Journal of Industrial and Engineering Chemistry 25 (2015) 122–130

Contents lists available at ScienceDirect

Journal of Industrial and Engineering Chemistry

journal homepage: www.elsevier.com/locate/jiec

An investigation into the influence of microwave energy on iron ore–water slurry rheology

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ARTICLE INFO

Article history:
Received 7 August 2014
Received in revised form 7 October 2014
Accepted 11 October 2014
Available online 27 October 2014

Keywords:
Microwave energy
Iron ore–water slurry
Viscosity
Rheology
Statistical design analysis

ABSTRACT

The transporting of slurries in pipelines depends largely on rheological behavior of the solid–liquid suspension. These rheological properties of slurries are very much influenced by the slurry concentration, particle size distribution and, surface characteristics. The present invention is concerned with the effect of these parameters on slurry rheology using microwave (MW) energy. Microwave pre-treatment for rheological behaviour of iron ore-water slurries (IWS) were carried out in an online Bohlin viscometer. Detailed experimental work for Indian iron ore were conducted at power level of 900 W and 30, 60, 90 and 120 s various exposure times in microwave oven. The microwave treated and untreated test samples were ground for rheological characteristic of slurries. It was seen that microwave-treated ore have better rheological properties as compared to untreated ore. This type of slurry is shear thinning and easy to transport as it exhibited pseudo-plastic behavior. The result showed that microwave-treated iron ore have a density lower than that of untreated ore after grinding. Statistical design analysis was employed to develop empirical equations and found to be encouraging and highly considerable.

Introduction

Recently, study has shown the importance of measurements of physical properties of solid–liquid slurries. Flow of these slurries is frequently encountered in many industrial and nature applications. The effect of slurry parameters is required to design such physical and engineering systems [1]. The characterization of the rheology of mineral slurries into Newtonian and non-Newtonian flows has been investigated [2]. A developed semi-empirical model demonstrates the complex influence of slurry properties on rheology, and also permits prediction of unmeasured rheological information [3]. Full shear rate-shear stress flow curve for unstable slurries have been shown using the single bobbin Debex on-line viscometer. The calibration algorithm based procedure incorporates turbulent flow correction in the measurement vessel [4].

The pseudo-plastic characteristics were exhibited by slurries having high solid content and a low proportion of fines, such as primary or secondary mill products [5]. A method of pipelining iron ore permits transporting a range of particle sizes in the slurry through the use of relatively small concentration additives like chemical dispersant and viscosity control additives. Many stiff pastes, made up of finely ground solid material with enough liquid to saturate the voids, have both a yield stress and a viscosity. The application of vibrations reduced both these rheological attribute [6–8]. Recently, it was found that microwave pre-treatment of ultramafic nickel ores prior to grinding reduces slurry viscosity and yield stress [9]. Microwave pre-treatment was found to greatly reduce the shear viscosity (average 80% reduction at 200 s^{-1}) and direct yield stress (peak yield stress reduced by 92–93%) of ultramafic nickel ore slurries.

The power requirements for pumping of solid–liquid suspensions depend largely on rheological behavior of solid–liquid suspensions. The nature of the suspending medium, solid concentration, shape, particle size distribution, surface characteristics, additives, pressure and temperature influence these rheological properties of suspensions very much. The rheological characteristics of coal–water suspensions were enhanced by microwave pre-treatment [10–12]. Microwave energy is a non-ionizing electromagnetic

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http://dx.doi.org/10.1016/j.jiec.2014.10.022

radiation with frequencies in the range of 300 MHz–300 GHz. The extensive application of microwaves has in the field of communication. The Federal Communication Commission (FCC) has been allocated certain frequencies for Industrial, Scientific, Medical and Instrumentations (ISMI) applications. Currently, 2450 MHz is the most commonly utilized frequency for the home microwave oven. Microwaves can pass through materials like glass, paper, plastic and ceramic, and be absorbed by food and water; but they are reflected by metals. Microwaves have longer wave lengths and lower available energy quanta than other forms of electromagnetic energy such as visible, ultraviolet or infrared light [13,14].

Microwave energy is derived from electrical energy with a conversion efficiency of approximately 50% for 2450 MHz and 85% for 915 MHz [15,16]. Various researchers emphasized on the advances in the microwave treatment of minerals from the early stages of development to possibilities for future utilization. It has been reported that stress-fracture in ore samples caused due to rapid microwave heating [17,18]. Experiments were carried out in microwave oven at 3 kW in batch operation for iron ores containing hematite, magnetite and goethite and heated to average maximum temperatures between 840 and 940 °C [19]. Grinding characteristics of Indian coal and iron ore was improved by microwave pre-treatment at 900 W power level [20,21].

The present study focused on influence of microwave energy on rheological characterization of iron ore slurries. The rheological behavior of slurries has been deliberated by laboratory viscosity measurements. Slurries with solid concentrations of hematite were varied from 20–40%. The microwave energy enhanced the rheological performance of slurries and found to depend mainly on solids concentration, particle size distribution and surface characteristics. Statistical design analysis was used and theoretical models developed for predicting viscosity of hematite ore slurry and the effect of various parameters.

