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Enhancement in Physico-Chemical Properties of Cellulose Based Kraft Paper with the aid of Poly-Amide-amine- Epichlorohydrin (PAE)

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***Abstract*—The current research work explores the possibility of enhancing both physico-chemical and dielectric characteristics of insulating kraft paper modified using wet strength resin (WSR), dry strength resins (DSR), and Apcotex. Six (06) different types of modified insulating were prepared using different layering (single side and double side layering) of additives. Prepared and modified samples were analyzed The physical (Appearance, Grammage, Thickness), chemical (pH, Ash Content), mechanical (Tensile Strength, Tear Factor, Elongation, Bursting strength), and dielectric properties (BDV, Moisture content) of the obtained and modified samples were measured in comparison with the reference (fresh) kraft paper. Results show that the addition of WSR (as single layer) to basic and traditional kraft paper can achieve the best performance. The enhanced density and inter-fiber bond strength are responsible for the increased tensile strength. Moreover, kraft paper layered (single) WSR demonstrates significantly improved AC breakdown strengths, with increases of 19% and 21% compared to the reference paper. In conclusion, the modified kraft paper utilizing WSR appears to be a promising nano-additive for enhancing cellulose insulation.**

***Keywords*—Kraft Paper, Wet Strength Resin, Dry Strength Resin, Apcotex, Breakdown Voltage, Tensile Strength, Bursting Strength, Tear Factor, Moisture Content.**

I. INTRODUCTION

Cellulose-based kraft paper and mineral oil have been frequently used in power transformers for approximately 100 years due to their inexpensive nature and outstanding insulating properties [1-3]. However, large insulation breakdowns in transformers have become a serious problem in recent years, possibly caused by the development of ultra-high voltage direct current (UHVDC) power transmission [4-7]. Big power transformers are costly to maintain and repair; transformer accidents can cause significant damage. Early diagnosis of power transformer breakdowns may substantially minimize revenue losses [8]. Oil-immersed transformers are widely utilized in power systems due to their excellent insulation performance, effective cooling capabilities, and long service life [9,10]. The internal insulation of transformers is primarily composed of two components: paper insulation (including insulating paper and cardboard) and liquid insulation [11,12]. During long-term operation, the transformer's oil/paper insulation deteriorates due to the effects of electricity, moisture, heat, and oxygen [13]. In practical terms, the insulation performance of insulating oil can typically be preserved through measures such as oil changes and oil filtering. However, insulating paper is challenging to replace, posing a direct threat to the operational lifespan of the transformer [14]. Hence, enhancing the dielectric properties of basic cellulose-based kraft paper used in oil-immersed transformers has emerged as a key research focus in the electric power industry [15]. Despite extensive research on mineral oil and other polymers, there has been relatively limited exploration into the modification of kraft paper [16,17].

Previous research efforts have primarily concentrated on enhancing the thermal properties of kraft paper and reducing its hygroscopicity and relative permittivity [18,19]. Mechanical and electrical strengths have often been overlooked in previous studies. Nanotechnology offers a fresh avenue for modifying insulating materials, potentially addressing these overlooked aspects. Nano-dielectrics have recently gained popularity. [20,21]. Liao et al. conducted a series of experiments on the insulating properties of nano-modified paper [22–24]. The researchers investigated the impacts of nano-metric hollow $SiO2$, nano-montmorillonite, and nano-$TiO2$. The theory suggests a notable enhancement in the AC breakdown strength of oil-impregnated paper through the precise concentration of nano additives. However, it emphasizes the importance of carefully balancing this concentration, as an excess can accelerate degradation in mechanical properties. These properties play a crucial role in the selection of kraft paper for oil-immersed transformers [25]. Furthermore, the production method for the previously mentioned nano-modified paper is frequently challenging because of the natural incompatibility of inorganic nanoparticles and organic cellulose fibers [16,26]. As a result, an organic nano additive could serve as an excellent substitute, particularly if it is derived from cellulose fiber and hence less prone to behave as an impurity. Furthermore, it has historically been documented that the swelling pattern of the fibers reacting with water has a direct effect on the tensile strength of paper [27]. Fiber-to-fiber contacts formed during the paper production, consolidation, and drying processes determine the strength. Hydrogen bonding is the major adhesive force in dry paper, and it only works over short distances. Since the bonds are sensitive to water, the infiltration of water into the dry paper matrix results in a rapid weakening of the fiber-to-fiber bonding and a simultaneous reduction in paper strength [28]. To mitigate the decrease in paper strength upon contact with water, reactive water-soluble polymers like polyamide-amine-epichlorohydrin (PAE) are frequently employed to enhance bonding between fibers, which represents the weak link in wet paper [29].

Therefore, in the current experimental work, a new additive such as; polyamide-amine-epichlorohydrin (PAE) in terms of dry strength resign, wet strength resin and Apcotex are explored. The variation in various characteristics of insulating paper are analyzed and compared with cellulose based traditional kraft paper.

II. Material Arrangements

The experimental work starts with the collection of material as required for smooth execution (described below):

A. Insulating Kraft Paper (KP_1)

Electrical grade cellulose based traditional kraft paper of 50 micron (thickness) and 4.0 g (weight) were selected as reference/virgin paper. The criteria for evaluating cellulose-based insulating paper are outlined in ANSI/IEEE C57.100, which specifies a dielectric constant greater than 1. The reference paper used in this experiment was supplied by Electra Paper Pvt. Ltd., Ambala, Haryana, India as shown in Fig. 1. The size of fresh paper was selected as 100 cm x 100 cm i.e. in accordance with experimental needs and setup specifications, since laboratory setup used for this experimental work was in condition to accommodate samples with thin thickness. The detailed technical specifications of the kraft paper were selected to meet the requirements for use as an insulating material according to the Indian standard IS: 1060 (Part-1).

