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Artificial neural network approach for rheological characteristics of coal-water slurry using microwave pre-treatment

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ABSTRACT

Detailed experimental investigations were carried out for microwave pre-treatment of high ash Indian coal at high power level (900 W) in microwave oven. The microwave exposure times were fixed at 60 s and 120 s. A rheology characteristic for microwave pre-treatment of coal-water slurry (CWS) was performed in an online Bohlin viscometer. The non-Newtonian character of the slurry follows the rheological model of Ostwald de Waele. The values of *n* and *k* vary from 0.31 to 0.64 and 0.19 to 0.81 Pa·sn, respectively. This paper presents an artificial neural network (ANN) model to predict the effects of operational parameters on apparent viscosity of CWS. A 4-2-1 topology with Levenberg-Marquardt training algorithm (trainlm) was selected as the controlled ANN. Mean squared error (MSE) of 0.002 and coefficient of multiple determinations (R^2) of 0.99 were obtained for the outperforming model. The promising values of correlation coefficient further confirm the robustness and satisfactory performance of the proposed ANN model.

1. Introduction

Coal-water slurries (CWS) are concentrated suspensions of coal particles in water and are used as fluid fuels. Generally, irregular structure attributes to substances of coal particles. They consist of an organic part, i.e., of hydrocarbon portions with associated functional groups (mainly phenolic, carbonyl and carboxyl groups) and an inorganic part (pyrite, clay, minerals), which constitute the ash content. Usually, the surface of a clean coal particle is hydrophobic where as ash is hydrophilic. The chemistry of the coal surface plays a significant role in the stability of coal water slurries [1]. Three main effects contributing to the surface properties are the number and type of polar groups (carboxylic and phenolic), the ash content and the hydrocarbon skeleton. The mineral matter of coal which constitutes the inorganic matter in coal is generally associated with the ash content in coal. The hydrophilicity of coal surface increases with increase in ash content of coal. The inner surface of hydrophobic coal is not penetrated by water and hence more of it is available in the inter-particular spaces. Availability of less water outside the hydrophilic coal particles decreases the fluidity or increases the viscosity of coal water slurry [2]. The viscosity of CWS increased with the hydrophilicity of coal, resulting in a distinct decreased in slurryability [3,4]. With increasing carbon content, the degree of carbonification increased and the amount of carbonyl groups and aliphatic carbon decreased, leading to the coal surface becoming more hydrophobic and the slurryability of CWS increased [5,6]. It was reported that the presence of polar hydroxyl, carbonyl, phenol groups and some peroxide type oxygenated moieties on the surface of coals decreased the coal hydrophobicity. Thermal and microwave treatments were attributed to the removal of pore water, hydration water, some hydroxyl functional groups and change in surface characteristics of these coals and hence an enhancement of rheological behavior was achieved using microwave energy [7,8].

Microwave energy is a non-ionizing electromagnetic 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 foods and water; but they are reflected by metals. Microwaves have longer wave lengths and

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lower available energy quanta than other forms of electromagnetic energy such as visible, ultraviolet or infrared light [9]. Microwave energy is derived from electrical energy with a conversion efficiency of approximately 50% for 2450 MHz and 85% for 915 MHz. Various researchers emphasized on the advances in the microwave treatment of minerals from the early stages of development to possibilities for future utilization [10–14].

Critical appraisal on the status of research shows that there is an increasing demand for new energy sources towards various methods of burning coal-water slurries in a pulverized fuel burner for energy generation or transporting the slurries through a pipeline. The power requirements for pumping of these 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. There is very limited research on rheological characteristics of microwave-treated coal-water suspensions and hence an effort has been made in the direction of rheological characteristics using microwave pre-treatment for Indian high ash coal. In addition to this a study has been made to develop a predictive artificial neural network (ANN) model to determine the apparent viscosity of coal-water slurry based on the process parameters like particle diameter, solid concentrations, microwave exposure time and shear rate. The set of experimental input and output data for slurry rheology has been trained, tested and validated by ANN, MATLAB software-package.

