Viscosity Analysis of Water-Soluble Polymers Used in Pre-Compressed Pressboard Insulation: An Experimental Approach

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ABSTRACT

Water soluble polymers are classified according to highly varied families of products of natural or synthetic origin and have several uses. Among these families, synthetic polymers are mainly used for bonding of boards and paper laminates which is used as an insulation for high voltage power transformers. The three main characteristics of water soluble polymers used in laminates are the molecular weight, concentration and internal structure. In general, the efficiency of the polymer will be greater if it posses longer molecular chain which inturn depend on their molecular weight. In addition to this, finding the viscosity of polymers is also a prime consideration for insulating purpose. Kinematic viscosity is a measure of the resistive flow of a fluid under the influence of gravity. In this paper experimental investigations have been carried out to measure the kinematic viscosity of synthetic polymer choosing different proportions of equal volume of insulations at 28° C, 40° C and 50° C. The insulating materials used for testing are polyvinyl alcohol (PVA), polyvinylpyrrolidone (PVP) and blending of both used in manufacturing of pre compressed press boards for high voltage power transformers.

Keywords: Water soluble polymers, Kinematic Viscosity, Povidone (Polyvinylpyrrolidone), Polyvinyl Alcohol, Power Transformers.

I. INTRODUCTION

The Pre compressed pressboards are used in power transformers as an insulation, these are made as large sheets of thin pressboard sheets. The transformer life depends upon the insulating material used. The most important andessentialinsulating materials used in large high-voltage transformers of having optimum dielectric strength, mechanical and chemical properties.From long period the oil impregnated, cellulose-based products like primarily paper and pressboards are used for insulation purpose. The chief disadvantage of cellulosic material for electrical use is that it is hygroscopic in nature and need 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 fibres with synthetic fibres. 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.

Viscosity is the magnitude that defines a fluid's resistance to flow. When there is a larger viscosity, the intermolecular forces of attraction are strong within a liquid. It is also important to note that the viscosity of liquids and gases are *dependent on temperature* but in reverse ways, for the liquid viscosity decreases if temperature increases whereas for gases viscosity increases as temperature increases due to the molecules present can move freely when they are heated. Since the ability of any molecules to move freely directly depends on their intermolecular forces. As the time of contact of molecules with each other increases the intermolecular forces which in turn avoid the molecules to move freely in substance[1].

Kinematic viscosity [2] is one of the physical properties which is comparatively easily measured. The theoretical interpretation of the measurements present extensive difficulties but is of great fundamental significance, as the viscosity information should be able, if properly interpreted, to provide or to enhancement of information on the amount of hydration or salvation, on the nature of the suspended or dissolved particles, their rigidity/stiffness and state of aggregation, and on the forces acting between the particles, which are properties of great interest to colloidal chemistry as well as to industry.
From everyday experience, it should be common knowledge that viscosity varies with temperature. When honey and syrups are heated continuouslyit is made to flow more freely. In general, the viscosity of a simple liquid increases with decreasing in temperature (and vice versa).As increase in temperature, the average speed of intermolecular forces decrease. In which the two quantities vary is nonlinear and changes when the liquid changes phase abruptly. The present paper discusses the kinematic viscosity of different polymers used for transformer insulation to increase insulation life and in turn increase the life of power transformer.

II. MATERIALS USED

Polyvinylpyrrolidone (PVP)

Figure 2.1: Polyvinylpyrrolidone Powder

Polyvinylpyrrolidone (PVP) is a chain polymer of vinyl and pyrrolidone, developed in the late 1930’s. PVP is obtained by a multistep synthesis that concludes by polymerization of vinylpyrrolidone in aqueous solution in the presence of hydrogen peroxide [3]. PVP is a white hygroscopic powder shown in figure 2.1, and unlike many synthetic polymers is soluble in a variety of traditional solvents such as water, chlorinated hydrocarbons, alcohols, amides, and amines. The interactions between the carbonyl groups in PVP and the hydroxyl group in polyphenols are well known. Due to these interactions PVP is used to isolate poly phenols. PVP formulations have been used to produce desired solution viscosity, allowing the deposition of a uniform coating thickness of a photo resist in the manufacture of high resolution display screens [4].

