The Influence of Chemical Additives on the Flow Behaviours of Solid-Liquid Suspensions: A Review

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***Abstract*— In this paper the effects of various chemical additives on the flow behaviours of soli-liquid suspensions are vigorously reviewed. Particular attention is given to the suspensions of coal ash and iron ore. The concepts of rheology, factors affecting the rheology, measuring techniques of rheology and common rheological models have also been discussed. Chemical additives are generally categorized by their function rather than by chemical composition or physical type. Based on their functions, chemical additives are classified as dispersants, flocculants, surfactants and anti-settling agents. All the chemical additives discussed in this paper are capable of changing the flow behaviours of the slurries under considerations. The function of these chemical additives is almost always very specific in nature in which some additives are proprietary products with highly specific functions that work well in some systems but cannot be used in others. Hence, correct additive selection is important to get the intended results.**

Keywords*— Solid-liquid suspension; non-Newtonian fluid; rheological behaviour; chemical additive

I. INTRODUCTION

In the design of slurry pipelines the rheology of slurry has been identified as a critical parameter for establishing the pressure drop requirements. Therefore, it would be useful to study the rheological behaviours of the slurry to estimate pressure drop and hence pumping capacity. Various physical and chemical properties of a slurries namely solid concentrations, particle size and particle size distribution, temperature, chemical additives and so on have significance influence on the slurry rheology due to change or modification in surface properties [15]. It is suggested that small particles occupy the voids between the larger particles increasing packing density and therefore increasing viscosity. It seems from this that solid concentrations may be achieved at acceptable viscosities by controlling the size and size distribution of the parental materials such as coal, iron ore, polymers and so on. At low solid concentrations, in most cases, constant viscosity is observed but as the concentration increases the rheological behaviours become complex and non-Newtonian behaviour is observed with the viscosity becoming dependent on the shear rate as well. The presence and types of chemical additives will also have effects on changing the rheological properties of the suspensions.

This review is thus designed to present some previous works with respect to the influence of chemical additives on the flow behaviours particularly on the rheological behaviours of soli-liquid suspensions and furthermore presents the general summary of the discussion.

II. RHEOLOGICAL BEHAVIOURS AND MEASUREMENT OF SUSPENSIONS

Rheology deals with the flow and deformation of materials under the action of applied forces. Kinematics (the flow of motion), conservation laws (deals with forces, stresses and energy interchanges arising from motion) and constitutive relations (links motion and forces) are the primary theoretical concepts that the rheology deals with. There are Newtonian and non-Newtonian fluids based on the constitutive relations. For this classification viscosity becomes a useful parameter which is defined as,

$$\eta = \frac{shear\ stress}{shear\ rate} = \frac{(F/A)}{(U/h)} = \frac{\tau}{\dot{\gamma}}$$

Where, F is tangential force applied on the surface, A is the area of the force applied, U is the flow velocity, h is the gap between the two layers, τ is the shear stress and $\dot{\gamma}$ is the shear rate.

In the case of Newtonian fluids, the viscosity is constant that is, viscosity is independent of the shear rate whereas for non-Newtonian fluids, it is variable, which means that the relation between the shear stress and the shear rate is nonlinear. Hence, a constant coefficient of viscosity cannot be defined.

Depending on the nature of fluid, different types of curves may be obtained as shown in fig.1 which demonstrates the rheological properties of a typical fluids. It is convenient to group such types of non-Newtonian materials in to two major categories: time–independent (shear thinning and shear thickening) fluids and time-dependent (thixotropic and rheopectic) fluids. In the former case, the value of the shear rate at a point within the fluid is determined only by the current value of the shear stress at a point. But in the latter case, the relation between the shear stress and the shear rate shows further dependence on the duration of the shearing and the kinetic history. Here on this particular paper the discussion will be limited to the non-Newtonian time independent fluids.

Rheological behaviours of a material is measured with the help of capillary viscometer or rotational rheometer. Measurements using capillary viscometers are based on the relation between viscosity and time. They use gravity as the driving force. Therefore, the results are kinematic viscosity values. The other measuring device is called RheoLabQC which is based on state-of-the-art technologies. It sets new standards for carrying out routine rheological tests and combines unrivaled performance with easy operation and robust design. Its uses in a wider ranges from quick single-point checks over flow curve and yield point determinations to complex rheological investigations.

