

Essential parameters responsible for rheological assessment of concentrated dispersion:-a comprehensive review

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In recent years, colloidal processing of advanced ceramics has received an increasing amount of attention in high-tech structural materials for their excellent mechanical properties. Rheological measurements are widely used to identify the nature and behavior of the dispersions, both as a means of studying their fundamental properties and as assessment of their suitability for particular technological purposes. Knowledge of their rheological behavior is essential for almost all dispersion in order to handle them satisfactorily. In this paper, we reviewed comprehensively those parameters which influence the rheological properties and the final assessment of the colloidal dispersion. These parameters allow a wide understanding of colloidal treatment for the process of dispersibility, which is useful way to predict and control a host of product properties, material behavior and end use performance.

Key words: Concentrated dispersion, Colloidal suspension, Rheological parameters.

Introduction

Colloidal processing techniques such as slip casting, tape casting, centrifugal casting, injection moulding and dip coating are employed to produce advanced ceramics of improved reliability. In all types of suspensions the rheological properties of the concentrated suspension play a significant role in controlling the shape forming behavior and optimizing the properties of the green body. The success in achieving the desired physical properties of different types of ceramic products relies on the critical application of the colloidal ceramic processing principle. Fundamentally, the rheological properties of concentrated colloidal suspensions are determined by interplay of thermodynamic and fluid mechanical interactions. It involves the manipulation and control of the inter-particle forces in powder suspension in order to remove heterogeneities and to optimize the suspension properties. These optimum properties of powder suspension are governed by the interaction of attractive and repulsive forces. The net effect of these forces acting on particle surfaces determines the state of dispersion of the colloidal suspension wherein the repulsive forces is maximized to counteract the formation of attractive forces that cause particle agglomeration. This repulsive barrier can be achieved by electrostatic or steric stabilization mechanisms, which depends on the liquid medium and the composition of the powder (Mukherjee, A., et al.

2008; Sarraf, and Havrda, 2007; Shin Y. et al. 2006).

In electrostatic stabilization mechanism, the charged particles develop an extended layer of similar charged ions in aqueous medium, which is known as the electrical double layer. The repulsion develops when there is an overlap between charged layer, thus particles remain separated. As the concentration of oppositely charged ions in the aqueous medium increases, the range of the electrical double layer interaction decreases due to screening effect brought by the excess ions (oppositely charged) in the continuous medium. This ultimately causes particle agglomeration. On the other hand, the steric stabilization is effected by adsorption of polymeric additives to develop protective colloids on particle surfaces. This results into effective repulsion rendered by the extended polymer layers in the continuous liquid medium. The combination of the two mechanisms (electrostatic and steric) in dispersing the particles is called electrosteric stabilization mechanism (Briscoe B.J. et al. 1998; Bergstrom L. 2001; Hidber P.C., et al. 1997; Bao Y., et al. 2002). Preferably, slurries or suspensions are effectively dispersed by electrosteric stabilization mechanisms to allow dispersion of particles at a high solid loading with minimum viscosity (Zhang Q., et al. 2006). Stable colloidal suspensions are widely employed in wet ceramic forming techniques including slip casting, tape casting, pressure casting and centrifugal casting. These techniques have been used for a long time in the forming of traditional and advanced ceramics. In those shaping techniques, the colloidal processing is an important tool in achieving the stable suspension involving the dispersion of particles that influences the

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succeeding forming steps. These fabrication steps include consolidation of dispersed particles by removing most of the aqueous medium, which is followed by further drying and burning out of organic additives. Subsequently, a high temperature densification is carried out to produce a final microstructure required for optimal performance. Advanced ceramics are manufactured typically by using conventional powder technologies. For enhanced mechanical and functional properties usually very fine powders in the scale of submicron or nanometer are desired. Ultrafine powders, however, exhibit significant agglomeration in initial state. In general, agglomerates yield to considerable material flaws and inhomogeneity during the fabrication process and represent a common reason for the failure of ceramic components. During forming the powder is processed to a green body exhibiting a particular density and microstructure. It is necessary to control the density and microstructure of the green part carefully to obtain a ceramic part with favourable mechanical properties. By reducing the size and number of defects and flaws, which depend in a large scale on the applied processing method, the average strength and reliability of ceramic components can be improved significantly. Therefore, special effort is inevitable for the control of defects and microstructure of green parts. Rheology constitutes a powerful technique for the evaluation of the stability of a suspension. The measurement of flow curves for different dispersant concentrations allows to determine the value at which a minimum viscosity is obtained and thus, to evaluate the best dispersing conditions for further processing steps. This can be made by control rate (CR) measurements, where the slip is forced to flow at an increasing velocity gradient or shear rate and the resulting torque or stress is measured. Basically, rheology is the study of the relationship between the applied stress and the resultant deformation of matter. The stress may be applied in various methods; tensile, compression, shear, or any combination of the three. Most ceramic systems, especially those with colloidal size particles, exhibit a rheological behavior between a Newtonian viscous fluid and a Hookean elastic solid, and exhibit both viscous and elastic characteristics. These systems are called viscoelastic. The behavior of such systems depends on the viscosity of the liquid, the amount of the solids, the size distribution of the solids, and interactions between the solid particles and between the solid and the liquid. The rheological behaviour of a ceramic suspension is controlled not only by the type of deflocculant used in the process, but also by water hardness and pH and characteristics of the raw materials used (type, shape, particle size). The flow properties of a fluid are characterized by the plot of the shear stress associated with a shear rate applied to the fluid. In general, suspensions can either exhibit Newtonian or non-Newtonian behaviour, with the latter including dilatant, plastic, pseudo-plastic and Bingham

behaviours. A Newtonian fluid exhibits a linear increase of the shear stress as a function of the shear rate. Two important rheological terms which are often associated with rheology studies are: yield stress, which is the intercept of the flow curve on the shear stress axis at zero shear rates; and viscosity, which is the slope of the line connecting the particular point on the flow curve with the origin. It has been found that the material flow is significantly different below and above the yield stress. Viscosity is observed constant throughout the entire shear rate range for a Newtonian fluid, while for non-Newtonian fluids, this value changes as a function of shear rate. Therefore, the viscosity of a non-Newtonian fluid at any point is referred to as 'apparent viscosity'. It has been revealed that as the amount of solid in mineral suspensions increases, the rheological behaviour of the slurries shifts from Newtonian to non-Newtonian, with the progressive appearance of a yield stress and an exponential increase in the slurry viscosity. The rheological properties of concentrated suspensions are of interest in several applications. Manufacturing processes in which large volumes of concentrated suspensions are handled, such as the production of solid rocket propellants and of various filled polymeric materials, requires the understanding and control of the basic rheological behavior of concentrated suspensions.

Investigations have revealed that the incorporation of particles to the polymer system highly affect the flow behavior of polymer. There abound many factors associated with fine particles such as concentration, size, shape, size distribution as well as suspension stability which play the part in governing the properties of flow. Many research studies have been carried out to develop the fundamental understanding of aspects of particulate systems and uncover the complexities of the system. In this paper, we comprehensively reviewed such parameters which directly or indirectly influence the rheological properties of the colloidal suspensions. Thus in order to prepare the optimal aqueous and non aqueous suspended slurries many parameters which impact the properties of slurries should be investigated with a systematic care such as: pH value, the concentration of dispersant, organic additives, temperature, and many more. To incorporate these parameters with a proper knowledge makes the understandable the nature and behavior of the dispersion of colloidal suspension using aqueous and non-aqueous solvents at different set of condition with a deep perceptive value and thus, the above measuring parameters can be employed by treating a systematic, prospective and careful approach for successful exploitation of the end product of materials.