Many chromatographic methods have been reported for the determination of PVP, either qualitative determination of the molecular weight range of the polymer or quantitative determination in formulations and products, with most focusing on the qualitative aspects such as the form of povidone present and whether materials with same K-value are structurally the same. A variety of capillary electrophoresis (CE) methods for the characterization and determination of povidone have been reported [5], including capillary zone electrophoresis (CZE) and capillary gel electrophoresis (CGE). Size exclusion chromatography (SEC) determinations of povidone have focused on molecular weight characterization of the povidone itself or the use of povidone as a molecular weight calibrator for other determinations [6]. In this paper, PVP with a molecular weight of approximately 50,000 with a K-value of 90, typical in ophthalmic solutions, were used. PVP originally was used as a plasma substitute and in a variety of applications. Its hygroscopic properties, film formation, and adhesion to different materials have made PVP widely used in pharmaceuticals, cosmetics, and industrial production.

Polyvinyl Alcohol (PVA)

Figure 2.2: Polyvinyl alcohol Powder

Polyvinyl alcohol (PVA) is also a water soluble polymer whose water solubility depends on its degree of hydrolysis, molecular weight, and tendency to hydrogen bond in aqueous solutions. Polyvinyl alcohol powder shown in Figure 2.2 has high tensile strength and flexibility, excellent film forming, emulsifying and adhesive properties, as well as high oxygen and aroma barrier properties. As PVA is produced by methonolysis of poly vinyl acetate, PVA can readily soluble in water and exhibits both higher and lower critical solubility temperatures. Long term stability can be obtained by treatment of aqueous PVA solution in absence of any additives, in order to produce gel structures having a wide range of industrial applications to enhance the mechanical properties of films because of its compatible structure and hydrophilic properties [8].

III. SAMPLE PREPARATION

PVP and PVA can be obtained in different grades, densities, molecular weights. Depending upon their molecular weights K values are expressed for PVP which are derived from relative viscosity measurements represents a function of the average molecular weight. The PVP K-15 and K-30 concentrations are less than 10% have little effect on viscosity in aqueous solution, whereas K-60 and K-90 considerably influence flow properties. This paper work is done by selecting PVP K-90 and PVA. The selected polymers PVP and PVA are supplied by N Shashikant& Co., Mumbai. Initially different molecular weight of polymers are readily soluble in water and it is heated in warm water by adding slowly with stirring using a magnetic stirrer with different rpm until a homogenous mixture is obtained to form a gel type solution as shown in figure 3.1, in all the preparation the volume of water is kept constant and percentage weight of polymer is varied from 5% to 20%. The same method is followed for different molecular weight of the polymers.

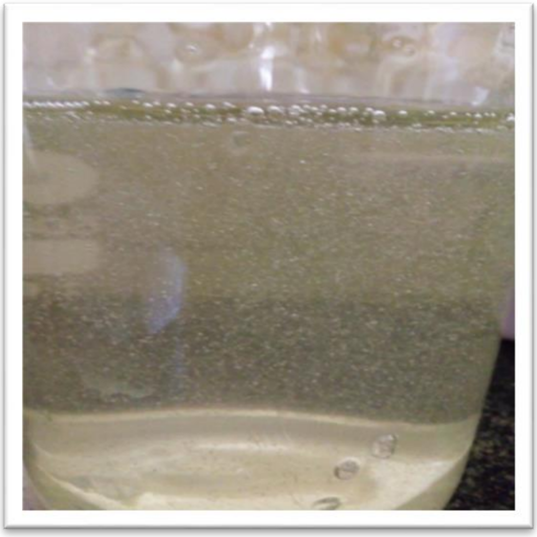

Figure 3.1: Insulation gel

IV. EXPERIMENTATION AND ANALYSIS

Various viscosity measurement techniques and instruments have been developed over the years, the most commonly used in engineering applications are capillary & rotational viscometers. In general, capillary viscometers are suitable for fluids with negligible non-Newtonian effects and rotational viscometers are suitable for fluids with significant non-Newtonian effects. Some of the viscometers have a special in built heating bath, in order to control & measure the temperature, so that the viscosity-temperature characteristics can be obtained. In most of the cases water is used in the heating bath, water is suitable for the temperature range between 0^0 to 99^0C, for higher temperature mineral oils are used and for low temperature like negative temperature up to -50^oC, ethyl alcohol acetone is used for testing the insulating gel [9].

