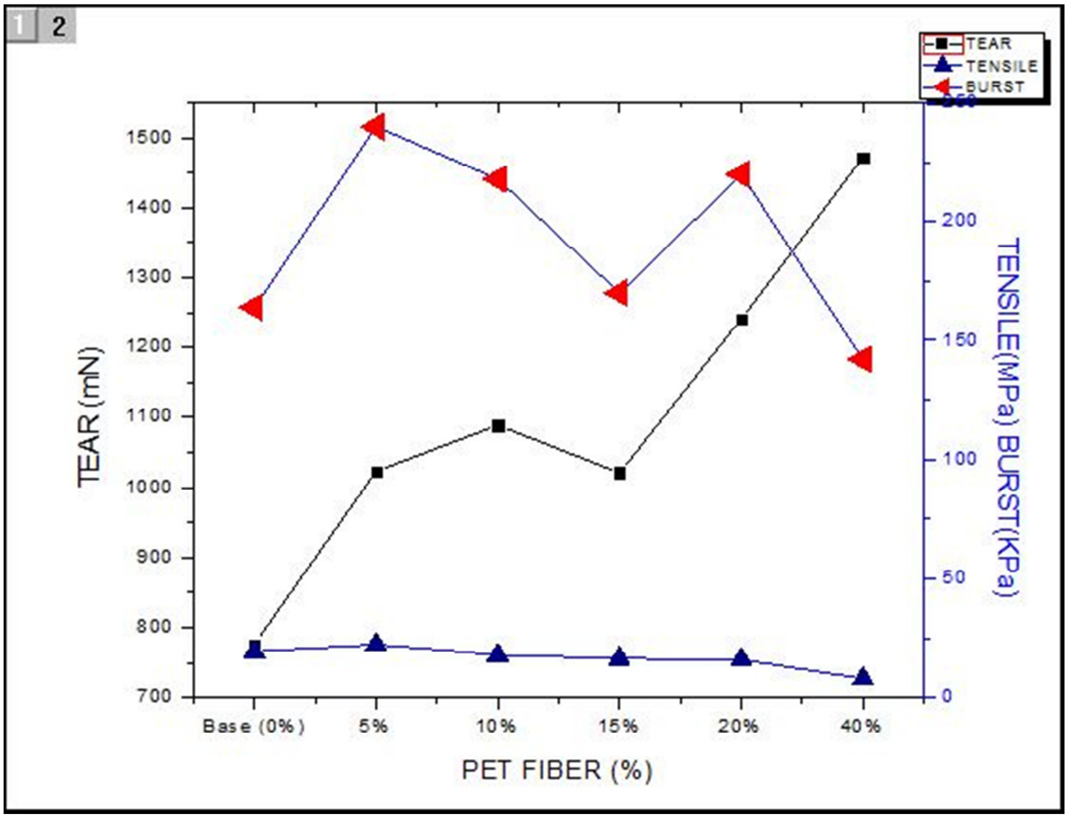

Fig 4.4: Effect on tensile, burst and tear on addition of PVOH (%weight) fiber

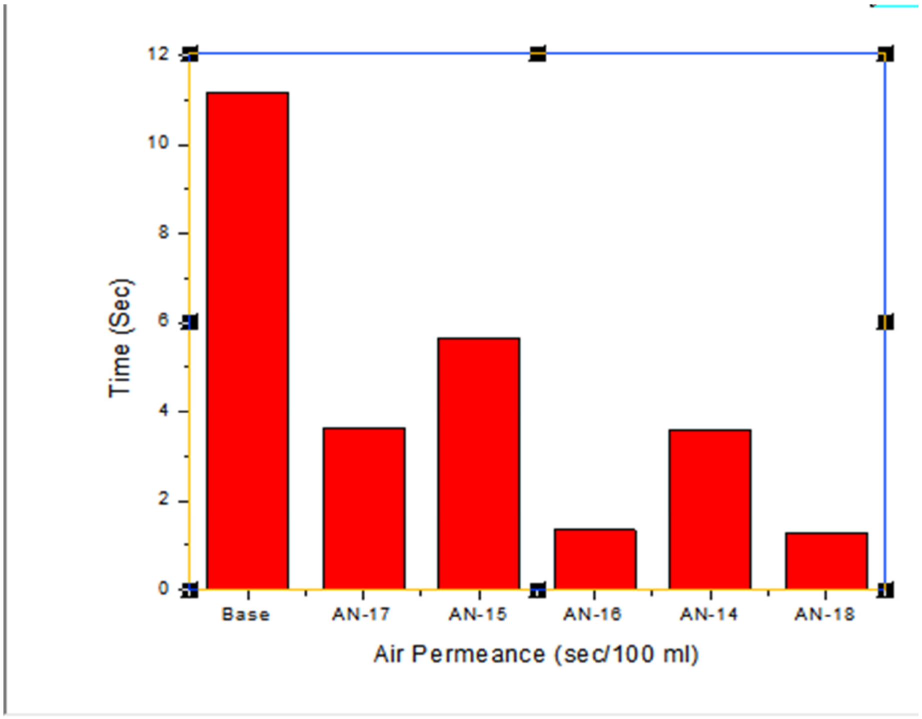

Fig 4.5: Effect PVOH fiber on air permiance

4.5: Experiment with PVOH granules

Table 4.18: Mechanical properties of 95% Kraft pulp+5% PVOH granules

AN21		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.10	6.91	0.07	734	235	25.78
2	59.80	8.68	0.072	740	228	26.20
3	60.20	7.36	0.075	737	230	26.12
4	61.30	8.06	0.063	741	227	25.59
Average	**60.35**	**7.75**	**0.07**	**738**	**230**	**26**

Table 4.19: Mechanical properties of 90% Kraft pulp+10% PVOH granules

AN20		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.10	6.81	0.06	862	162	25.78
2	59.80	7.67	0.08	858	157	24.34
3	60.20	6.18	0.06	859	159	25.1
4	61.30	7.14	0.07	861	162	24.78
Average	**60.35**	**6.8**	**0.0675**	**860**	**160**	**25**

Table 4.20: Mechanical properties of 80% Kraft pulp+20% PVOH granules

AN19		**Test**				
Sr.No.	**Basis Weight (gsm)**	**Air Permiance (Sec/100)ml**	**Thickness (mm)**	**Tear Resistance (mN)**	**Burst Strength (kPa)**	**Tensile Strength (MPa)**
1	60.10	7.61	0.07	862	212	24.78
2	59.80	9.16	0.08	873	208	23.34
3	60.20	9.80	0.06	859	211	23.87
4	61.30	7.30	0.07	876	209	24.01
Average	**60.35**	**8.43**	**0.07**	**869**	**210**	**24**