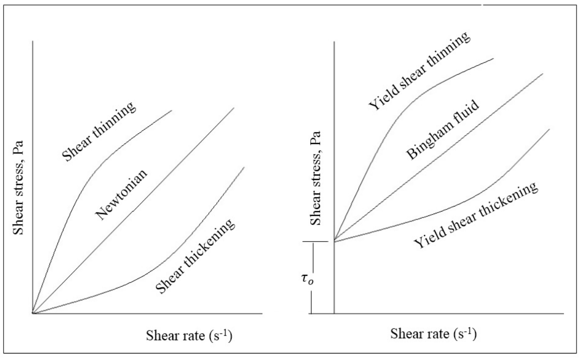

Fig. 1. The rheological behaviours of a typical fluids.

Details of the specifications of this rheometer geometry and the measuring techniques can be found in [10]. The measurement of rheological properties is applicable to all materials from fluids such as dilute solutions of polymers through to concentrated solid-liquid suspension, to semi-solids such as pastes and creams, to molten or solid polymers as well as asphalt.

III. MODELLING OF THE RHEOLOGY OF SLURRY

There are several mathematical models applied on rheogram in order to transform it to information on fluid rheological behaviour. The model equation that best represents a given slurry depends not only on the nature of the behaviour of the slurry, but also the quality and range of viscosity data available for the slurry. Hence, a relatively simple equation might be adequate to represent the viscosity data over only a limited shear rate. However, if a wide range of shear rate is covered, a complex equation might be needed to represent the entire range of data.

Typical models that have been found useful for representing rheological properties of non-Newtonian slurries are listed in table 1. Both the Bingham plastic and Casson models approaches to Newtonian behaviour as the shear stress or shear rate increases but exhibit proper limiting behaviour at both extremes of the shear rate and are consequently useful for representing the viscous properties of slurries that exhibit an apparent yield stress resulting from the interparticle contact resistance in a rest state. The power-law and Herschel-Bulkley models will fail giving better results at very low and high shear rates [29]. According to [28] and [30], the Sisko model has been found to be efficient for describing the shear stress-shear rate dependence for many non-Newtonian slurries over the range of the shear most appropriate to the flow in pipes.

IV. CHEMICAL ADDITIVES ON THE RHEOLOGY OF THE SLURRY

Certain chemical additives enhance the fluidity of the slurries and hence enable the slurries to be pumped at much higher concentrations thus reducing the water requirements. So, the selection of appropriate additives should be recognized as one of the most essential factors in the preparation of highly concentrated slurries. It is, therefore, relevant to investigate the effects of chemical additives on the rheological behaviours of slurries.

Table I. Typical rheological models for non-newtonian fluids

Model name	Model equation	References
Herschel-Bulkley	$\tau = \tau_h + K_h\dot{\gamma}^p$	[31]
Sisko	$\tau = \eta_s\dot{\gamma} + K_s\dot{\gamma}^m$	[1]
Casson	$\tau^{1/2} = \tau_c{}^{1/2} + (\eta_c\dot{\gamma})^{1/2}$	[20]
Power-Law	$\tau = K_p\dot{\gamma}^n$	[22]
Bingham plastic	$\tau = \tau_b + \eta_b\dot{\gamma}$ for $\tau > \tau_b$ $\dot{\gamma} = 0$ for $\tau < \tau_b$	[22]

Where, τ_h, τ_c and τ_b are yield stress of the respective models. η_s, η_c and η_b are limiting viscosity and K is the consistency index for the respective model. τ and $\dot{\gamma}$ are shear stress and shear rate respectively

According to [18], the chemical additives must be chosen such that they should provide sufficient viscosity, electro-kinetic potential and the desired stability. Generally speaking, the chemical additives can be categorized in to four based on their nature and functions, namely dispersants (deflocculants), coagulants (flocculants), surfactants and anti-settlings. Dispersant reagents adsorb onto the surface of minerals and disperse them as individual particles. In order to disperse particles, the charge on their surfaces needs to be of the same sign, and the higher the charge the greater the repulsive forces between particles. A dispersing agent prevents flocculation, or the combining of suspended matter into aggregates large enough for gravity to accelerate their settling out. In flocculation, the fine particulates interact with the added chemicals and consequently aggregate to form flocs. The flocculation process primarily involves transport of a particle to the closest distance of approach of another particle leading to collision and adhesion of particles resulting in aggregation and formation of flocs [11]. Surfactant is a non-reactive surface active agents that can greatly reduce the surface tension of the medium or the interfacial tension with other phases. Surfactant has a hydrophobic and a hydrophilic part in which the former consists of an uncharged group. Depending on the nature of the hydrophilic part the surfactants are mainly classified as cationic and anionic surfactants. Cationic surfactant group can fastens to the surfaces where they might acts as positively charged substance which is able to adsorb on negatively charged substrates to produce hydrophobic effect. An anti-settling agent is a suspension or rheological additive whose function is to prevent or retard particle settling and to maintain uniform consistency of the slurry during transportation.