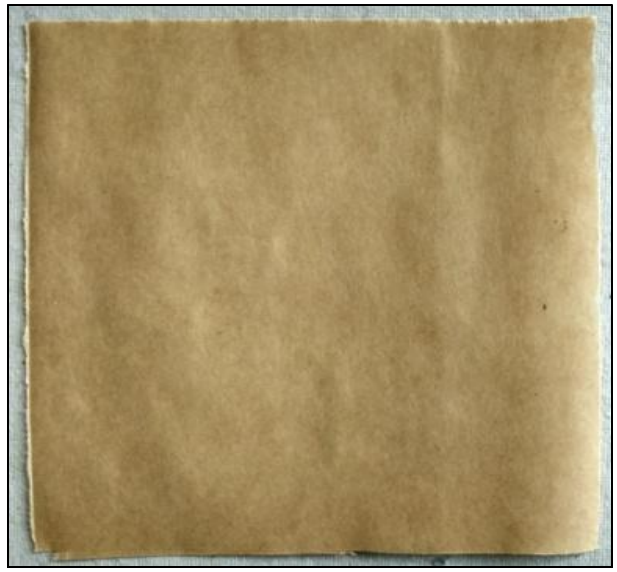

Fig. 1. Reference kraft paper (KP_1) appearance

B. Wet Strength Resin (WSR)

The most commonly wet strength resin is polyamideamine epichlorohydrin (PAE) commercially available and therefore procured from the for the layering purpose in the experimental work.

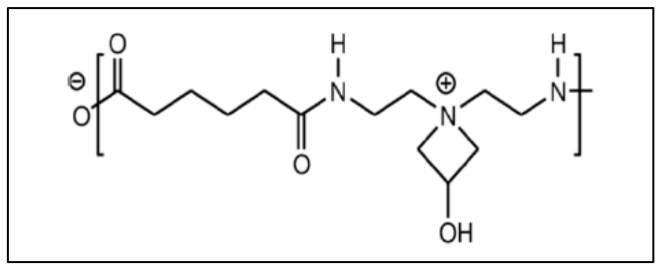

Fig. 2. Chemical structure of Wet Strength Resin

PAE (Anmo Super PAE) was provided by Anmol Polymers Private Limited, Distt. Sirmour, Himachal Pradesh (India). The technical specification of the same is mentioned in Table 1. PAE solutions were diluted with deionized water prior to each experiment.

Table 1. Technical specifications of WSR

S. No.	Testing Properties	Standard Requirements	Test Value
1	% Solids Contents	14.00 to 16.00	15.21 %
2	pH	2.00 to 4.00	3.18
3	Color	Pale Yellow	Pale Yellow
4	Appearance	Liquid	Liquid

C. Dry Strength Resin (DSR)

During that earlier period, dry strengthening agents were commonly known as "beater additives," and their application was guided by their natural affinities for wood fibers. Certain dry strength resins have been suggested to enhance both specific bond strength and the bonded area, whereas polyacrylamides and carboxymethyl cellulose (CMC) grafting primarily focus on improving specific bond strength.

PAE (Super Bonded FMP-C) was provided by Anmol Polymers Private Limited, Distt. Sirmour, Himachal Pradesh (India). The technical requirement of the same is stated in Table 2. PAE solutions were diluted with deionized water prior to each experiment.

Table 2. Technical specifications of DSR

S. No.	Testing Properties	Standard Requirements	Test Value
1	% Solids Contents	14.00 to 17.00	16.067 %
2	pH	6.00 to 8.00	6.48
3	Color	Colorless	Colorless
4	Appearance	Viscous Liquid	Viscous Liquid

D. Dry Strength Resin (DSR)

Apcotex PT800 is a refined Carboxylated Styrene Butadiene latex designed specifically for coating various types of paperboards and papers. It is made using cutting-edge emulsion polymerization technology, which ensures product uniformity. It is provided by Electra Paper Pvt. Ltd., Ambala, Haryana, India. The detailed technical specification of the same is given in Table 3.

Table 3. Technical specifications of Apcotex PT800

Appearance	Milky White
Emulsifying System	Synthetic anionic
Total Solids	50.0 + 1.0
pH @25ºC	6.5+ 0.5
Brookfield Viscosity@ 25ºC	150 -500 cst
Surface Tension@ 25ºC	45 $\pm$ 3.0 dyne/cm
Film Characteristics	Clear and slightly Tacky
Compatibility	Compatible with other coating color substances

III. Sample Preparation

To optimize dielectric performance, fresh kraft paper (KP1) with a thickness of 50 microns and a weight of 4.0 g was selected. Two sheets, each from different paper rolls, were cut into squares measuring 100 cm x 100 cm for the modification process. Both basic insulating papers were initially cleaned and dried in an air circulating oven measuring 35 cm x 35 cm x 35 cm, with a volume of 45 L, at a temperature of 90°C for a duration of 36 hours to eliminate moisture content. The one-sided and two-sided coating of DSR, WSR and Apcotex was applied on each surface of both fresh insulating paper samples. The all exercise was completed using paint brush of size 12 during day time (as shown in fig 3) so that it can dry easily. Later, the prepared modified paper samples were left for hardening for another 20 h as suggested by the electrical grade insulating paper manufacturer as shown in fig 4.

The layering was completed on single side and on both sides of fresh paper samples. In this way, total six (06) modified paper samples from KP1 were prepared such as; KPws, KPwd, KPds, KPdd, KPas, KPad where "s" and "d" in subscript indicates single and double layering of DSR, WSR and Apcotex (as shown in figure 5). The additive content in modified paper samples were measured by Micro Kjeldahl method and the concentration found in modified paper samples is shown using table 4.