Essential Parameters Influence Rheological Properties

1) Effect of Particle Size/Packing/Distribution

- 2) Effect of dispersants
- 3) Powder Loading/Volume Fraction Influences
- 4) Effect of Pigments Loading
- 5) Effect of Electrolytes
- 6) Effect of pH
- 7) Effect of Milling Treatment
- 8) Effect of shear rate/stress
- 9) Effect of Temperature on Dispersion Structure and Rheology
- 10) Effect of Aging
- 11) Miscellaneous factors

Effect of Particle Size/Packing/Distribution:

Ceramic suspension processing require attention be paid to a variety of parameters. The rheology and processing ability of the suspensions and the particle packing also depend on other relevant factors such as particle size and particle size distribution. The surface chemistry of the particles is another relevant factor in colloidal processing. Previous theoretical and experimental works have demonstrated the influence of the interparticle forces on suspensions' viscosity and packing ability of the particles during slip casting. To understand the relationships between, particle size distribution and size ratio, and the rheological behaviour of the suspension as well as their packing ability either in suspension or in green bodies many workers (Chang C. and Powell 1994; Olhero and Ferreira 2004; Collins and Hoffmann 1979; Barthelmesa et al. 2003) have done profound job using different set of conditions. In cases where high volume loadings are desired, the concomitant high viscosity is usually not favorable from a processing standpoint. However, high solids loadings can be attained with a small increase in viscosity using suspensions having a distribution of particle sizes rather than particles of similar sizes. From a practical and experimental standpoint, this effect is well known. The packing of ceramic suspensions is best described by continuous distributions and is based on the Andreasen approach. The size of particles and their distributions directly influence the packing ability of the powders in suspension. This view is in agreement with that reported by Greenwood et al. (1997) who showed that a reduction in viscosity was strongly dependent on the particle size ratio. For suspensions with differing size distribution, Leong, et al. (1995) demonstrated that the particle number concentration based on the fine size fraction is a more appropriate parameter to use in any correlation with rheological parameters, because the fine particles determine the properties of the flocculated colloidal suspensions. In their investigation, they found that the use of particle concentration based on the fine size fraction instead of volume fraction provided a better correlation, because the fine particles govern the properties of the flocculated network structure. The effect of particle packing on the rheology and casting behavior and cast cake characteristics of

aqueous alumina suspensions as investigated using the Andreasen approach. The dispersion and structure formation within the suspension were investigated by Smith and Haber (1995) using electrokinetic sonic amplitude measurements. Particle packing with continuous size distributions was correlated with suspension viscosity. Specifically, contouring the particle size distribution to the ideal packing equation resulted in lower viscosity. Thus, particle packing with extended size distributions in suspensions caused low viscosity, and high green density; the surface chemistry provided small discontinuous flocs, and rapid filtration rates were obtained. Moreover, Chang and Powell (1994) studied the dependence of the viscosities of highly concentrated bimodal suspensions on the particle size distribution and the relative fractions of the two particle populations using a parallel-plate viscometer. For a fixed volume fraction of particles the viscosities of the systems with a bimodal size distribution of solids are less than the viscosities of a suspension with a unimodal size distribution of particulates. Experimental results show that at a fixed volume fraction the shear viscosity of a concentrated suspension having a bimodal size distribution of solids is reduced in comparison to the properties of a suspension with a unimodal size distribution of particulates. In other words, it is possible to achieve higher loading levels while maintaining processability, or to obtain a reduction in viscosity by using a multimodal particle size distribution. The influence of particle size and particle size distribution and of the particle size ratio on the rheological behaviour of the suspensions and densities of green slip cast bodies was studied by Olhero and Ferreira (2004). The results show that the flow properties of slips are strongly influenced by the particle size distribution. The viscosity of suspensions increases with the addition of fine particles, imposing some practical limitations in terms of volume fraction of fines that can be added. On the other hand, increasing the size ratio enhanced the shear thinning character of the suspensions, while decreasing the size ratio led to an accentuation of the shear thickening behaviour. Furthermore, to study the effect of particle size and particle size distribution on viscosity, viscosity-shear rate, and viscosity time behavior, Collins and Hoffmann (1979) used PVC particle fractions prepared by air classification. The results showed that a broadening of the distribution leads to elimination of the shear instability and a decrease in the shear thickening (dilatant) observed at high shear rates. This change is found to be more pronounced when the size distribution is broadened by the addition of coarse particles. Addition of coarse particles is also shown to result in a reduction in the viscosity at low shear rates. These results were interpreted by Collins and Hoffmann (1979) in terms of particle packing and electrokinetic effects. The influence of particle shape (aspect ratio) on the intrinsic viscosity was investigated

by Gregorová et al. (2009) taking three Czech kaolin products (floated kaolins) as paradigmatic examples. An average aspect ratio is obtained for each kaolin from a comparison of particle size measurements using sedimentation and laser diffraction. Barthelmesa et al. (2003) studied the dynamic behavior of concentrated suspensions of non-spherical particles theoretically by coupling a rheological law to a population balance model accounting for coagulation and fragmentation of the detailed particle size distribution. The effect of particle size distribution on the rheological properties of aqueous polystyrene latex dispersions with nearly the same *z*-average particle sizes but varying degrees of polydispersity, 0.085, 0.301, and 0.485, respectively, has been systematically investigated by Luckham and Ukeje (1999) using steady-state shear and oscillatory shear measurements.

Thus, after reviewing the above segment, it can be concluded that the particle size, the size distribution and the surface area of the particles plays an important part in rheological characterization of the colloidal suspension and finer particles having higher surface area tend to give higher viscosities under similar surface charge conditions.

Effect of Dispersants:

The rheological stability of a slip is one of the most important properties necessary for the production of uniformly high quality materials. Using dispersions of higher solid loading in preparation of ceramic green body has a very important role on the quality of the ultimate products. When ceramic powders are added to a suspending medium such as water, the presence of attractive van der Waals forces typically results in the particles aggregating to form clusters. These flocculated suspensions display a relatively high-suspension viscosity that can make processing difficult and, more importantly, the flocs can become flaws in the final microstructure leading to a reduction in the final component properties. By this, efficient de-agglomeration and dispersion of the ceramic powder in a liquid medium is crucial for minimizing defects. To obtain a ceramic suspension with high solids content that can be successfully processed it is necessary to have a low viscosity and stability. This requires efficient dispersants and conditions to obtain components with high green strength, which facilitates early mould release and green machining. To reduce the viscosity and obtain the stability dispersants are used frequently by many of the researchers (Sarraf, H. and Havrda, J. 2007; Briscoe B.J. et al. 1998; Mukherjee, A., et al. 2008). Suspensions containing insufficient and excessive amounts of dispersant show a relatively higher viscosity than those with an adequate amount due to the insufficient surface coverage and bridging flocculation between polymeric species, respectively. Some of alkaline silicates and carbonates such as sodium silicate (Na_2SiO_3) or