This review is focused on two solid parental materials, namely coal ash and iron ore and discussed briefly in the following sections. After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

A. Coal Ash Slurries

Nam-Sun, et al. [19] investigated the effect of adding surfactants and electrolytes on viscosity of bituminous coals slurries prepared from South African coal. Two types of surfactant, anionic and non-ionic, were used as dispersing agents. The Na salts or condensates of naphthalene sulfonate were used as anionic surfactants and ethylene oxide groups as the non-ionic dispersants. They observed that the slurry exhibits pseudo-plasticity over the whole range of CWM 1002 (Formaldehyde condensate of sodium naphthalene sulfonate) concentration. They also observed that the apparent viscosity decreases abruptly in proportion to increasing amount of surfactant, reaches a minimum and then levels off. Furthermore, the rheological behaviour of the coal-water mixture approximates to Newtonian after the surfactant concentration exceeds 0.4 wt%, corresponding to the minimum viscosity. They also examined the influence of electrolytes using Mg (OH)2, Ca(OH)2, KOH and NaOH at concentrations up to 0.3 wt% of total slurry. It is shown that the addition of the electrolytes has a profound effect on the reduction of slurry viscosity, and that a more pronounced effect is observed with KOH and NaOH.

Zeki and Woodburn [33] experimentally investigated the effect of initial surfactant loading, the particle size distribution and the ash content of feed materials on the viscosity of the slurries prepared from Bickershaw coal, British. A non-ionic surfactant called Triton X-405 (p-tert-octylphenoxy-Polyethoxyethanol) was used. The initial reagent loading was increased to 7.0 mg/g coal and solid concentration of 60% by weight for all measurements. They observed that when the reagent loading was increased to 8.40 mg/g coal the viscosity values dropped sharply. Further reagent loadings; 10.5 and 14.0 mg/g coal did not cause a significant reduction in the viscosity of the slurries. They concluded that to produce pumpable coal slurries with more than 60% coal, it will be necessary first to achieve a significant level of de-mineralization, and also to use high levels of surfactant addition.

Dincer, et al. [5] investigated the effects of different chemicals used as dispersing agent and stabilizer on the stability and viscosity of Turkish-origin bituminous coal slurries. Three chemicals namely polyisoprene sulphonic acid soda (Dynaflow-K), a derivative of carboxylic acid (AC 1320) and naphtalenesulfonate–formaldehyde condensate (NSF) were used as dispersants and CMC-Na (sodium salt of carboxymethyl cellulose) was used as stabilizer. They observed that using polymeric organic dispersing agents of the Dynaflow type concentration is increased from 0.14% to 0.2%, the viscosity of coal–water slurry was decreased. And also observed that when Dynaflow was present as a dispersing agent in the coal–water slurry, the viscosity of the slurry was not affected by increasing concentrations of CMC. The viscosity of the slurry became very high when CMC was added to attain an acceptable state of stability in the coal-water slurries mixed with surface active anionic dispersing agents of NSF kind. The same observation was made in experiments where AC 1320 was used as the dispersing agent. Generally, anionic dispersing agents of Dynaflow type were more effective. They concluded that the viscosities of these slurries decrease with increasing concentrations of dispersing agents. When the coal–water slurry contains a polymeric type dispersing agent, its viscosity is not affected by increasing concentrations of the stabilizer. However, the viscosity of such slurries rapidly increases in the presence of surface active ionic structures.

Guanzhou, et al, [4] investigated the functions and molecular structure of ideal organic binders for iron ore pelletization based on the molecular design, interface chemistry, polymer science as well as failure model of a binding system. Their investigations proved that -COO and -OH are ideal polar and hydrophilic groups of organic binders, respectively. They concluded that good organic binders for iron ore pelletization should contain structurally sufficient polar groups (X) and hydrophilic groups (Y) and possess the structure mold like $[X\text{-}P\text{-}Y]_n$.