The physical and dielectric properties could only be carried (as per the procedure mentioned in the Indian standard IS: 1060 (Part 1) after the curing period.

Fig. 3. Layering of fresh paper with additives (WSR, DSR and Apcotex) during day time

Fig. 4. Drying process of modified paper samples

Table 4. Percentage increase in weight (due to additives) in Prepared Samples

S. No	Modified paper samples	Weight of paper samples (g)	Inc. in weight (%)
1	Virgin kraft paper without layering (KP_1)	4.0	-
2	Kraft paper with single layer of WSR (KP_{ws})	5.04	26%
3	Kraft paper with double layer of WSR (KP_{wd})	6.1	52.5%
4	Kraft paper with single layer of DSR (KP_{ds})	5.2	30%
5	Kraft paper with double layer of DSR (KP_{dd})	6.3	57.5%
6	Kraft paper with single layer of APCOTEX (KP_{as})	7.0	75%
7	Kraft paper with double layer of APCOTEX (KP_{ad})	9.9	147.5%

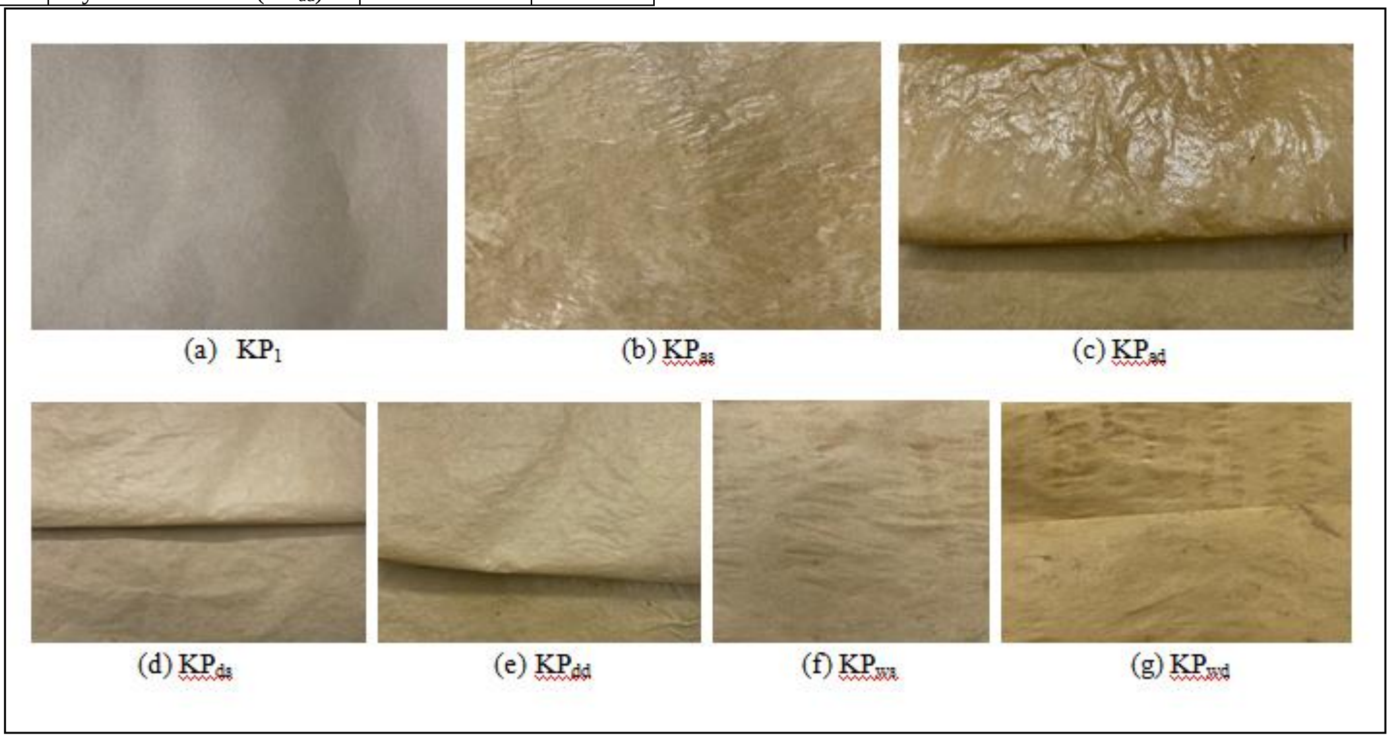

Fig. 5. Appearance of virgin/ modified paper samples with single/double sided layering of DSR, WSR, and Apcotex

III. Experimental Work Results & Discussions

The various physico-chemical, mechanical and dielectric characteristics such as; Thickness, Weight, GSM, Bursting & Tensile strength, Elongation, Tear factor, Cobb value, Dielectric strength (BDV), Oil penetration, Oil absorption, Ash content etc. of virgin, and modified paper samples are analyzed and compared.

A. Paper Thickness

Thickness is a vital parameter while selecting a paper as insulating material. Thickness determines the bending stiffness of a paper. Thickness of virgin and modified kraft paper samples is measured in micron (1 micron = 1/1000000th of a meter) using microprocessor based motorized thickness micrometers of accuracy: ±0.0025mm as per the procedure mentioned in ISO R-534 [31]. The observed thickness (considering average value from five readings) of fresh/modified paper samples is shown in figure 6. The thickness for the virgin kraft paper were measured as 50micron but after layering of Apcotex it is measured as 100microns for single side and 145 microns for double side layering. Whereas, the measured thickness with layering of DSR 65 micron and 79 microns for single and double side layering respectively. Moreover, it is observed as 62.5 micron and 74 microns of layering of WSR for one side and double side layering respectively. The increase in paper thickness with addition of number of layering's of WSR is quite natural and are within the limits specified by Indian Standard IS: 9335 [39]. Thus, it can be concluded that the paper samples modified with one side layer of WSR are having optimal results in terms of paper thickness.

