An Empirical Model for the Prediction of the Viscosity of Slurries of Coal Fly Ash with Varying Concentration and Shear Rate at Room Temperature

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Coal fly ash (CFA) is attracting increasing attention as a raw material for processing into multiple products. Well designed processing equipment requires an understanding of how a suspension's rheology changes with increasing solid concentration and shear rate. Current rheological models applied to CFA are insufficient to describe rheological behaviour over a wide range of concentrations. The current paper (summarised from [1]) analyses the flow curves of two types of coal fly ash differing in particle size, shape, and distribution over a range 10-70 wt%. It has been shown that both samples exhibit complex non-Newtonian. A new generalised modelling procedure has been proposed to predict the viscosity behaviour of solid suspensions. The resulting model was able to predict the relative viscosity as a function of both concentration and shear rate with a high degree of accuracy. It is envisaged that this will be extremely useful for the purpose of processing equipment design involving mixing operations.

Although there are many semi-empirical equations in the literature that can describe viscosity-concentration behaviour at higher solids loadings, and there are several equations that can adequately describe viscosity-shear rate behaviour such as the power law, there are few relationships that describe both. The current study examines two suspension types: a raw unrefined CFA and a processed CFA that has undergone sequential processing to remove, lightweight, carbonaceous, magnetic, and oversize fractions hereafter referred to as improved fly ash residue (IFA) [2]. The flow rheology (2-200 s^{-1}) of the two ash types was studied as a function of the concentration.

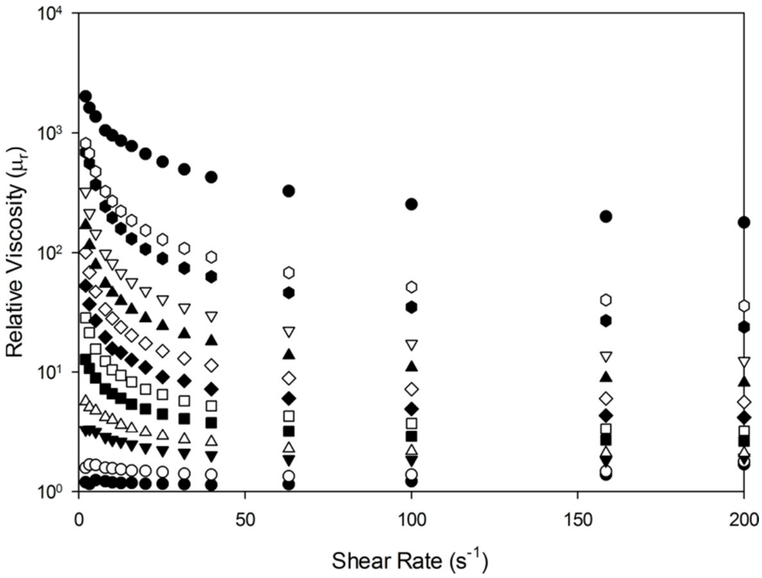

Figure 1 - Relative viscosity as a function of shear rate for IFA. Concentrations 10-70 wt% from top to bottom of figure

Figure 1 shows the viscosity of the suspension relative to pure water as a function of the shear rate for IFA. It is clear from an initial inspection of the results that the more concentrated suspensions exhibit differing degrees of shear thinning behaviour. As such any rheological model will have to deal with non constant terms for the power law index, *n*.

Following a method similar to Turian et al. [3], a model was proposed that consisted of two stages. Sisko's [4] model for lubricating greases is a simple relationship that considers the non-

Newtonian fluid in two parts: a Newtonian region at high shear and the shear thinning region at lower shear rates. It has previously found to be robust in fitting to rheological data for mineral suspensions.

$$\mu = \mu_\infty + m\dot{\gamma}^{n-1} \qquad [1]$$

In this equation the viscosity μ is related to the viscosity μ_∞ at an infinite shear rate $\dot{\gamma}$. The parameters m and are the shear thinning constants of the power law relationship. This equation as it stands does not allow the prediction of viscosity change with increased concentration. The equation is modified to predict μ_∞ by first curve fitting the raw data with the Sisko model to obtain μ_∞ for different concentrations of ash. Then the Krieger Dougherty model was fitted to the μ_∞ *vs.* concentration curve. The parameter ϕ is the volume fraction of the ash, ϕ_m is the maximum packing fraction, and [μ] is the intrinsic viscosity.

$$\mu_{r\infty} = \left(1 - \frac{\phi}{\phi_m}\right)^{-[\mu]\phi_m} \qquad [2]$$

The parameters *m* and *n* were highly suspension dependent and so they were fitted with the following arbitrary mathematical relationships.

$$m(\phi) = b\phi^c \qquad [3]$$

$$n(\phi) = d\phi^2 - e\phi + f \qquad [4]$$

Analysis of the raw data allowed the suspension dependent parameters *b-f*, $\phi_{m,}$ and [μ] to be obtained. A comparison of the model for IFA at a shear rate of 5 s^{-1} is shown in Figure 2.

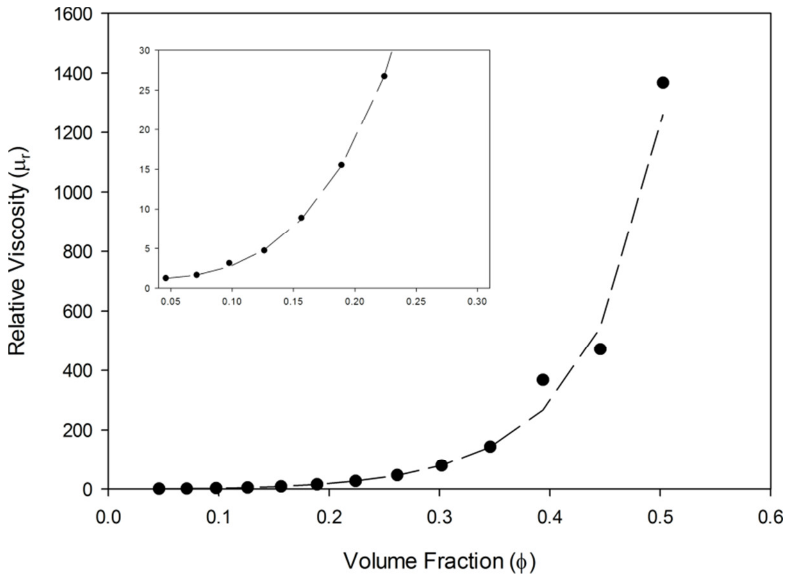

Figure 2 – Relative viscosity as a function of volume fraction for IFA suspensions. Circles are experimental and dashed line is the model prediction.

1. Blissett, R.S. and N.A. Rowson, *An Empirical Model for the Prediction of the Viscosity of Slurries of Coal Fly Ash with Varying Concentration and Shear Rate at Room Temperature.* Fuel, In press.
2. Blissett, R.S. and N.A. Rowson, *A review of the multi-component utilisation of coal fly ash.* Fuel, 2012. **97**(0): p. 1-23.
3. Turian, R.M., et al., *Characterization, settling, and rheology of concentrated fine particulate mineral slurries.* Powder Technology, 1997. **93**(3): p. 219-233.
4. Sisko, A.W., *The Flow of Lubricating Greases.* Industrial & Engineering Chemistry, 1958. **50**(12): p. 1789-1792.