In this paper the kinematic viscosity of polymer solution mixtures were tested by using torsional viscometer shown in figure 4.1. It consists of a wire of standard diameter or gauge passing vertically through a cylindrical tube at the top. The free end of the wire at the bottom is attached to a circular disc, which rotates over a circular graduated disc, the cylinders of varying diameter can be fixed which is completely immersed in the solution. The solution container may be placed over a platform which can be lowered or raised by means of guides over a vertical stand. By rotating the flywheel of one complete revolution in the clockwise direction standard graph of redwood seconds viscosity angular motion in degrees or different diameter of cylinders and corresponding gauge of wire is noted. The solution polymers are tested for viscosity measurements viscometer readings were taken for different temperatures at different percentage of polymers and also PVP and PVA are blended with constant stirring to form a homogeneous mass of equal percentage. Finally the viscosity is compared with individual polymer and for the combination.

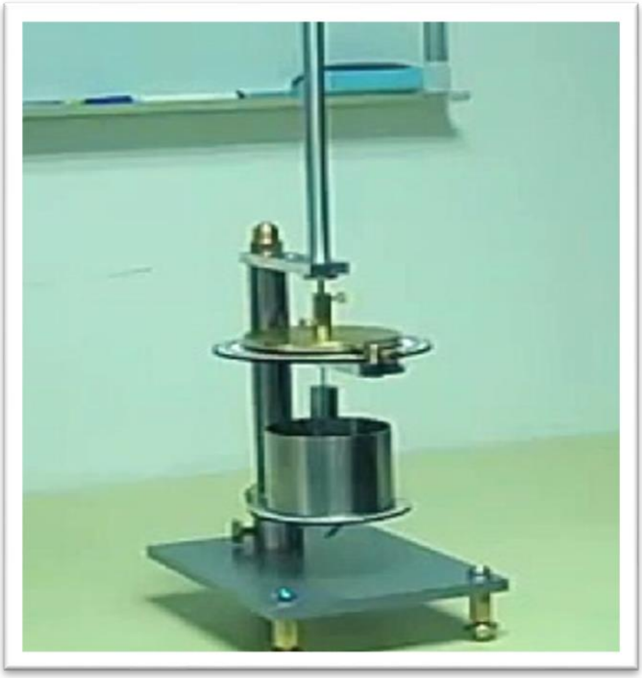

Figure 4.1: Torsional Viscometer

V. RESULTS AND DISCUSSION

For present investigation the insulating polymers were prepared by using different proportions of PVP, PVA and blending of both in equal quantities. The solution viscosity varied slightly with increasing in temperature. The experimental values of different proportion of solution are selected in such a way that by adding PVA & PVP to a constant of water with an ambient temperature, its kinematic viscosities are calculated by using torsional viscometer at different trials of temperatures like 28° C, 40° C and 50° C. The calculated kinematic viscosities are tabulated in tables. Table 1, 2 and 3 shows the readings of Kinematic viscosity of four different percentage of solution (i,e. 5%, 10%, 15%, 20%) Which have a considerable difference in sensitivity of viscosity to temperature.

Table I. Kinematic Viscosity of PVP

Trials	Temperature in ° C	Polyvinylpyrrolidone (PVP)			
		5%	10%	15%	20%
1st	28	1.35	1.48	1.97	2.22
2nd	40	0.98	1.25	1.75	2.09
3rd	50	0.88	1.19	1.67	2.01

Table II. Kinematic Viscosity Of PVA

Trials	Temperature in ° C	Polyvinyl Alcohol (PVA)			
		5%	10%	15%	20%
1st	28	1.09	1.29	1.85	2.09
2nd	40	1.07	1.2	1.72	2.03
3rd	50	1.02	1.02	1.08	2

Table III. Kinematic Viscosity Of PVP + PVA

Trials	Temperature in ° C	PVP + PVA			
		5%	10%	15%	20%
1st	28	1.43	1.51	2.09	2.22
2nd	40	1.08	1.29	1.77	2.03
3rd	50	0.93	1.23	1.62	1.97

The Figures 5.1, 5.2 and 5.3 shows an empirical parameter which compares the viscosity of PVP, PVA and blending of both insulating solution is extremely sensitive to the operation temperatures. With increasing in the percentage as well as molecular mass of polymer, the solution becomes more viscous is shown. From the engineering point of view it is important to know the viscosity value at the operating temperature, since it determines the insulating property in polymer solution.