B. Paper Weight

Weight of an insulating kraft paper must be low as it can be because it affects the transformer weight and ultimately concluded in terms of cost. The weight of fresh/modified paper samples was measured using microprocessor based digital grammage tester (calibrated) as per the procedure mentioned in ISO: 536 [30].

The variation in weight of virgin & modified kraft paper samples is shown in figure 7. The graph clearly indicates that the weight of paper is increased proportionally with the number of layers which is quite natural. The weight of fresh kraft paper (KP1) was 4.0 g which increased to 7.0, 9.9 with apcotex for single and double side layering and 5.2 and 6.3 with DSR against one side and double side layering, and 5.04 and 6.1 with WSR for single and double side layering respectively.

C. Grammage

Grammage is defined as weight of the substance/test piece to the per unit area. It is measured in g/m^2. The procedure for measurement of grammage is followed from Indian Standard ISO-536 [30]. The variation in grammage of virgin & modified kraft paper is presented in figure 8. The graph clearly indicates that the grammage of paper samples increases proportionally with the number of layers of Apcotex, DSR and WSR. The grammage of fresh kraft paper (KP_1) was 40 g/m^2 while it is measured as 70 g/m^2, 52 g/m^2, and 50.4 g/m^2, with one sided layering of Apcotex, DSR and WSR respectively and rises up to 99 g/m^2, 63 g/m^2, and 61 g/m^2, respectively on both sides layering using Apcotex, DSR and WSR on paper samples.