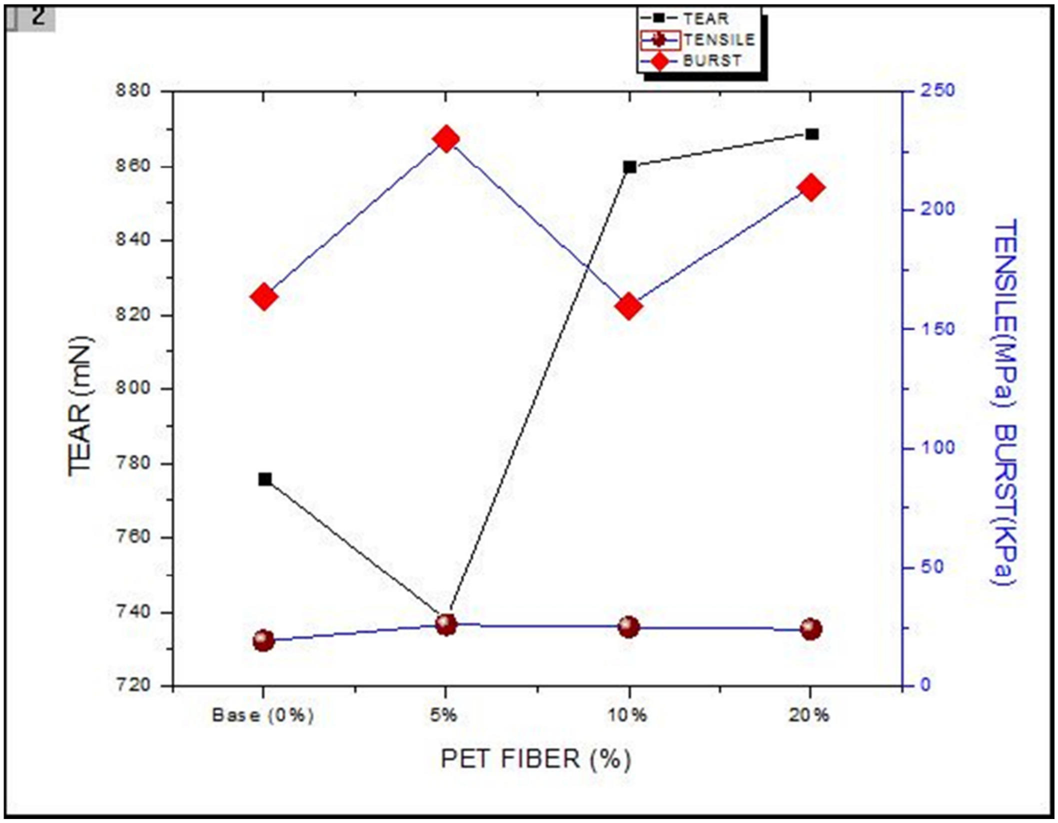

Fig 4.6: Effect on tensile, burst and tear on addition of PVOH (%weight) granules.

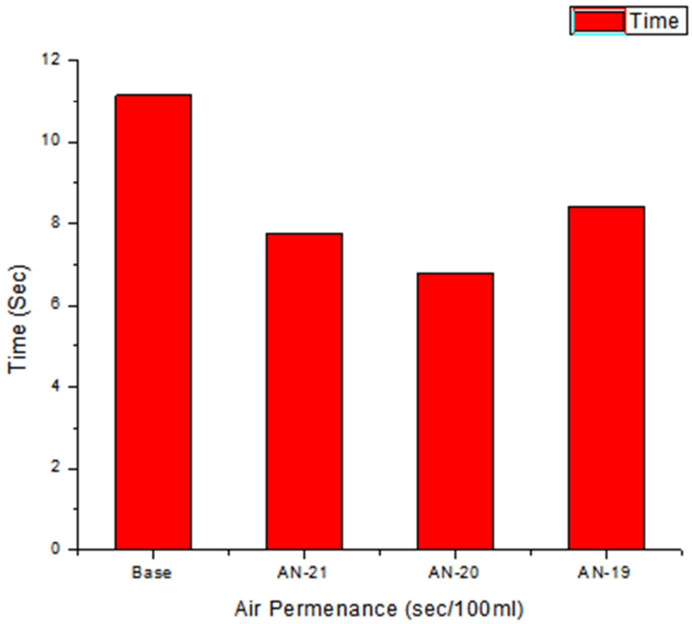

Fig 4.7: Effect of PVOH (weigth %)granules on Air Permeance It is very interesting that there is very much increase in Air permanence and Tensile strength by using only PVOH granules. We find out the maximum tensile stress (26MPa).

Chapter 5: Conclusions

The strength of cellulose paper increased by addition of binder but if we increased the quantity of binder beyond a limit then tensile strength is decreased. The addition of binder increase the tensile as well as burst strength but increase in fiber decreases the dielectric constant so we have to add sufficient amount of fiber. The tensile properties also depends upon density of cellulose paper as the density of cellulose paper increase there is sufficient amount of increase in tensile and burst strength of paper. These properties also depend upon disintegrator cycle because if we increase disintegrator cycle beyond a limit there is increase in CSF value due to which tensile and burst strength of paper decreased. So, by analysis we find out best result when we use (90% Kraft Pulp + 5% PVOH granules) in the absence of fiber we achieved tensile strength 26 MPa which is 33% greater than the base paper. It is desirable to add sufficient amount of synthetic fiber to increase the tensile strength without disrupting the sheet structure to the point tear strength is decreased. It is also observed that by increasing the pressing pressure and time the tensile strength increased.

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