calcium silicate (CaSiO_3), and sodium carbonate (Na_2CO_3) or calcium carbonate (CaCO_3) are used as dispersant to provide the fluidity of both ceramic clays and suspensions. Among these common dispersants, sodium silicate (Na_2SiO_3) is known to show good performance on dispersing clays in ceramic processing. On the other hand, anionic polyelectrolytes such as polyacrylates and polyphosphates are also used in some case to regulate suspension viscosity (Andreola, F. et al. 2004, 2006). In general, suspensions can be dispersed by electrostatic, steric, or electrosteric stabilization mechanisms. Electrostatic stabilization is accomplished by generating a common surface charge on the particles. Steric stabilization, on the other hand, is achieved by adsorption of polymeric additives which serve to form protective colloids. Electrosteric stabilization requires the presence of adsorbed polymer or polyelectrolyte and significant electrical double-layer repulsion. The main problems, related to ceramic processing, found to exist in electrostatically stabilized systems derive from aging effects and complications of processing multiphase systems. Organic additives often are used as dispersants to increase repulsive forces between ceramic particles in suspension. Typically, these additives are charge-carrying long-chain polyelectrolytes. These additives adsorb on particle surfaces and modify the surface charge of these particles in suspension and thus enhance the interparticle electrostatic repulsion while further providing a steric barrier to agglomeration. Commonly used polyelectrolyte dispersants typically have molecular weights in the range 6,000-15,000. Dispersants of lower molecular weight may have advantages over such polyelectrolytes owing to their low costs, higher adsorption capacities, lesser effects on post-firing microstructure and lower environmental impact both in polar and non polar solvents (Hidber et al. 1993, 1997, Studart et al. 2003, Zürcher and Graule 2005). Heinrich and Aneziris (2007) studied the effect of deflocculating agent addition for 40 vol.% solid containing slurry in the range of 0 to 0.2 wt.% with respect to solid on the absolute viscosity. They observed that the addition of very small amount deflocculating agent reduced viscosity sharply and produced stable slurries. Yuping Z. et al. (2000) demonstrated the relation between the concentration of dispersant and the apparent viscosity of slurries at shear rate of 350 s^{-1} using two kinds of alumina slurries with 25 and 30 vol.% solid content respectively and observed that the viscosity of slurries decreased on the addition of dispersant. When the concentration of NH_4PAA was about 0.0015 g/ml, the viscosity of alumina slurry changed to 50 mPas, which was near a constant. With the concentration of dispersant increased in advance, the viscosity of slurries did not change very much and 25 and 30 vol% alumina slurries had the consistent results. Sarraf, J. Havrda, (2007) studied the influence of dispersant concentration (wt.%) on the rheological behavior of the

highly concentrated (77 wt.%, $pH = 9-10$) aqueous α - Al_2O_3 suspensions at different shear rates in the range of $0.03-1000 \text{ sec}^{-1}$. They finally observed the behavior of viscosity vs. shear rate, shear stress vs. shear rate, viscosity vs. dispersant concentration and shear stress vs. dispersant concentration at different set of conditions. Anklekar, R. M. (1998) studied two anionic dispersants viz. tri-ammonium citrate (TAC) and Darwin C (Ammonium polymethacrylate) for the determination of the optimum dispersant concentration. The alumina slurry was prepared by mixing 125 g of the powder in 75 ml of DM water (30 vol.%), containing different amounts of the above dispersants, in a roller mill for 8 h and measuring the viscosity of the slurry as a function of shear rate using a concentric cylinder rotational viscometer. From the above discussion, it can be pointed out that evaluation of the colloidal suspension by means of dispersant measurements needs considerable care and systematic approach for more interpretation of the final results.

Powder Loading/Volume Fraction Influences:

The higher the solid loading, the lower the liquid content of the slurry which in fact will lead to a green body of higher packing factor or higher density which also minimizes the shrinkage of green body. This is only possible if the samples at high levels of solid loading maintain its stability against sedimentation and aggregation of the particles with acceptable viscosity for easy casting. In colloidal ceramic processing, a high solid loading is required to achieve desirable physical properties of ceramic products. This is because of the fact that the density of the ceramic slurry defines the green density of the formed ceramic material. It is therefore necessary to optimize how high the solid loading in the ceramic suspension at considerably low viscosity to allow easy casting. It can be observed that the increase in solid loading leads to an increase in the viscosity of the slurry. This could be attributed to the fact that increasing the solid loading decreases the liquid medium for dispersion causing the viscosity to approach infinity at a maximum solid fraction. At the maximum solid loading, the adsorbed polymeric layers interlock which prevents the flow of the suspension. Moreover, as the solid loading increases the separation distance between particles decreases, which causes particle agglomeration and makes the flow impossible. For direct casting process, it is desirable that the viscosity is kept at a minimum level to allow casting (Greenwood R et al. 2002; Shin Y et al. 2006; Singh BP et al. 2004). Further, only the suspension with a specific low vol.% of solids presented a nearly Newtonian behavior, the others presenting pseudoplastic behavior. Additionally, it can be observed that the pseudoplasticity increased as the solid concentration increased. This fact is probably related to higher particle interaction. The structure of a colloidal suspension in rest is the result of a balance between the interparticle potential and the

Brownian particle motion. When the solid concentration is very high, the repulsive force between particles is insufficient to prevent their interaction, and agglomerates are formed with water inside them. As the shear rate increases, agglomerates are broken and the water inside them is released leading to a decrease in viscosity. In order to study the effect of powder loading to the rheological behavior of the MIM feedstocks, the formulations of coarse and fine powder feedstock with powder loading of 62 and 64% volume was prepared by Amin S.Y.M. et al. (2009). The remaining volume fraction is binder, consists of 73% weight of polyethylene glycol (PEG) and 25% weight of polymethyl methacrylate (PMMA). About 2% weight of stearic acid (SA) is used as a surfactant. They observed that the viscosity of a pseudo-plastic substance decreases as the shear rate increases (shear thinning). This could be due to particle orientation and ordering with flow as well as breakage of particle agglomerates released together with the binder. The dependence of relative viscosity on solid concentration against shear is shown by P. K. Senapati et al. (2009). The shear thinning behavior or "pseudoplastic" behavior of the slurry was observed and that the flow pattern of slurry is almost perfectly Newtonian with only a slight degree of shear thinning when the solid concentration of the slurry was less than $\phi < 37.8$, and that the shear thinning trend of the slurry become more predominant at increased solid concentration. The shear thinning behavior observed in the viscosity curve at higher solid concentration was confirmed by them from the shear stress-shear rate plot which may be attributed to the increase of interaction between particles. Varela J.A. et al. (2002) observed the decrease in the optimized amount of deflocculant as the solid concentration increases, up to a limit of 56.4 vol.% of solids, which presents an increase in the optimized amount of PAA. Another important point was notified that the increased viscosity of the suspensions with solid concentrations above 36.5% after the addition of higher amounts of deflocculant which may be due to electrostatic repulsion between: (i) free charged polymers and (ii) negatively charged free polymers and free polymers adsorbed in the particle.