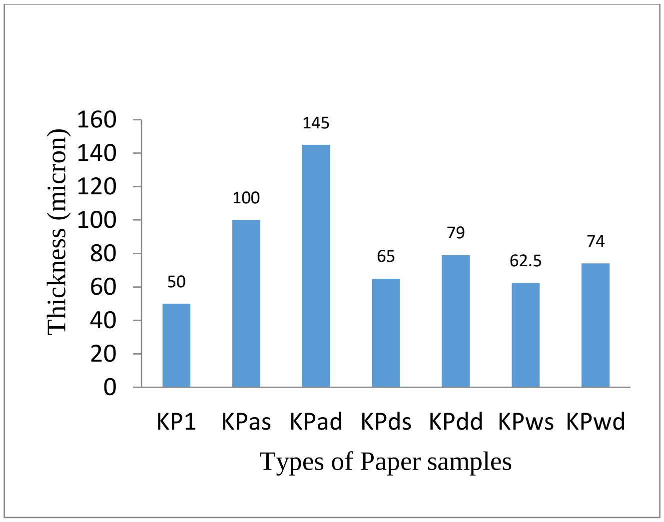

Fig. 6. Thickness variation in fresh/modified samples

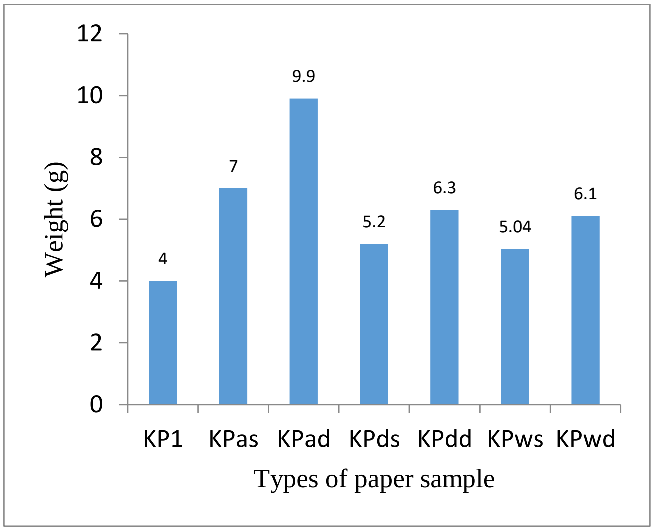

Fig. 7. Weight variation in fresh/modified samples

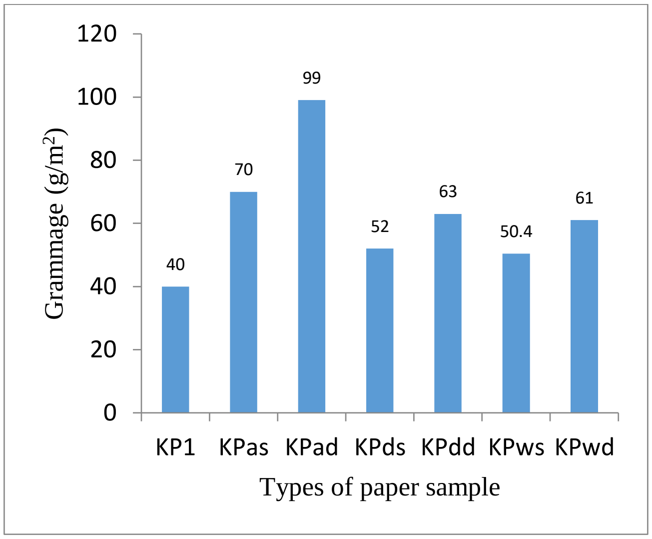

Fig. 8. Grammage variation in fresh/modified samples

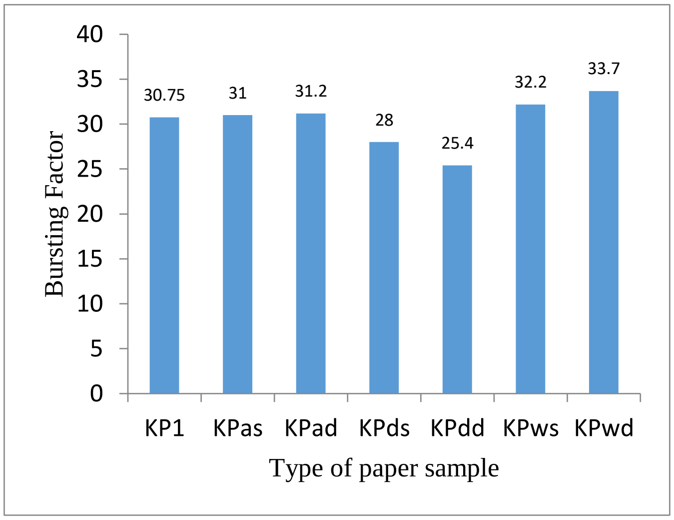

Fig. 9. Bursting St. variation in fresh/modified samples

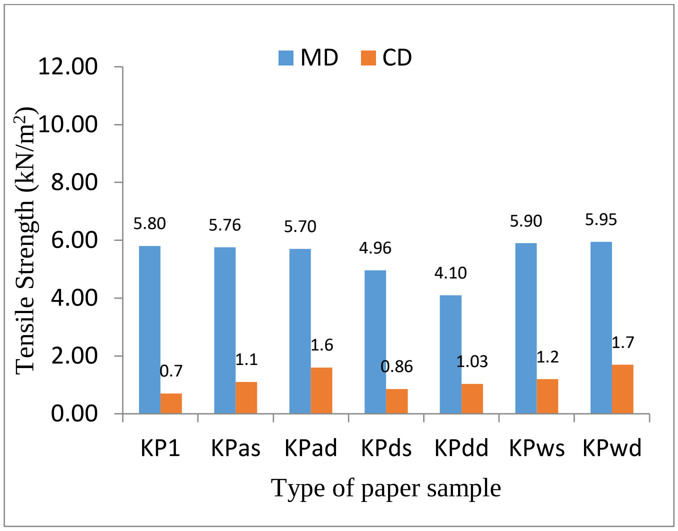

Fig. 10. Tensile St. variation in fresh/modified samples

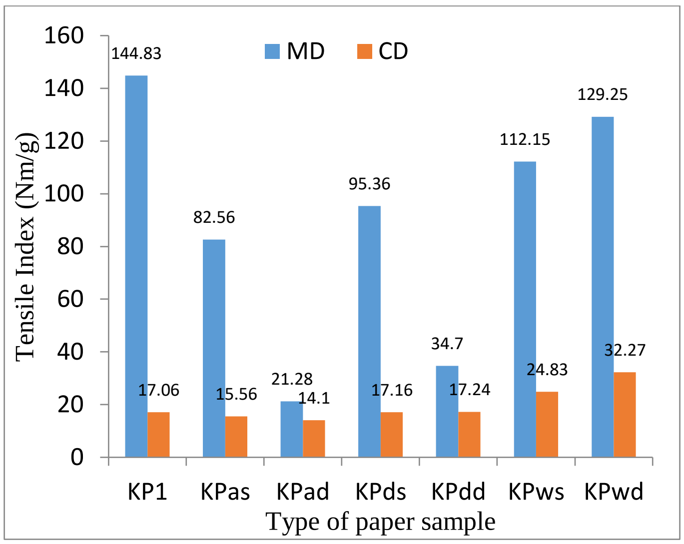

Fig. 11. Tensile index variation in fresh/modified samples

D. Bursting Strength / Burst Factor

Bursting strength of paper indicates the strength of a paper i.e. how much pressure a paper can tolerate before rupture. A digital bursting strength analyzer was used to determine the bursting strength of virgin & modified kraft paper samples as per the procedure mentioned in ISO:2758 [38].

The observed values for virgin & modified kraft paper is shown in figure 9. The bursting factor of fresh kraft paper (KP_1) was 30.75 while it is measured as 31 and 28 and 32.2 with one sided layering of apcotex, DSR and WSR and rises up to 31.2 and 25.4 and 33.7 respectively on both sides layering using apcotex, DSR and WSR on paper samples. The figure clearly indicates that bursting factor is directly proportional to the layering of apcotex and WSR. Whereas, it is inversely proportion to the layering of DSR. It may be due to organic compounds in DSR weaken the insulation of hydrogen bonding of both of kraft paper. The results are calculated by taking mean value of four readings of each sample.

E. Tensile Strength / Tensile Index

Tensile strength indicates the serviceability y of insulating paper. It directly specifies the flexibility and physical capacity of paper, generally measured in both machine direction (MD) as well as in cross direction (CD). The tensile strength is generally expressed as the breaking length. Figure10 presents the results obtained for tensile strength of virgin & modified kraft paper in machine direction (MD) as well as in cross direction (CD). The graphical representation is done by considering the average value of the tensile strength of virgin & modified paper samples. The average values of tensile strength in machine direction (MD) for virgin kraft paper was 5.8 kN/m^2 and after one sided layering of Apcotex, DSR and WSR it is measured as 5.76 kN/m^2, 4.96 kN/m^2 &5.9 kN/m^2 and after double layering of Apcotex, DSR and WSR it is 5.70 kN/m^2, 4.10 kN/m^2 & 5.95 kN/m^2 respectively. It can be seen that, paper samples prepared with double layer of WSR are much stronger and break failure cannot occur just after yielding, exhibiting a high tensile strength. The single layered modified paper sample such as KPas and KPds shows a medium tensile strength in comparison with KPad and KPdd. It may be due to millions of pulp fibrils such as; lignin and hemicelluloses present in the paper for which strength can be increased with changing in structural level. The tensile strength of the virgin and modified paper samples is also measured in cross direction of paper and shown in figure 4.10. The average valued of tensile strength in cross direction (CD) for virgin kraft paper was 0.7 kN/m^2 and after one sided layering it is measured as 1.1 kN/m^2 for Apcotex, 0.86 kN/m^2 for DSR and 1.2 kN/m^2 for WSR. Whereas, with double layering it is 1.6 kN/m^2 for Apcotex, 1.03 kN/m^2 for DSR and 1.7 kN/m^2 for WSR. It can be seen that the layering process having same impact on tensile strength of paper samples in cross direction as well.

