SUMMARY

Ash deposition is a problem in power generation when coal with high ash and alkali contents are utilised. The problem is more severe in fluidised bed combustion where the ash deposition can cause agglomeration of the bed material, and may lead to defluidisation of the unit. The successful operation of fluid bed combustion with coal high in ash and alkali content will depend on the ability to control ash deposition. The rheological properties of coal ash under furnace conditions are important in controlling the stickiness and mobility of the molten ash deposition. Therefore, a good knowledge of the rheological properties of coal ash will improve the understanding of the mechanisms associated with ash deposition, and may assist in controlling the deposition and agglomeration of fluid bed material.

At present, a good deal of information about coal ash rheology under conditions similar to those found in fluidised bed combustion is not known, and greater understanding is required. This is primarily due to a lack of reliable instruments and measurement techniques. In this work, a new high temperature rheometer has been developed based on the principle concepts of viscometric flow. The developed rheometer allows fundamental rheological properties, such as shear stress and shear rate, to be obtained without relying on calibrations with materials of known properties. With this instrument the flow characteristics of the tested samples can be determined directly without assuming a particular fluid model. The new rheometer has the capability to measure the rheological properties of materials at temperatures ranging from 500°C to 1300°C and under different processing conditions.

Rheological characteristics and properties of a range of low rank Australian coal ashes have been carried out using the newly developed high temperature rheometer, equipped with a cone and plate measuring geometry. It has been found that coal ash samples exhibit thixotropic and viscoplastic flow behaviours. SEM and XRD analyses have revealed that during high temperature rheological measurements the coal ash sample is basically a suspension of colloidal mineral solids in a molten eutectic liquid. The solid phase is mainly silica (SiO₂), and the liquid phase is a mixture of alkali sulphates mainly CaSO₄, MgSO₄ and Na₂SO₄ compounds. The equilibrium viscometric data of coal ash samples is found to be satisfactorily described using the Herschel-Bulkley model. The equilibrium rheological properties are strongly affected by the concentration levels of CaSO₄, MgSO₄ and Na₂SO₄. The operating temperature and chemical composition of the
surrounding gas phase were also found to affect the rheological properties of the coal ash samples.

In order to obtain a better understanding and to model the rheological properties of the coal ashes, a series of synthetic ash mixtures were examined. The synthetic mixtures contained the key chemical components that represent the solid and the liquid phases. The solid phase is represented by silica (SiO₂), while a mixture of CaSO₄, MgSO₄ and Na₂SO₄ compounds represented the liquid phase. In this work, the rheological characteristics of mixtures of synthetic ash were investigated using a factorial experimental design. Using the synthetic ash mixtures together with the statistical design experiment, the effect of key chemical compounds on the rheological properties could be systematically investigated. The rheological results showed that the synthetic mixtures exhibited thixotropic and viscoplastic behaviours. It was also found that mixtures predominantly high in CaSO₄ and MgSO₄ had a high degree of thixotropy behaviour, while those mixtures predominantly high in Na₂SO₄ showed a lower degree of thixotropy behaviour. The statistical analysis also showed that Na₂SO₄ is the most significant chemical compound causes a high yield stress and high viscosity. In contrast, CaSO₄ and MgSO₄ were found to decrease the value of the yield stress and the viscosity. The rheological behaviour of the synthetic ash mixtures can be used to describe rheological behaviour of the coal ash samples.

Relationships between the equilibrium flow properties and chemical compounds, and temperatures are developed using a linear regression method. The statistical analysis has shown that CaSO₄, MgSO₄ and Na₂SO₄, and their interactions are all significant compounds that have effects on the yield stress and viscosity of the synthetic mixtures. It was also found that the yield stress and viscosity decreased with increasing concentration level of either CaSO₄ or MgSO₄. Yield stress and viscosity are increased with increases in the concentration of Na₂SO₄. The statistical models can successfully predict rheological properties of ash with high concentrations of CaSO₄, MgSO₄ and Na₂SO₄, but it fails to predict the rheological properties of ashes that also high in concentrations of either Fe₂O₃ or Al₂O₃, or a combination of both.

The relationship between ash rheology and fluidised bed agglomeration has been established. The yield stress of a coal ash may be used to describe the tendency of the molten ash to deposit on surface of the fluid bed particles. Yield stress also determines the tendency of stickiness of the molten ash deposit to adhere the fluid bed particles during fluidised bed combustion process. The viscosity of the molten ash describes the
ability of the molten ash layer to adhere the fluid bed particles after a collision. High viscosity ash tend to hold the colliding particles together longer than a low viscosity ash. Shear thinning behaviour of the ash samples (decreasing viscosity with increasing shear rate) suggests that the operating conditions could be arranged so as to minimise the chance of agglomeration. For example, in order to avoid agglomeration a high viscosity coal ash would benefit from operating the fluidised bed combustion at a high velocity, this is because a high velocity means a higher shear rate and this causes a reduction in the viscosity of the molten ash. Thus, particles agglomerated by a low viscosity ash would be easily broken by the hydrodynamic forces present during the fluidised bed process. Finally, information about ash rheology has formed a basic knowledge for estimating tendency of fluid bed agglomeration when coal obtained from different source is being used.
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