E. Ewais, et al. (2002) investigated the viscosity behaviour as a function of shear rate and volume fraction of the particles for aqueous zirconia suspensions containing 0.4 wt.% (based on dry solids) dispersing agent. The viscosity showed changes with both shear rate and volume fraction of the particles. Newtonian behavior is observed for volume fractions of up to 20 vol.%. At higher volume fraction of the particles and moderate shear rates, the viscosity falls monotonically with increasing shear rate and does not appear to approach a final limiting value at high shear rates. There is at least three orders of magnitude change in viscosity as the solid loading is increased from 5 to 45 vol.%. It appears that the differences in viscosity at

various volume fractions are more significant at low shear rate which is due to the fact that at low shear rates, the inter-particle forces are dominant and control the viscosity of the suspension. Viscosity of solutions with different volume fractions in two shear rates (0.1 and 5.99 sec^{-1}) has been studied by Hezaveh H. et al. (2012). The results showed that for both rates of shear, viscosity increase nonlinearly with increasing volume fraction. This can be explained due to more resistance that rises against external force as particles must move out each other way. Also in higher concentrations, particles can effect more on continuous phase as they can cause some immobilizing in continuous phase. Behzadfar, E. et al. (2009) investigated the viscosity, stress response, and dynamic moduli of samples of different volume fractions were taken into consideration. They found that the steady shear viscosity of suspensions, with different solid volume fractions, is given as a function of shear rate and increasing the solid content, the viscosity increased, particularly at low shear rates. Higher viscosity of suspensions is mainly due to the existence of local structures in the media that immobilize the fluid, preventing it from participating in the hydrodynamic flow field. In all samples, shear thinning behavior was observed. Higher filler content intensified the shear thinning behavior.

Thus, from the above discussion, it can be seen that the particle content in suspensions clearly influences the rheological behavior and the presence of particles in filled systems results in higher viscosity, shear thinning behavior, and appearance of yield stress.

Effect of Pigments Loading:

Organic and inorganic pigments are one of the prime constituents of the surface coating systems (paints, inks, etc.) and contribute directly to their properties and decorate functions. They produce colour and opacity, and also affect the gloss, consistency, texture, porosity and thickness of the coating films. All these effects are related to some extent to the degree of the dispersion of the pigment. The viscosity of the suspension studied by Hosseini, S. S. et al. (2007) is highly affected by amount of pigment loading. It can be seen from their experiments, that at lower shear rates the effect of pigment concentration is more sensible; increase in pigment concentration results in higher viscosity values. This mainly denotes that the presence of agglomerates imposes higher resistance to flow. The inorganic nature of the particles may also contribute to this behaviour through the induction of friction between the components. The effect of pigment loading levels off by exceeding a certain shear rates. This implies that at higher shear rates, the network structure has been broken and no difference can be distinguished between pigment particles and macromolecules. Similarly, the effect of pigment concentration is more tangible for samples containing higher molecular weight carrier. As

the molecular weight decreases, the system loses its network integrity due to the severe decrease in the length of macromolecules. As a result, the suspension behaves rather like Newtonian fluids by possessing a constant viscosity value for different shear rates. These figures similarly show that the effect of molecular weight on the flow behavior is more sensible at low shear rate values. It should be noted that this is valid only for the suspension systems carrying $16 \text{ v/v\%}$ and $12 \text{ v/v\%}$ pigment loadings. The higher viscosity values for higher molecular weights are expected since the presence of macromolecules with long chains that are entangled into each other. Furthermore, the effects of additive types and oxide loadings on the sedimentation bulk density and suspension rheology have been carried out by Joo-Hyeok Lee et al. (2012) for alumina and alumina/zirconia suspended in a TBA liquid medium. The addition of a dispersant improved the sedimentation density, with the effect somewhat pronounced for a surfactant addition; however, additional introduction of a binder lowered the sedimentation density. In reverse, a decrease in the low shear viscosity when a dispersant and a dispersant/surfactant were added was generally observed. However, the introduction of additional binder greatly increased the low shear viscosity, possibly due to the primary binding of the particles by soft polymer chains. Alumina and zirconia particles appear to be non-interactive based on the sedimentation and rheology behaviors. The influence of starch additive on the viscosity of slurries with varying alumina loadings and the corresponding microstructures of resulted alumina foams fabricated using the PCC technique has been investigated by Yin L. (2009). The effect of starch additive on viscosity is more profound in higher alumina loading slurries than that in lower alumina loading slurries. This is likely due to the combined functions of increasing total solid loading and up taking water by starch. Starch may facilitate the fluidity of lower alumina content slurry at a given total solid loading, which is caused by the higher packing efficiency in dual size particles distribution compared with mono size particles system. Thus from the above discussion, it can be interpreted that the rheological measurement are strongly influenced by the pigment additions.

Effect of Electrolytes:

Another important parameter which directly affects the rheological properties of the suspension is considered as electrolytes. By knowing other properties of the additives, a suitable concentration and nature of the electrolyte is essential to improve the process of dispersion. The effects of the electrolyte concentration and pH on the settling behavior, floc sizes and rheological behaviour of kaolinite suspensions were investigated by Nasser and James (2009). They found that the settling behaviour of kaolinite changes with the

ionic strength and pH of the suspension. In the acidic pH range, (pH 2) particles settle in flocculated form regardless of electrolyte concentration, however, in the basic pH range, the particles settle both, in dispersed form (at lower electrolyte concentrations) and in flocculated form (at higher electrolyte concentrations). The Bingham yield stress and time-dependent behaviour for these flocculated and deflocculated suspensions was also investigated by them. It was found that the kaolinite suspensions in the deflocculated form show viscosity time-independent behaviour with negligible Bingham yield stress. While the flocculated suspensions show marked non-Newtonian time dependent behaviour. This work has been very successful in establishing the link among particle-particle interactions, floc size, Bingham yield stress, breakdown rate constant, and extent of thixotropy. Mäurer T. and Czarnetzki B. K. (2001) observed the formation of aggregates on addition of electrolytes to aqueous zeolite sols that are larger than in the absence of these salts, and that can exist in a broader pH range. While this qualitative behavior could be expected from the DLVO theory, the exact conditions of aggregation cannot be predicted, because zeolites exist in a great variety of different crystal structures and compositions. The knowledge of both, the specific IEP of a zeolite and the means to trigger its aggregation, are prerequisites for efficient solid-liquid separation. However, the addition of electrolytes allows for flocculation and facilitated recovery of the zeolite crystals at $\text{pH} > 2$. The effects of the KCl, CaCl_2 , and AlCl_3 electrolytes (same anion and different cation) on the zeta potential of coal samples at different particle sizes are studied by Doymus K. (2007) as a function of electrolyte concentration. According to his analyses, the zeta potentials of AlCl_3 as a function of electrolyte and 1.10^1 M as a function of concentrations were different from the zeta potentials of other electrolytes and concentrations. The results of the experiments to investigate the effect of suspension pH and concentration of electrolytes on the zeta potential of coal particles were analyzed using analysis of variance (ANOVA). According to the results of this analysis, K^+ , Ca^{2+} , and NO_3^- ions on the surface of coal particles had a minor effect on the observed zeta potentials. However, Al^{3+} , SO_4^{2-} and CO_3^{2-} ions on the surface of coal particles had a significant effect on the observed zeta potentials. In the presence of the electrolytes (Na_2SO_4 and AlCl_3), the relative viscosity of the silica dispersion was found to be reduced by Zhou W. et al. (2008) and observed weaker hydration of the silica in aqueous solutions. The higher the concentration of the electrolytes, the weaker the hydration, indicating that the destabilization of the colloidal silica dispersion in aqueous solutions might be realized through adding the high-valence electrolytes to weaken the hydration of the particle surfaces (hydration forces between the particles). Also, it has been shown that the negative

zeta potentials of the colloidal silica in aqueous solutions greatly reduced in the presence of the electrolytes. Therefore, the high-valence electrolytes (Na_2SO_4 and AlCl_3) as the coagulant of colloidal silica in aqueous solutions might be originated from that the presence of the electrolytes simultaneously reduces the electrical double layer repulsive force and the hydration repulsive forces between the particles in aqueous solutions. Consequently, to adjust the balance between van der Waals forces and Coulombic forces associated with the charged particles, the role of electrolyte is very significant.