Tensile index is also identifying inherent paper capacity like breaking length and expressed in Nm/g. In order to show the effect of additives on the mechanical properties of paper samples, the calculated results for tensile index of the virgin and modified kraft paper in both of direction such as; machine direction (MD) & cross direction (CD) are summarized in figure 11. The measured tensile index in machine direction (MD) for virgin kraft paper was 144.83 Nm/g and after one sided layering it is measured as 82.56 Nm/g for apcotex, 95.36 Nm/g for DSR and 112.15 Nm/g for WSR and after double layering it is 21.28 Nm/g for Apcotex, 34.7 Nm/g for DSR and 129.25 Nm/g for WSR. It clearly indicates that with Tensile index is increasing with the single layering of Apcotex and DSR and WSR. Further, with the increase of concentration the tensile index of modified paper samples gets reduce except WSR.

The tensile index of virgin and modified paper samples is also measured in cross direction (CD) of paper and shown in figure 4.12. The calculated average values for tensile index of virgin kraft paper was 17.06 Nm/g and after one sided layering of Apcotex it is measured as 15.56 Nm/g &17.16 Nm/g and 24.83 Nm/g for DSR and WSR respectively. After double layering it is 14.10 Nm/g for Apcotex, 17.24 Nm/g for DSR and 32.27 Nm/g for WSR. It can be seen that the layering process having same impact as it was in the case of tensile strength as it totally depends upon the structure of the material. These results indicate that the desirable tensile properties of WSR based paper samples can be achieved by appropriate layering method.

F. Elongation

The primary material stiffness measurement parameter is the ratio of the stress and strain tensile modulus. This test was performed to determine elongation % of paper before fracture. It must be high for the better insulation. Elongation is usually more in cross direction (CD) than in machine direction (MD). Total nine measurements are made on each fresh and modified paper test sample cut from both the machine direction (MD) and the cross direction (CD). The central value of the test pieces, in each direction, is taken as the result and shown in figure 12.

The measured elongation of virgin kraft paper in machine direction (MD) was 2.55 % but after one sided layering it increases to 2.61% with Apcotex, and 3.1% with DSR and 3.5% with WSR and further increase to 2.92% with Apcotex, and 3.8% with DSR and 3.9% with WSR after double sided layering. With increasing values of elongation representing increased flexibility and an enhanced level of deformation resistance. Thus, it may be concluded that the addition of alkyl phenolic resin results in an increased elastic modulus and a subsequently increased cellulose elongation.

The elongation of virgin and prepared samples using APR is also measured in cross direction (CD) and comparative summary results are shown in figure 12. The elongation in the virgin kraft paper was measured as 5.5% respectively whereas with one sided layering it is measured as 6.42% with Apcotex, 6.8% with DSR, and 6.9% with WSR respectively and after two sided layering it is measured as 7.75% with Apcotex, and 7.9% with DSR and 8.1% with WSR respectively for modified kraft paper samples.

G. Moisture Content / Cobb Value

Cobb test determines the quantity of absorbed water content by paper. Water content in insulation paper adversely affects the properties of insulating paper as it increases the degradation rate, also the insulating paper becomes conducting reducing its life span which results in early failure of transformer. Figure 13 shows the variation of paper sample mass as a function of time.

The initial mass of virgin kraft paper was 57 mg but after one sided layering of it is measured as 31 mg &88 mg and 49 mg for Apcotex, DSR and WSR respectively whereas it is measured as 10 mg &116 mg and 42 mg for Apcotex, DSR and WSR with double sided layering. As per the results obtained by cobb test, a large decrease in water content is measured in prepared samples. This indicates that the decreasing the water content does not simply increase the strength of paper samples; it also results as durable and can withstand at higher temperature. According to the above observation the modified paper can be a better alternate to the traditional insulating paper.

H. Oil Penetration / Oil Absorption

Oil absorbency is the rate of oil absorption through a paper sample and measured in percentage. The rate of oil absorption in virgin kraft paper was observed as 15.9 % but samples prepared using single side layering shows oil absorption rate of 7 %, 5.52 % and 6 % respectively for Apcotex, DSR and WSR and samples prepared using double side layering shows absorption rate of 4 %, 16.8 % and 6 % respectively for Apcotex, DSR and WSR respectively. Figure 14 clearly indicates that the rate of oil absorptions is decreasing with increasing concentration of additives.

Oil penetration determines the time in seconds for which a drop of castor oil produces a uniform translucent spot by permeation through specimen. The obtained results for virgin kraft paper for oil penetration was 4.5 seconds and in samples prepared using single layer oil penetrates in 6 sec., 8 sec., & 5.5 sec. for Apcotex, DSR and WSR respectively whereas it found to be penetrate in 7.3 seconds, 4.0 seconds and 7.0 seconds in double layered kraft paper samples.