Kaushal, et al. [9] have done experimental investigation on the effects of newly developed chemicals on coal slurries obtained from Makum field in Assam and Sirka coal of North Karanpura field, Jharkhand, India. The two new additives are naphthalene-based and naphthalene-toluene based chemicals. The additive concentration was varied from 0.2 to 1.6 wt. % (dry Ledo coal basis) and the coal loading was held constant at 60% wt. They observed that the optimum concentrations of the additives naphthalene-based and naphthalene-toluene based in coal-water slurry were 0.8 and 0.9% by wt., respectively, on dry coal basis. For the same additive concentration, naphthalene-based additive gave lesser viscosity than naphthalene-toluene based additive for slurry concentrations ranging from 50 to 70% by wt. They concluded that slurries with high coal concentration (65–70%) having acceptable viscosities (< 1000 mPa s) can be formulated using the additive concentration of 0.8 and 0.9 wt. % (on coal charge), respectively.

Eisa, et al. [3] studied the effects of three dispersants namely, sulphonic acid, sodium tripolyphosphate and sodium carbonate on the rheological properties of low rank coal obtained from the main coal seam of El–Maghara coal mine, Northern Sinai, Egypt. The solid concentration was kept constant at 40% solids by weight through all tests and the chemicals are added at dosages range from 0.5 to 1.5 wt. % of solids. Furthermore, two stabilizers were tested in conjunction with sulphonic acid dispersant, namely, sodium carboxyl methyl cellulose (CMC-Na) and xanthan gum in dosages from 0.05 % to 0.25 % wt. of solids. They observed that the shear stress decreases with the increase in the amount of all the additives up to 0.75 % and then increases with increasing the additives concentration. They also observed that increasing the dosage of dispersant behind this value does not lead to an improvement in flow properties of considered slurries. Among these dispersants, sulphonic acid recorded the best performance. With respect to the effect of tested stabilizers on the slurry viscosity, they found that the stabilizers increase slurry viscosity. CMC-Na recorded better performance compared to xanthan gum where less viscosity is obtained at all stabilizer dosages. The best dosage of (CMC-Na) as a stabilizer was found as 0.1 % wt. of solids.

He et al., [15] reviewed the slurry rheology in ultrafine grinding, methods for the characterization of the slurry rheology, empirical equations for modelling the rheological behaviours and use of dispersants which affect the slurry rheology. They concluded that the effect of dispersant is crucial since the solids content of a ground material with an appropriate dispersant in a stirred media mill increases by about 30 wt.% and the fineness of the final product significantly enhances. They also concluded that for the slurry rheology control polyacrylic acid or its salts is the mostly used dispersant as a grinding aid.

Pearse [17] reviewed in detail the predominant reagents used and their mode of action in the mineral processing industry. According to this revision, lime and sulphuric acid are the highest volume bulk inorganic reagents used in mineral processing. Lime is being used for pH adjustment, coagulation, heavy metal precipitation, causticisation and depression of pyrite in flotation whereas Sulphuric acid is used for pH adjustment as well as for the leaching of oxide copper, lateritic nickel, zinc calcine, titanium dioxide from ilmenite and uranium minerals. He concluded that polyDADMAC (diallyldimethyl ammonium chloride) and quaternised polyamines are the main coagulants used in the minerals industry and low molecular mass polymers of sodium polyacrylate are used as the dispersing reagents.

Chandel, et al. [25] investigated the effect of additive on pressure drop and rheological characteristics of fly ash slurry at high concentration of 50, 60, 65, 68, and 70%. Mixture of sodium carbonate and Henko detergent (5:1) at 0.2% by weight has been used as an additive. They observed that mixture of sodium carbonate and Henko detergent as additive reduces both viscosity and yield stress of fly ash slurry significantly. The reason behind reduction in viscosity is that in the turbulent flow regime there is a reduction in interparticle friction, whereas in the laminar flow regime, this effect can be attributed to the reduction of surface tension and zeta potential of the fine particles due to the presence of additive. They also observed that with additive for any given concentration, there is significant reduction in pressure drop in comparison to original fly ash at any selected velocity.

Naik, et al. [7] evaluated the rheological characteristics of fly ash slurry at varying temperatures (20 to 40ºC) with and without an additive to facilitate smooth flow in the pipelines. Six fly ash slurry samples were prepared from a thermal power plant situated in the southern part of India. The cationic surfactant cetyl trimethyl ammonium bromide (CTAB) and the counter-ion sodium salicylate (NaSal) was selected. The concentration of the slurry is kept constant at 30% by weight and the additives surfactants at concentrations of 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% of the total weight of the slurry. An equal amount of a counter-ion same as that of the surfactant concentration was also added to the slurry. They observed that the untreated fly ash slurry exhibited turbulent flow behaviour whereas by addition of the surfactant to the fly ash slurry the rheological characteristics were improved. They also observed that the surfactant additive modified the surface properties of the fly ash particles from negative zeta potential values to positive values and suspension stability of the slurry was improved. They concluded that the surface tension of the treated fly ash slurry is reduced considerably compared to the untreated fly ash slurries and that of the suspending medium (water) which implies that this fly ash has got greater potential to be transported in hydraulic pipelines with the addition of a cationic surfactant (CTAB) and a counter-ion (NaSal) which would reduce specific energy consumption and water requirements.