Effect of pH:

As one of the important parameters in aqueous processing, the effects of pH value must be considered. The pH affects the net particle surface charges, the degrees of dissociation of carboxylic groups and polymer chain conformation, causing the variation in the adsorption behaviors of the polymer on particles. As a result, particle stabilization and suspension properties are altered with pH value of the suspension. The pH changes essentially modify the surface charge which in turn controls the interparticle interactions. At the pH where the effective potential (the zeta-potential) on the particles is zero, called the isoelectric point (iep), the viscosity is high and as the pH changes away from the iep the viscosity decreases. This is due to the fact that at the iep the van-der Waals attractive forces dominate and aggregation of the particles occurs. At pH values away from the iep the electrostatic repulsion of the particle/double layers stabilises the suspension and hence prevents the particles coming close to each other and agglomerating. As a result the viscosity of the suspensions is lower. Luo, L.H. and Tok A.I.Y. (2006) studied the stability of the suspension at various times which was measured from the change of sediment volume as a function of pH and time. The results showed that the slurries were not well-dispersed at a low pH. For 0.01 vol.% concentration 10GDC nano-particles in the pH range of 1-8, sedimentation was observed after 2 days and the sedimentation was complete after 4 days. After 4 days, the suspension at pH 9-10 was able to sustain at a loss of approximate 40% sedimentation volume with respect to the first day. The effect of the variation of the solid content as a function of pH on the zirconia suspensions was also investigated by Khan A. U. et al. (2012). The viscosity against the pH for the three different solid content suspensions of zirconia at shear rate of 1.46 sec^{-1} was studied. They observed that as the solid content of the suspension is increased, the "stability region", that is the pH range which gives the low viscosity, decreases. When the solid content of the suspensions is 25% wt/wt, the suspensions have low viscosities in the pH range of more than 11.0 to less than 5.0. The extreme pH conditions, especially the high acidic pH values, are

not suitable from the processing view point and have deleterious effects on the quality of the suspensions as well as on the products. This narrowing of the stability region, using pH adjustment, serves to indicate that it is not possible to produce high solids loading suspensions using pH control alone. It has also been observed that the pH of the acidic suspensions increases with time and this effect is more pronounced at the higher volume fractions and under the more extreme acidic condition. Zhang L. et al. (2012) studied zeta potential of TiO_2 nanoparticles varied from a positive charge to a negative charge as the range of pH varied from 2 to 11. At pH 5, zeta potential reached zero. The particle size of TiO_2 increased from 150 nm to 500 nm as pH was increased from 2 to 6, but further increases of pH resulted in decreasing particle size. The results suggest that TiO_2 nanoparticles tend to aggregate in acid conditions, while they will be dispersed in basic conditions. Coagulation performance was significantly affected by pH. With coagulation conditions were under pH 6.5, no obvious flocs were formed and turbidity maintained steady. On the other hand, in basic conditions of pH 7 to 10.5, obvious coagulation occurred and turbidity reached optimal removal. However, when the pH was increased to 11, restability of TiO_2 nanoparticles was seen and turbidity increased back to the original value. The impact of pH on TiO_2 removal can be explained by charge neutralization. In acid conditions, TiO_2 carried a positive charge similar to the hydrolysis product of alum. The two parts repulsed each other and thereby hindered the formation of big flocs. When the pH ranged in basic conditions between 7 and 10.5, however, the negative charge carried by the TiO_2 was opposite the positive charge of the alum hydrolysis product. The consequence, Charge neutralization resulted in efficient coagulation and optimal turbidity removal. At the higher pH value of 11, the hydrolysis product of alum carried a negative charge again resulting in no obvious coagulation with turbidity returning to its original value. SEM micrographs of the platinum particles obtained from 25 °C, 40 °C and 50 °C temperatures were shown by Beyrdbey B. et al. (2009) respectively. They found that no characteristic platinum structure was observed until pH = 10. Increasing the temperature and pH values has affected the structure, size and uniform distribution of platinum particles. It was observed that the morphological distribution changes remarkably for particles obtained at high temperature and high pH values compared to particles obtained at lower temperature and lower pH values. Whitby C. P. (2003) investigated the influence of PAA/PEO comb polymer additions on the stability of colloidal silica suspensions as a function of varying pH conditions was investigated by measuring the adsorption behavior and the macroscopic flow behavior of the suspensions and by measuring the direct interactions between silica surfaces in the presence of such additives. Our observations reveal that the PAA backbone of the

copolymer preferentially adsorbed onto the silica surface, resulting in a strong pH dependence. Stress viscometry measurements indicated that under basic and neutral conditions, where the copolymer adsorbs only to a small extent, the silica suspensions were destabilized by the addition of high copolymer concentrations. Under acidic conditions, the silica suspensions were restabilized at higher adsorbed copolymer densities. Singh B. P. et al. (2004) measured the turbidity of the alumina suspensions using the Nephelometer and presented in terms of Nephelometric turbidity units (NTU). They conducted the experiment at different pH with and without dispersant for understanding variation in turbidity behavior and found interesting results. They pointed out that in the presence of dispersant at optimum Dosage (2.29 mg/g), the turbidity values are highest in both very acidic as well as very alkaline pH. The minimum turbidity was obtained at pH value of 5.76, which is very close to the pH iep (5.65). Thus by comparing the turbidity data with surface charge they found to be in accordance with the DLVO theory. Hence, the behavior of the dispersion of the concentrated colloidal suspension can be understood to some extent by considering the range of pH and amount of dispersion properly with respect to powder loading for the measurement of turbidity. Therefore, it can be incorporated from the above discussion that rheological investigations of the suspension have profound interest of the researcher with a wide range of experimental condition and obviously, thus pH measurement is more reliable and frequently used way for evaluation of dispersibility of the colloidal suspension especially when aqueous solvents are necessary to be considered.

Effect of Milling Treatment:

In any particular application, the optimum performance is given by pigment particles of particular size, so the problem of producing material having a narrow size distribution has received considerable attention. Milling treatment is useful technique which frequently employed to reduce the size of particles and thus the colloidal suspension becomes more homogeneous and stable. A proper knowledge of essential parameters is necessary to understand the behavior and different degree of dispersion of the colloidal suspension at a particular set of condition. Essentially, ceramic slurries for tape-casting are composed of numerous components: ceramic powders, solvents, dispersants, binders, plasticizers, and other additives such as homogenizers and releasing agents. The preparation of slurries is commonly carried out in two stages, namely I) deagglomeration of powders and dispersion in the solvent with the aid of dispersants, and it mixing with binders and plasticizers. Deagglomeration of powders is necessary to obtain well-dispersed slurries and to avoid flocs. Ball milling is a widely used comminuting process in wet processing to reduce the average particle size and break agglomerates.