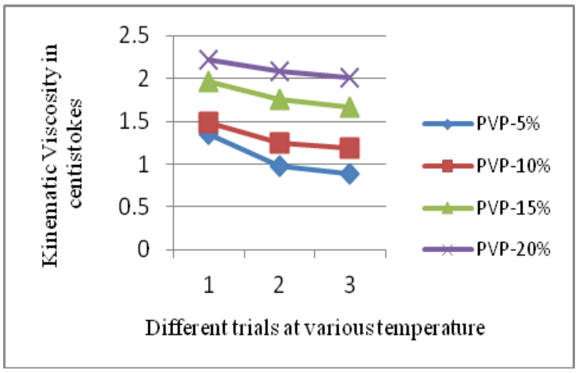

Figure 5.1: Kinematic Viscosity of PVP

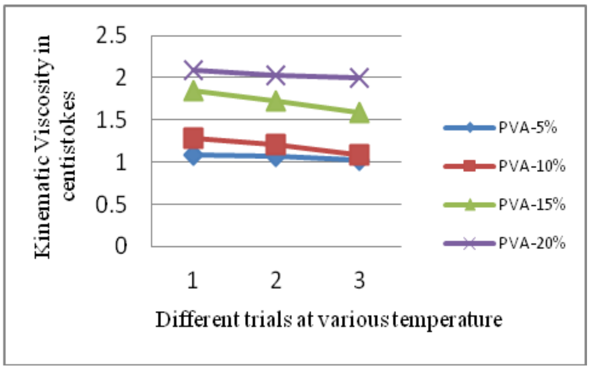

Figure 5.2: Kinematic Viscosity of PVA

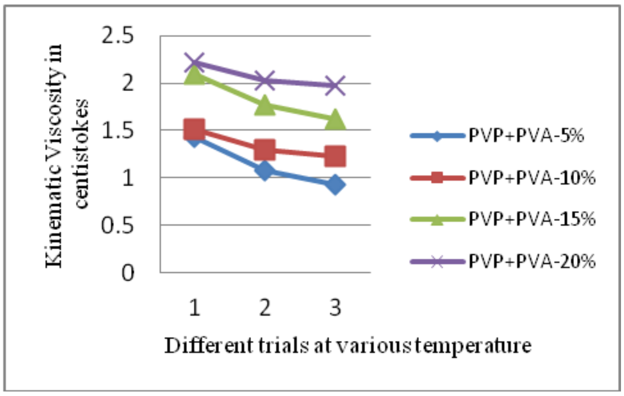

Figure 5.3: Kinematic Viscosity of PVP and PVA

As observed from Figures 5.1, 5.2 and 5.3 it may be observed that the percentage of polymer increases in a given volume of water, viscosity also increases. Further the change in viscosity with different temperature also measured and the highest percentage of PVP, PVA and the corresponding combination shows very little change in viscosity with change in temperature and other percentage of polymers it also observed there is substantial decrease in viscosity for PVP in Figure 5.1, and combination of PVA and PVP in figure 3. However in case of PVA with different percentages of polymer the change in viscosity is marginal in Figure 5.2.The viscosity at a specific temperature can be either calculated from the viscosity temperature equation or obtained from the viscosity temperature ASTM chart. (American Society for Testing Materials)

VI. CONCLUSION

The insulating solution polymers PVP, PVA and mixture of both were prepared and tested for viscosity measurements at different temperatures. The viscosity index is an inverse of the solution with temperature. High values indicate that the solution shows slightly relative decline in viscosity with temperature. The temperature of the solution increases in the apparatus by external heating. It was observed that the viscosity provide low resistance for low temperature, as temperature increases (40^o C to 50^o C), the viscosity resistance increases slightly.At the end, the results of different polymer viscosities are compared with individual polymer and for the combination and the experimental investigation shows that the polymer PVP solution and combination of both PVP and PVP gives better result than polymer PVA. These kinematic viscosities of different polymers will play a most important role in preparation of transformer insulation to increase insulation life and in turn increase the life of power transformer.

VII. ACKNOWLEDGEMENTS

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