Chandel, et al. [26] conducted experiments with fly ash slurries at four concentrations (50.2%, 60.1%, 65.3% and 70% by weight) with additive on the performance characteristics of centrifugal and progressive cavity screw pumps. Mixture of sodium carbonate and Henko detergent (5:1) at a concentration of 0.2% by weight has been used as additive. They observed that at rated speed, the performance of the centrifugal pump improves with the addition of drag reducing additive. In the case of progressive cavity screw pump, pump performance deteriorate with the addition of drag reducing soap solution at rated speed.

Naik, et al. [8] investigated the effects adding a cationic surfactant namely Cetyltrimethyl Ammonium Bromide (CTAB) along with a counter-ion Sodium Salicylate (NaSal) on the rheology of lignite fly ash obtained from Ennore thermal power station, Tamilnadu, India. The dosage of CTAB and NaSal, mixed in equal proportions, ranged from 0.1 to 0.5% by weight of solids and the slurry concentration kept constant of 40% by weight with a temperature ranging from 20 to 40ºC. They observed that the shear stress and viscosity decreased with the increase in the amount of surfactant and then increased with increasing surfactant concentration from 0.3 to 0.5% by weight of solids. Hence the best surfactant dosage is 0.3%. They concluded that the surfactants are capable of modifying the surface properties of the fly ash particles and improved the suspension stabilities of the slurry.

B. Iron Ore Slurries

El-Shall [6] reviewed the use of chemical additives on possible ways to improve the grinding efficiency. They concluded that the chemical additives such as Flotigam P, Sodium oleate and Oleic acid can influence grinding due to the effect of interactions between mineral particles and balls and mill wall and among particles themselves due to changes in frictional characteristics.

Mahiuddin, et al [27] studied the effects of chemical additives with or without stabilizing agents and/or calcium ion for alumina removal on iron-ore fines and slime. The chemical additives were used are lignite based additives (major constituent is humic acid) and phenol based additives (phenol-formaldehyde-bisulfite). They observed that there were a possibility of recovering around 68-78% concentrate with 65-84% alumina removal for iron-ore fines in different washing media, whereas, in the case of slime, around 40% concentrate with ~ 61% Fe was recovered. Hence, they concluded that the selective dispersion-cum-settling technique using chemical additives is a promising avenue for beneficiation of slime and fines.

Dash, et al. [14] studied the adsorption characteristics of polyacrylamide polymer (anionic and non-ionic flocculants) on iron ore tailings. An anionic flocculants Magnafloc-1011(a copolymer of acrylamide and sodium acrylate) and a non-ionic flocculants Magnafloc-333 (polyacrylamide) were used. They found that the settling rate increased with increasing flocculants dosage up to a maximum value at 80 g /t solid corresponding to the maximum adsorption of polymer. However, at higher pH the clarity of supernatant liquid was very poor and flocculation was not effective for ultrafine particles at that pH.

Marcos and Peres [12] investigated the effect of twenty reagents on the rheological behaviors of highly concentrated iron ore slurry. The selected reagents were three poliacrylic acids (DPW 410, DPW 510, and DPW 610), sodium poliacrylate and phosphate (AG DISPER), three poliethelenimines (DPW 1210, DPW 1310, and DPW 1410), two amine polyvinyls (DPW 710 and DPW 810), three polyethylene oxides (DPW 910, DPW 1010, and DPW 1110), two acrylamide and sodium acrylate copolymers (Magnafloc 919 and Magnafloc 1011) and two polyacrylamides (Magnafloc 351 and Magnafloc 333), citric acid, sodium hydroxide, sodium hexametaphosphate, and lime. For all tests the pH was set to 10 and the reagents were dosed at 300, 600 and 900 g/t.

They observed that none of the reagents showed significant increase in the dispersion degree but the three polyacrylic acids, citric acid, and sodium hexametaphosphate reduced the fluid consistency index and the plastic viscosity at the dosage 300 g/t beyond this dosage no change was observed. They also observed that there is a significant reduction in degree of dispersion when lime is added and optimum dosage was 400 g/t.