For each material and solids loading, an effective ball milling time can be acquired from the particle size distribution of the milled product. In addition to particle size reduction, ball milling also provides dispersion and mixing of a suspension. The effects of ball milling time on the dispersion and stability of a suspension can be studied from its sedimentation and rheological behavior. A well-dispersed and highly stable suspension precipitates slowly, presenting a low sedimentation height, dense sediment and a cloudy supernatant. By contrast, a poorly dispersed suspension precipitates relatively quickly, showing a relatively high sedimentation height and a clear supernatant. Thus, from the results of the rheological behavior in conjunction with particle size reduction, mixing and dispersing efficiency, optimum ball milling time is necessary parameter for preparing suspension of suitable homogeneity. Effect of ball milling can be estimated by measuring viscosity profile at different shear rate and also observing the sedimentation heights of the suspension slurries. Because the rate of fine grinding is very dependent on the frequency of the collisions, usually a higher rotation speed and enough milling treatment tend to break particles into pieces resulting in well dispersed homogeneous suspensions. The effects of ball milling time on the rheological behavior of PZT aqueous suspension were studied by Traiphol N. (2007) at a high shear rate for 20 h 30 h and 40 h ball milled suspensions which showed shear thinning (pseudoplastic) behavior. The degree of pseudoplastic behavior can be evaluated from the relationship between the apparent viscosity (η) and shear rate ($\dot{\gamma}$) expressed by a power law model which relates between the apparent viscosity (η) and shear rate ($\dot{\gamma}$); $\eta = K\dot{\gamma}^{n-1}$, where K is the shear rate factor (consistency index) and n is the shear thinning constant (shear rate exponent) which indicates the divergence from Newtonian behaviour. For a shear thinning system, n is less than 1. Lower the value of n stronger is the shear thinning behaviour of the suspension. The 30 h ball milled suspension exhibited the lowest n value of 0.14 corresponding to the strongest shear thinning behavior, which is preferred for tape casting investigated by Traiphol N. (2007). It can be seen that the green density increases with increasing milling time for all the mixtures tested. This is in agreement with the rheological results obtained by Olhero, and Ferreira (2004) discussed above. They pointed out that when the packing ability of particles increases the viscosity of the slurry decreases. Further, a more favorable Particle size distribution would enable higher green densities to be obtained. For all mixed suspensions, green densities increased with increasing milling time, due to size reduction of silica powders and a more efficient deagglomeration of fumed silica. Increasing amounts of fumed silica led to a first increase of particle packing up to a maximum, followed by a

decreasing trend for further additions. Good relationships could be observed between rheological results and packing densities. Effect milling treatment on the dispersion was further investigated by Sakka et al. (2007) using milling conditions are as followings; the diameter of the zirconia beads is 0.5 mm, the pump circulation speed is 40 ml/min, the disc rotation speed is 5.2 m/s (1986 rpm), and the milling time is 1 h for 20 vol% suspension with a substantially higher dispersant addition (2.4 mass %). Changes of the average particle size are studied by rheological properties and the SEM techniques after milling treatment for fixed times. After 1 h of milling treatment, the suspension remains at a low viscosity, no agglomerated particles was observed and no zirconia contamination was detected by ICP atomic emission spectrometry. Deagglomeration and dispersion by ultrasonic agitation of sub-micrometer powders has been found much more effective than ball milling. However, ultrasonic treatment is not efficient to mix the slurry components and can break the long-chain molecules of the binder. Ultrasonic vibrations induce pressure waves in the solvent and cavities can be produced when pressure is enough. At rather low pressures, the size of cavities oscillates around a constant value (stable cavitation) and bubbles develop and burst at the surface of the liquid (deaeration). At rather high pressures, the size of cavities oscillates around an increasing value (transient cavitation), then cavities collapse violently, which produces intense stresses able to break powder agglomerates into smaller aggregates. Hence, the knowledge of milling treatment plays a very profound role to control the process of dispersion.

Effect of shear rate/stress:

The measurement of rheology is a useful tool to identify characteristics of dispersion, both as a means of studying their fundamental properties and as assessment of their suitability for particular technological purposes. Thixotropy Pseudoplasticity, rheopexy, shear and time dependent behavior, transient viscosity behavior etc. are the essential rheological properties upon which the characterization and behaviour of the dispersion may be employed. There are many types of viscometer used and there has been a tendency in certain fields to characterize materials by measuring a single rate of flow at a given shear rate. For adequate understanding of the rheological properties of the dispersion, some more advanced viscosity measuring device such as rotational and cylindrical, rheometer, are frequently used at wide range of experimental condition. Knowing its rheological behavior, therefore, is useful when designing pumping and piping systems. Ceramic literature provides abundant examples where the quality of suspensions is quantified by the state of aggregation through phenomenological models such as power law, which relates between the apparent viscosity (η) and

shear rate ($\dot{\gamma}$); $\eta = K\dot{\gamma}^{n-1}$, where K is the shear rate factor (consistency index) and n is the shear thinning constant (shear rate exponent). As a function of shear stress and particle volume fraction, Lee Y. S. and Wagner N. J. (2006) studied a relationship between shear rheology and flow small-angle neutron scattering of charge-stabilized silica nanoparticles dispersed in ethylene glycol. Shear thickening has also been observed in colloidal suspensions of rod-like anisotropic particles. Rheological investigations of suspensions of ceramic materials by Bergstroms (1996) demonstrated that aqueous suspensions of rod-shaped silicon carbide whiskers exhibited discontinuous shear thickening at volume fractions as low as 0.172. Both Beazley K.M. (1980) and Bergstrom (1996) attribute the shear thinning observed in anisotropic particle suspensions to particle alignment with flow, while the observed shear thickening is attributed to increased collisions between particles resulting from misalignment at higher shear rates. Beazley K. M. (1980) suggests that particle rotation during flow may result in particles interlocking and jamming in disorganized clusters. This type of instability is thought to increase with increasing particle anisotropy, as rods and disks with higher aspect ratio should "entangle" to form aggregates of randomly oriented anisotropic particles more readily at lower particle loadings, ultimately resulting in the observed shear thickening behavior. Dilatancy (shear thickening) in Concentrated Dispersions was well studied by Boersma W.H., et al. (1990). Sarraf H. and Havrda J. (2007) established a Relationship between viscosity measurement and shear-thinning behavior using various rheological flow models and observed that the alumina suspensions shows typical shear thinning (or pseudoplastic) behavior and can be fitted well by the following three different flow models of: Power law model, Herschel-Bulkley model and Bingham model. However, according to the Bingham model, the particles in a flocculated suspension form floc groups or a network, because of the mutual attraction between particles, and the Bingham yield value can be used as a parameter that indicates the degree of flocculation. It was evident that using different rheological flow models can give better attribution and prediction of shear thinning behavior. The extensional properties of shear-thickening colloidal suspensions of silica in polypropylene glycol were studied by Chellamuthu M. et al. (2009) using a filament-stretching rheometer as a function of concentration and extension rate. The shear rheology of a series of suspensions of concentrations 17.5 wt%, 25 wt% and 30 wt% demonstrated a shear-thinning behavior at low strain and strain rates and shear-thicken at high strain and strain rates owing to the formation of large hydrodynamic clusters. Khodakov G. S. (2004) presents a theory describing the physicochemical mechanism of steady-state laminar suspension flow. A

scaling model is presented by Sarvestani A. S. (2010) to analyze the nonlinear rheology of unentangled polymer melts filled with high concentration of small spherical particles. The steady-state shear viscosity of the mixture in nonlinear shear thinning regime follows the power law. Of course, from the above discussion, it can be interpreted that rheological properties directly influenced by employing particular set of condition at different shear rate and stress.