I. Breakdown Voltage (BDV)

The dielectric breakdown voltage of an insulating paper refers to its capacity to endure electric stress. It is the voltage measured in kV/mm at which breakdown occurs between two electrodes under prescribed test condition. Research findings on modifying agents for electrical insulation applications have suggested that modified insulating papers exhibit either slight degradation or significant improvements in breakdown characteristics compared to the virgin samples. These results give a huge motivation to carry out the BDV test in this research work. The figure 15 explains the variation measured in breakdown strength (BDV) of paper samples in mineral oil and in air. With the increase of layers of additives, the paper samples become stronger in terms of mechanical strength. It has been already clarified that; higher mechanical strength results in better dielectric strength of paper. The BDV of fresh paper in oil is measured as 60 kV/mm, whereas for single layered it is measured as 90, 75 & 65 kV/mm with Apcotex, DSR and WSR respectively. Further, it is found as 85, 70 & 57 kV/mm for double layered modified paper samples with Apcotex, DSR and WSR.

The BDV in air is also measured for kraft paper and the observed results are shown in figure 15. The breakdown voltage of fresh kraft paper in air is measured as 16 kV/mm, and it is measured as 19, 18 and 17 kV/mm Apcotex, DSR and WSR respectively. whereas it is 20, 19 & 16 kV/mm for double layered paper samples. It shows a little enhancement in dielectric strength of paper samples in air also. So, it can be concluded as the WSR based paper samples can be used as an alternative to the traditional kraft paper.

J. Electrical Conductivity

The conductivity of an electrolyte solution indicates its capacity to conduct electricity. Its SI unit is siemens per meter (S/m). Traditionally, conductivity is determined by connecting the electrolyte in a Wheatstone bridge circuit. The result obtained for fresh and modified paper samples expressed in micro siemen / meter by calculating mean value out of three determinations is shown in figure 16. A significant decrease in electrical conductivity is measured in modified paper samples. The initial values for the electrical conductivity in virgin kraft paper was 4.8 µS/m whereas with one sided layer it is found 5.16 µS/m, 5.1 µS/m and 4.6 µS/m with Apcotex, DSR and WSR respectively. However, with both sided layering it is measured as 5.45 µS/m, 5.35 µS/m, and 4.5 µS/m with Apcotex, DSR and WSR.