2. Materials and methods

2.1. Materials

The material used for this investigation was an Indian high ash coal. It is referred as coal-X, having 38% ash content. The samples were collected in a lot as per the standard from the Jamadoba washery before technical processing in TATA steel plant (TISCO) for blast furnace coke making. A representative sample of 15 kg was drawn by coning and quartering method in a clean surface from the original coal samples of 50 kg for microwave treatment.

2.2. Microwave treatment

A prototype microwave oven (LG MC-808WAR model) was employed in present investigation for microwave pretreatment of coal. The system is illustrated in Fig. 1. The oven was a 530 mm (W) × 500 mm (D) × 322 mm (H) dimension and with specifications frequency 50 Hz, power level 900 W at high level, output frequency 2.45 GHz, usable volume 27 L, and weight of 26 kg. Microwave oven was incorporated with 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.

Original sample (coal) 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. Microwave pretreatment of coal was accomplished by keeping the glass container on the floor of the oven in the revolving tray. The coal sample was distributed uniformly throughout the container. 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 cautiously. Then the oven was set at a power level of 900 W and programmable time of 60 s, 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. A ball mill was employed to grind the microwave treated coal 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 consecutive intervals of 5 min for a total time of 20 min. All untreated and MW treated coal samples were prepared in similar manner.

2.3. Rheology measurement

A portable viscometer was used in this study to carry out the rheological characteristics of slurries. This viscometer directly measured the rotational speed of a rotor, V (r/min) and the shear stress related torque, M (mN·m), shear rate γ (s^{-1}), shear stress, τ (Pa) and apparent viscosity μ (Pa·s). These were calculated by following relation, $\tau = (C1 \times M)$, $\gamma = (C2 \times V)$, $\mu = (\tau/\gamma)$. Bohlin Visco 88 BV employed with three concentric cylinder measuring systems as per the standard. This made 8 measuring system in different possible combinations. The outer cylinders were equipped with a bayonet fitting and the inner cylinders had a spring-loaded chuck attachment. This created the measuring systems easy to interchange. The outer cylinders were equipped with bottom lids to discharge excess sample. The O-rings in the bases were made of EPDM (Ethylene Propylene). The material of the outer and inner cylinders and also the bases was stainless steel. Cup and bob type measuring systems come in various forms such as coaxial cylinder, double gap, Mooney cell etc. For DIN standard coaxial cylinders they are referred to by the diameter of the inner bob. i.e., a C25 is a coaxial cup and bob having a 25 mm diameter bob. The diameter of the cup is in proportion to the bob size as defined by the DIN standard. Cup and bob measuring geometries require relatively large sample volumes and are more difficult to clean. They usually have large mass and large inertias and so can produce problems when performing high frequency measurements. Their advantages come from being able to work with low viscosity materials and mobile suspensions. Their larger surface enabled them a greater sensitivity and so they will produce good data at low shear rates and viscosities.

Coal-water slurries are concentrated suspension of coal particles in water. About 10 mL of sample was placed in the cylinder of the viscometer after placing the bob/vane properly within the cylinder. The slurries were prepared with 30%, 40% and 50% (by weight) solid concentrations in the suspending medium. Then with the help of programmable panel, the online viscometer was putted on in operation. Various options relating to the rheometer, geometry, sample details and shear rate range was set as followed by the commands given by the software. Approximately two minutes required for all measurements. The apparent viscosity of the slurries was measured by a computer controlled rheometer. A shear rate up to 224.60 s^{-1} was used to measure the apparent viscosity. A shear rate range of 0–300 s^{-1} was designed for rheological measurements of the coal samples. The detail scope of the experiments performed is given in Table 1. Consistent readings of the apparent viscosity were met by selecting these shear rates by trial and error. The pH value of the solid-liquid suspension was varied between 8