Effect of Temperature on Dispersion Structure and Rheology:

The effect of temperature on the stability of colloidal suspensions is important in many industrial applications. In particular, changes in particle interaction with temperature can significantly alter the physical properties of a colloidal dispersion. Many researchers have found that the viscosity of the suspension becomes lower as the temperature increases. The trend of decreasing viscosity at elevated temperatures occurs due to increased kinetic energy of the particles promoting the breakage of intermolecular bond between adjacent layers which results in decrease in viscosity of the limestone slurry. Also the temperature dependence of viscosity can be represented in terms of a simple Arrhenius type of equation for the range of temperature investigated. The relation between viscosity and temperature may be presented as $\eta_r = A e^{E_a/RT}$ or $\ln \eta_r = E_a/RT + \ln A$ where, η_r is the relative viscosity at a particular shear rate, E_a is the fluid-flow activation energy, T is the temperature in Kelvin, R is the universal gas constant, and A is a fitting parameter. Zylal G. et al. (2012) conducted experiments to observe the response of Dynamic viscosity profile of the suspensions of three different ceramic nanopowders of 15 wt.% Y_2O_3 , $Y_3Al_5O_{12}$, $MgAl_2O_4$ in ethyl alcohol at various temperatures. The systematic experiments have been carried out and show that the temperature and concentration of nanopowders in the base fluid has a significant influence on the viscosity of suspensions. Effect of slurry temperature was also studied by Senapati P. K. et al. (2009) and they pointed out that during the process of grinding the ore samples, the temperature of ground slurry fluctuates between 30°C to 60°C depending upon the grinding conditions which affects the slurry rheology. The variation of temperature with relative viscosity of the limestone slurry sample at 40.4 vol.%, 43.1 vol.% and 46.0 vol.% solids concentration respectively at shear rate range of 1 to 300 sec^{-1} was studied. The relative viscosity of the slurry decreases in the range of temperature studied (30 °C-50 °C). Millán, A.J. et al. (2001) studied variation of viscosity vs. temperature of slips containing concentrations of deflocculant of 0.5, 0.8 and 1.0 wt.% at a shear rate of 100 sec^{-1} . The evolution of viscosity with temperature was continuously recorded using the rheometer connected to a temperature probe by varying viscosity of the agarose solution during both the heating and the cooling processes.

The increase of viscosity during heating was found related to the dissolution of agarose in water and the observed change of viscosity in the cooling curve corresponds to the binder T_g indicating the gelling temperature at specific concentration. The effect of temperature on suspension rheology also has been investigated by Joo-Hyeok Lee, et al. (2012) at a shear rate of 100 (sec^{-1}) for 30 vol.% of TBA-based freeze casting alumina and alumina/zirconia slurries, and viscosity-temperature relationship. With an increase in the temperature applied, the viscosity functions generally showed a shear thinning. The onset of the viscosity drop, viz. the start of power law behavior, is a sign of a break up of the equilibrium structure of orientation along the flow direction. Suspensions with a certain level of 3-dimensional structure could become oriented along the flow direction, and this would give a lower viscosity, possibly by interlayer slip. An increased temperature in a suspension system induces the viscosity reduction of TBA solvent; as a result, interlayer slip could be improved. Regardless of the oxide type, the onset of the viscosity drop started at about 28 °C, somewhat higher than the freezing temperature of TBA (25.3 °C). In particular, the second plateau region in the 100A suspension was observed at 30-40 °C; different from alumina/zirconia mixtures. Moreover, to study the structural and rheological properties of the carbon-black/dispersant/ basestock-oil system over a wide range of temperatures and compositions, You-Yeon Won et al. (2005) performed some useful experiments and observed that when dispersant is added, the structure of the carbon-black aggregates becomes very sensitive to variations in temperature. To illustrate this, agglomerate structures for 4.0 wt % carbon-black samples at two different temperatures, 25 and 100 °C, are recorded with optical microscopy as a function of dispersant concentration. The structure evolves from highly dispersed primary aggregates at high dispersant concentration to more strongly aggregated clusters as the dispersant concentration is decreased, to ultimately form a strongly connected gel network in the absence of dispersant. They further pointed out that the temperature of the sample has a dramatic influence on this transition; increasing the temperature from 25 to 100 °C causes the transition to the gel state to occur at a significantly higher dispersant concentration. Clearly, the strength of the attractive inter-particle interactions increases as the temperature is increased. The structure of the carbon-black aggregates and the resultant suspension rheology change dramatically as the temperature of the sample is increased. At low temperatures the primary aggregates are separate and well dispersed, and fluid like rheology is observed for the suspension. By contrast, at high temperatures the primary aggregates agglomerate, forming a more tenuous, sample spanning network resulting in a solid like rheology for the suspension. The inter-particle

attractive interactions increase as the temperature is raised, resulting in a critical-like fluid-to-gel transition. Thus, investigation of the effects of temperature on the repulsive portion of the inter-particle interaction potential due to the steric stabilization of the dispersant as well as the attractive interaction resulting from the van der Waals forces is another important considerable factor.

Effect of Aging:

Understanding the influence of storage time on rheological properties of the alumina suspensions is very important in many applications and fields such as tape casting processing advance coating, ink-jet printing, ceramic engineering, forming process of nano-powders etc. When considering the properties of sediment beds, the strength of particle bonds and the number of bonds that have to be broken, which is determined by the network structure which is in turn related to the aggregate structures, are of critical concern. Hence, to optimize the basic solid-liquid separation processes, it is very necessary to lay emphasis on understanding behavior of what controls aggregate properties and how these proper ties impact on sediment bed properties especially when the consideration of aging is essential. Bye and Sing (1973) investigated the aging behavior of aluminum hydroxides prepared by the hydrolysis of their benzene or ethyl benzene solutions with water and other solvents. They showed that phase transformation to pseudoboehmite or bayerite occurs during aging at room temperature, causing changes in the surface area of the gels. The rheological behaviour of the slips was also studied by A.J. Millán, (2001) on the fresh slips having 70 wt.% solid concentration at pH 11, but also after ageing for 24 and 48 h. Storage time makes the pH to slightly decrease and consequently viscosity increases. After 48 h ageing, the slip tends to become dilatant as a consequence of that change in pH. To allow reliable and reproducible results on aging and yielding materials Y. Auffret et al. (2009) utilized a creep-flow-based measurement procedure. Investigation of the effects of different parameter such as the pre-shear time, the recovery time and the applied stress magnitude on the viscoelastic properties of a lyotropic liquid crystal phase is reported. Cryo-TEM observations indicate the formation of multi connected bilayers at rest. Shearing the investigated material shows a propensity to acquire all the macroscopic properties of “soft jammed systems”. These properties are then interpreted in terms of shear-induced structural rearrangement on the basis of cryofracture observation obtained at different times after the preshear imposed. Understanding the influence of storage time on the rheological properties polymeric fumed silica gels is very important in the field of composite polymer electrolytes. A rheological study of the aging process of Aerosil R805 suspension