Experimental

Materials

The material used for this investigation was an iron ore obtained from Joda mines, Keonjhar (India) prior to further processing. It was a most commonly naturally occurring ore averaging iron content of 64% and a density of 4.63×10^3 kg/m^3. The sample contained alumina and silica of 2.2% and 3.2%, respectively leads to affect grinding behavior of the mineral phases in ore comminution process. A representative sample of 15 kg was selected for microwave treatment.

Microwave treatment

The system illustrated as Fig. 1, mainly consisted of a prototype microwave oven (LG MC-808WAR model) which was used for microwave pretreatment of iron ore. The oven was a 530 mm (W) × 500 mm (D) × 322 mm (H) capacity with specifications frequency 50 Hz, power level 900 W at high level, output frequency 2.45 GHz, usable volume 27 L, weight of 26 kg. Microwave oven has five microwave power settings (i.e. 180, 360, 540, 720 and 900 W). Different power level was selected by repeated presses of the MICRO key where as high power was automatically selected. Door handle, microwave radiation-proof oven cooker window, stirrer fan cover, revolving tray, control panel and oven cavity light were main parts of the oven. An inert atmosphere was maintained by purging nitrogen gas at a controlled flow rate inside the oven. Air vent was provided to expel generated hot air, steam and vapors within the oven cavity during cooking in the microwave oven.

Experimental procedure

Original sample (iron ore) of 15 kg was crushed to −3/4 in. + 1/2 in. mesh sieves in a jaw crusher. The samples of −3/4 in. + 1/2 in. (19.05–12.7 mm) fractions were taken in a glass container of around 500 g capacity. The height of the sample bed was maintained approximately equal to the diameter of the container. The container containing the samples was kept on the floor of the oven in the revolving tray. An inert atmosphere was maintained by purging nitrogen gas at controlled rate through a rotameter for about 5 min, and then the door was closed carefully. Then the oven was set at a power level of 900 W and programmable time of 30, 60, 90, 120 s respectively. A digital thermometer (range 0–200 °C, type is Pt-100) was incorporated to measure the temperature of the test sample in the actual experiment Then the microwave treated samples were collected for different sized fractions by ball mill. A ball mill was employed to grind the microwave treated test sample of −3/4 in. + 1/2 in. (19.05–12.7 mm) fractions for 20 min. The sample was taken out after every 5 min and sieved in a sieve shaker thoroughly using 52, 72, 100, 150, 200 and 300 standard BSS mesh screens. Five solid samples of −52 + 72, −72 + 100, −100 + 150, −150 + 200 and −200 + 300 mesh particle sizes were collected and weighed. The average particle sizes of these fractions used were 253, 182, 127, 90 and 60 μm respectively using particle size analyzer. The oversize material (>295 μm) was returned to the mill for further grinding in successive intervals of 5 min for a total time of 20 min. All untreated and MW treated iron ore samples were prepared in similar manner.

Rheology measurement

The viscometer is the Bohlin Visco 88 BV, a portable viscometer for laboratory use. This viscometer directly measures the rotational speed of a rotor, V (rpm) and the shear stress related torque, M (mN m), shear rate γ (s^{-1}), shear stress, τ (Pa) and apparent viscosity μ (Pas). These are calculated by following formula, $\tau = C1 \times M$, $\gamma = C2 \times V$, $\mu = \tau/\gamma$. The Bohlin Visco 88 BV employs a concentric cylindrical geometry with a rotating inner cylinder and stationary outer cylinder. A synchronous motor drive the spindle through a calibrated spring and the viscometer displayed the deflection. It works in a principle that the torque required to turn an object in a fluid indicates the viscosity of that fluid. The concentric cylinder can be configured in to 8 different measurement systems (3 DIN, 2 wide gap, 3 infinite sea) corresponding to knob 1–8 on the instrument. Any inner cylinder has 8 rotation speeds (20–1000 rpm) correspond to a shear rate range 12–1200 s^{-1}. The torque developed on the inner cylinder due to a sample is directly related to the sample viscosity and should be in a range of 0.5–9.5 mN m for the accurateness of the measurement. The gap between the inner bob/vane and outer cylinder is thin so that there is almost a constant gradient of shear over it.

Iron ore-water slurries are concentrated suspension of iron ore particles in water. About 10 ml of sample placed in the cylinder of the viscometer after placing the bob/vane properly within the cylinder. The slurries were prepared with 20, 30 and 40% (by weight) solid concentrations in the suspending medium. Then the online viscometer is started on with the help of programmable panel. According to the instructions shown on the computer screen, all operations can be done for the setting up the various options relating to the rheometer, geometry, sample details and shear rate range. A whole viscosity measurement was spent about 120 s. The apparent viscosity of the slurries was measured by a computer controlled rheometer. A shear rate of 552 s^{-1} was used to measure the apparent viscosity. All rheological measurements of the samples were done in a shear rate range 0–600 s^{-1}. Consistent readings of the apparent viscosity were met by selecting these shear rates by trial and error. In all the tests the pH value of the slurry varied between 8 and 8.5 and