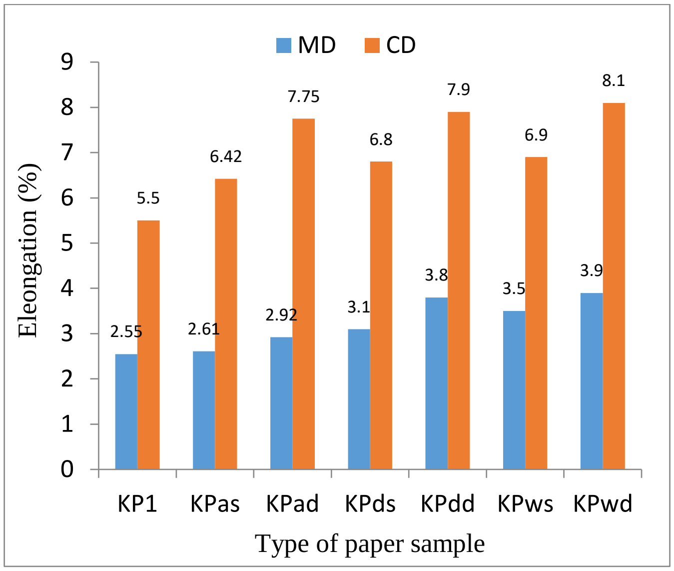

Fig. 12. Elongation variation in fresh/modified samples

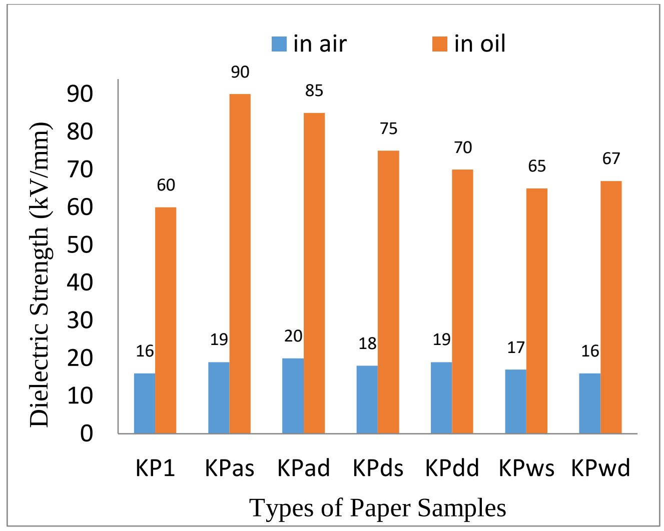

Fig. 15. BDV variation in fresh/modified samples

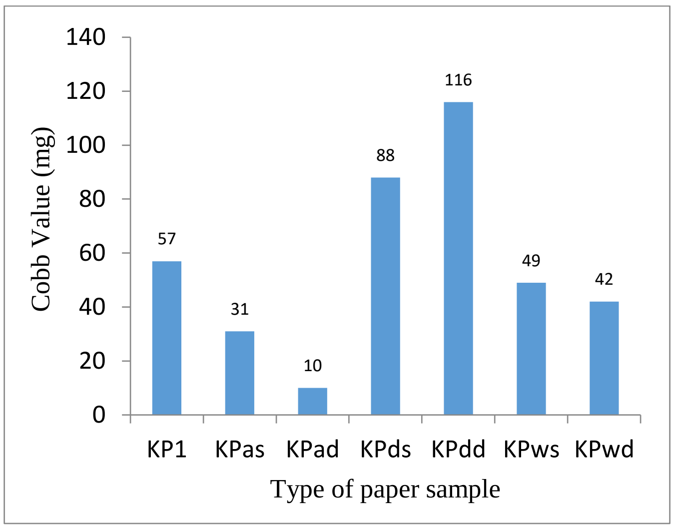

Fig. 13. Moisture Content variation in fresh/modified samples

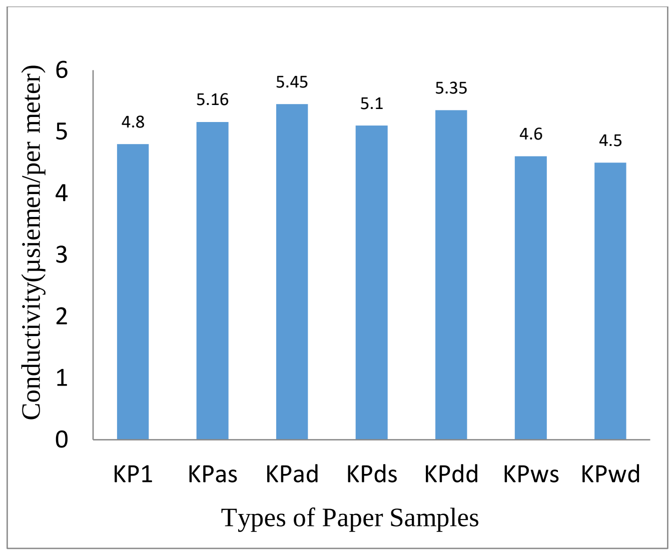

Fig. 16. Electrical Conductivity in fresh/modified samples

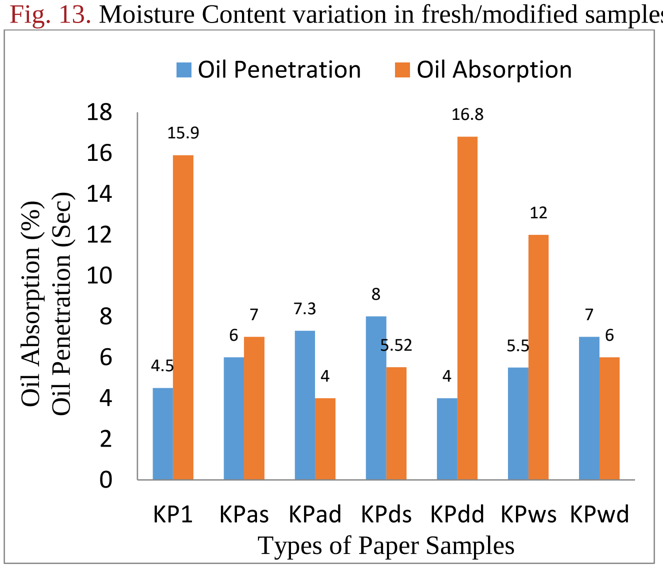

Fig. 14. Oil Absorption/Penetration variation in fresh/modified samples

V. CONCLUSION

In the experimental work efforts were made to upgrade the solid insulating paper by modifying it in six (06) different types of paper using additives of Apcotex, DSR and WSR. The physical, mechanical and dielectric properties of the fresh and all modified paper samples were analyzed and compared. The results obtained are summarized as follows:

- Resin based insulating paper provides a solid insulating system which has high dielectric strength, high tensile strength, high static strengths as well as dynamic strength in between and through of paper with significant change in breaking factor and bursting strength. Therefore, it can be concluded that, the physical, mechanical and dielectric properties of cellulosic paper samples significantly improve upon addition of resins.

- Visual observations based on absorbance, and colour, indicates that the modified/upgraded kraft papers are similar to the traditional kraft paper.

- The result of 26 % wet solvent resin (WSR) filled insulating paper recommends one of the best insulating system which has no voids and cracks, proves to be better in mechanical properties.
- The maximum increase in thickness of paper samples is observed as 25%, 30% and 100% with addition of single layer of WSR, DSR and Apcotex whereas it is observed as 48%, 58% and 190% with addition of double layer of WSR, DSR and Apcotex. Therefore, modified paper with single layer of WSR shows optimum results w.r.t the requirements as per mentioned in Indian standards.
- The increase in bursting strength indicates more suitable and healthy paper which is observed in the WSR based modified papers. The total increase in bursting strength in modified paper samples follows pattern: KPdd < KPds < KP1 < KPas < KPad < KPws < KPwd.
- The tensile strength of the modified kraft paper samples is increased by 57%, 22%, 57% and 71 % with single layering of DSR, Apcotex and WSR respectively and 47%, 128% & 142% with double layer of DSR, Apcotex and WSR respectively.
- An increase in elongation is also observed with the addition of Apcotex, DSR and WSR. The maximum increase of 2.35%, 21.56% and 37.25% is observed with single layer of Apcotex, DSR and WSR respectively whereas the increase of 14.50%, 49%, and 53% is observed with the double layer of Apcotex, DSR and WSR.
- The moisture absorption should be decreased with the increase of layering additive. However, in case of DSR based modified paper it is increased with layering. But with the addition of Apcotex and WSR it is decreased by 45% and 14%.
- Therefore, WSR resin filled nature makes the paper high moisture resistance as compared to basic kraft paper.
- The breakdown voltage value of modified paper also shows increasing trends with the addition of single and double layer of apcotex, DSR and WSR. The measured BDV of fresh and modified paper samples follows the pattern KP1 < KPws < KPwd < KPdd < KPds < KPad < KPas.
- The layering process offers high flexibility of its use in high voltage applications.

Therefore, out of three (03) selected materials, for upgradation of kraft paper, it can be concluded that the better dielectric properties of insulating paper can be achieved with all three materials. However, wet strength resin proved itself more suitable as compared to the other Apcotex and DSR.

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