in Polypropylene Glycol Mw 2000 has been carried out by F.J. Galindo Rosales (2007) conducting steady and oscillatory experiments. They found that the samples have gel appearance at rest, which means that silica particles have developed a three dimensional network inside the polymer matrix. To understand aging behavior and thus material response Christopoulou B. C. et al. (2009) conducted some creep and recovery tests, which revealed a rich, albeit complex response. Although the waiting time, the time between pre-shear (rejuvenation) of the glassy sample and measurement, affects the material's response, it does not play the same role as in other soft glasses. For stresses below the yield value, the creep curve is divided into three regimes with increasing time: viscoplastic, intermediate steady flow (associated with the first ageing step) and long-time evolving elastic solid. This behaviour reflects the interplay between ageing and shear rejuvenation. S. Keysar et al. (1999) studied that Alumina gels showed shear thinning behavior throughout an aging period of 6 months. The viscosity increases with time, reaching an asymptotic value after 1-2 weeks. This effect can be attributed to syneresis of the gels at this period. Viscosity-shear rate curves for the alumina gels showed shear thinning behavior and negligible thixotropy. The shear thinning is ascribed to separation forces that act between particle clusters at low shear rates, and the interaction between particle pairs as the network break into smaller pieces at higher shear rates. When considering the properties of sediment beds, the strength of particle bonds and the number of bonds that have to be broken, which is determined by the network structure which is in turn related to the aggregate structures, are of critical concern. Hence, to optimize the basic solid-liquid separation processes, it is very necessary to lay emphasis on understanding behavior of what controls aggregate properties and how these proper ties impact on sediment bed properties especially when the consideration of aging is necessary.

Miscellaneous Factors:

In this section, we consider those remaining factors which may also be consider during the assessment of rheological characterization of the colloidal suspension. Viscosity of ferrofluids in different weight fractions at constant shear rate of 5 sec^{-1} , under various magnetic fields has been investigated by Hezaveh H. et al. (2012). They observed that at a constant shear rate the viscosity increases with increasing magnetic field. However, this increment is followed by decrease in viscosity after a certain peak value (around 0.3 A). At high concentrations (30 wt.%) this phenomenon is more sensible. This can be attributed to phase separation in the ferrofluid. The magnetoviscous effect is directly related to the effective number of magnetic nanoparticles, which have roles in the formation of new structures. The aggregation leads to phase separation in the ferrofluids. Increasing viscosity

under magnetic field can be due to supplementary dissipation of the nanoparticles motion relative to the base fluid. Under magnetic field, particles form chains molecules oriented according to direction of the field. As this magnetic field increases, these chains become longer and consequently interaction between nanoparticles becomes stronger. All these results to decrease fluidity of the ferrofluid against shear rate. Ferrofluid resists until chains formed cannot stand against magnetic force applied, and then they destroy and as a result, viscosity decreases. Electrical conductivity is another important slip parameter to be considered. The conductivity measurement can be used to control more precisely the concentration of deflocculant added than the weight of the deflocculant content. It is well known that in constant current density experiments, when the ceramic deposit is forming, the voltage must increase to assure that a constant current is passing through. The final voltage defines the development of the deposit. The slip conductivity has been stabilized as a key parameter to define the processing conditions. To ensure the success of the process, specific requirements of conductivity must be satisfied. Hence, considering the three slip parameters studied, Electrophoretic deposition (EPD) experiments have been conducted by Ferrari B. & Moreno R. (1997) on slips containing different concentrations of deflocculant, that is, with different conductivities. The final voltage measured after the deposition experiments obtained applying the same current density (6.4 mA cmm²) at three experimental temperatures (24 °, 31 ° and 38 °C). They observed that Electrophoretic deposition (EPD) process depends on both the characteristics of the slip and the imposed electrical conditions. Again Moreno, R., Ferrari B. (2000) studied the colloidal properties of the slurry which determine both the viability of the EPD process and the properties of the deposit and found that the slurry conductivity is a critical parameter capable of predicting whether the deposit will be obtained or not. Heinrich and Aneziris (2007) observed the addition of binder influenced the stability of the slurry by making them more viscous and found the viscosity of slurry increased as the binder content increased. The increase in viscosity with binder addition could be due to active polymer presence. They could impede the relative motion of ceramic powder particles, giving rise to an increase in viscosity. The effects of solvent composition on the tape casting of TiO₂ slurries were examined by Jingxian Z. et al. (2004) using four different azeotropic binary solvent systems. Results showed that azeotropic EtOH/MEK mixture had the highest dielectric constant and thus more the effective solvent system for tape casting of TiO₂ sheets. Green tapes prepared from the EtOH/MEK systems exhibited a high packing density with smooth and defect free surface. The dispersion, viscosity and rheological characteristics of the tape casting slurry for PSZ were studied systematically by

Kumari K. G. V. et al. (2005) at every stage of the slurry preparation using different solvent systems in combination with three different dispersants. The effect of spindle speed on the viscosity of slurries containing different amounts of solids was studied by Heinrich and Aneziris, (2007). A microscopic study of the effect of shear on a dense purely repulsive colloidal suspension was done by Viasnoff, V. et al. (2003) using multi speckle diffusing wave spectroscopy to monitor the transient motions of colloidal particles after being submitted to an oscillatory strain. This technique proves efficient to record the time evolution of the distribution of relaxation times. After a high oscillatory shear, they show that this distribution displays full aging behavior. Conversely, when a moderate shear is applied the distribution is modified in a non-trivial way. Whereas high shear is able to erase all the sample history and rejuvenate it, a moderate shear helps it to age. They called this phenomenon overaging. They demonstrate that overaging can be understood if the complete shape of the relaxation time distribution is taken into account. They finally reported how the soft glassy rheology model accounts for this effect. For optimum conditions, very short times (2-3 min) of ultrasonic agitation are enough to obtain well dispersed, stable slurries. The role of aging of slurries has also been examined. A minimum of viscosity was obtained at about acoustic power 360 W for both BaTiO_3 and Al_2O_3 . The increase in viscosity beyond a power threshold probably results from a ultrasonically-induced coagulation at high power levels. By understanding electric and dielectric properties of the dispersion, evaluation of the dispersibility concept can also be studied. Khastagir, and Adachi (2000) studied the Rheological & Dielectric properties of aggregation of barium titanate particles suspended in polydimethyl siloxane. Abdelhalim M. A. K. et al. (2011) studied rheological and dielectric properties of different gold nanoparticle sizes and investigated that Gold Nano Particles have strong dielectric dispersion in the frequency range of 20 Hz-100 kHz which was particles size dependent and hence, conductivity increased with increasing the size of Gold Nano Particles. The influence of parameters such as acoustic power, temperature, and treatment duration on the dispersion efficiency has been studied by Chartier T. et al. (1991). Thus, it is noteworthy that these factors are also responsible for understanding the concept of dispersion in a prospective way.

Conclusions

From the above discussion, it can be revealed that the above considered parameters are very useful to understand the nature and behavior of the dispersion of colloidal suspension using both aqueous and non-aqueous solvents at different set of condition with a deep intellectual sense.

Hence, for successful exploitation of the end product of materials these parameters with a systematic, prospective and careful approach play a significant role in the final assessment of the rheological characterization of the suspension. Thus consideration of a collective approach of these parameters is a necessary fundamental aspect for proper investigation of the concentrated colloidal suspension to predict and control a host of product properties, material behavior and end use performance. Moreover, this literal comprehensive review of dispersibility assessment by considering parameters will definitely help to understand the concept of dispersion processes by treatment of conventional as well as advanced techniques.

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