Marcos and Peres [13] investigated the effects of the slurry's rheological behavior and the state of aggregation and dispersion on wet ultrafine grinding of an iron ore concentrate. They observed that the addition of lime caused an increase in specific energy consumption, with significant increase in yield stress and consistency index of the fluid.

Sandra et al. [24] reviewed the influence of dispersants on the quality of iron ore pellets, by means of their action on the colloidal and rheological properties. They concluded that the use of colloidisant agents such as polymers formed of monomers of acrylic, methacrylic, maleic, itaconic or vinylsulfonic acids, or their derivatives such as vinyl, ethoxylated, propoxylated, sulfonic or phosphonic, Sulphide or sulfonated condensates of formaldehyde with naphthalene, phenol or melamine provide faster formation of green pellets, with the same or greater strength and lower contaminant content.

The Samarco project has also been using lime as additive to transport the iron ore slurry through pipeline. Initially, internal corrosion was the main concern therefore the reagent was used only for pH correction. However, an alternative was sought so that the slurry rheology could still be controlled in case lime addition became impracticable. This alternative consists of adding soda for pH correction and an organic coagulant (quaternary ammonium salt) as a rheology modifier. This investigation showed that no plug formation and allowed solid particles to settle, forming a loose sediment after rest. Furthermore, the results indicate a low probability of plug occurrence in the pipeline and the formation of a readily re-slurryable sediment upon shutdown of the pumping system.

According to the Active Minerals International, LLC website [32], Acti-Gel® 208 is a low-dose (~0.05% to ~0.20% total dry weight material basis) rheology modifier and anti-settling agent that provides superior particle suspension, stabilizes mixtures, and dramatically improves the workability, flowability, pumpability and performance of slurries and pastes. This chemical up to now have not been investigated by any researchers how it affects the rheological properties of iron ore slurries. Many other chemical additives are being used in the mineral processing industries such as in iron ore transportations. Additional reviews on the functions or effects of the chemical additives are given in table II

TABLE I. SOME OF THE CHEMICAL ADDITIVES AND THEIR FUNCTIONS ON THE IRON ORE SLURRIES

No	Name of the chemicals	Functions/effects	Parental solids	References
1	Tapioca starch, Potato starch and corn starch; Sodium Silicate and Sodium Hexametaphosphate	Flocculants; Dispersants – used in corn starch	Iron ore tailings	[23]
2	Magnafloc and Rishfloc; Sodium petroleum sulfonate and sodium lauryl sulfate–anion, cetyl trimethyl ammonium bromide-cationic,	Flocculants; Surfactants	Iron ore fines	[2]
3	Calcium lignosulphonate	As surfactants (dispersant)	Ferrosilicon and magnetite	[21]
4	Magnafloc-1011 an anionic and Magnafloc-333 a non-ionic	Flocculants	Iron ore tailings	[14]
5	limestone	Increased the reducibility by increasing the porosity of the pellets as the limestone decomposed in the sintering.	acid iron ore pellets	[16]

V. SUMMARY

The rheology of a non-Newtonian slurry is highly complex and is influenced by many parameters, namely solid contents, particle size and particle size distribution, particle shape, slurry temperature, pH, the surface chemistry of the solid particles, chemical additives and so on. Hence, the interpretation of the rheological behaviours of slurry must essentially take into account the identification of the respective effects of these main factors and their interactions.

Non-Newtonian materials can be mainly categorized in to two namely, time –independent (shear thinning and shear thickening) fluids and time-dependent (thixotropic and rheopectic) fluids. In time –independent fluids, the value of the shear rate at a point within the fluid is determined only by the current value of the shear stress at a point. But in the case time-dependent fluid, the relation between the shear stress and the shear rate shows further dependence on the duration of the shearing and the kinetic history.

An excessively high viscosity makes handling of slurry impossible due to the poor fluidity which increases specific energy and pump capacity. Hence, various mechanisms have been designed for the last decades to reduce this problems. One of the mechanism is the uses of chemical additives that may provide sufficient viscosity, electro-kinetic potential and the desired stability. The chemical additives can be categorized in to four based on their nature and functions, namely dispersants, coagulants, surfactants and anti-settlings.

In most of the literatures the chemical composition of the suspensions after the additions of chemicals were not investigated. Hence, it is difficult to analyze beyond their effects on the flow behaviours.

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