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Physicochemical and rheological characteristics of charcoal slurry fuel

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Abstract

Charcoal slurry fuel (CCF) was prepared from a mixture of charcoal, water and a surfactant. Some properties of the slurry were examined and evaluated. The rheological characteristics which were evaluated from the measurement of the viscosity of the slurry at varying solid concentrations showed it to be a Newtonian and non-Newtonian fluid depending on the solid concentrations. The slurry was stable at below 40% solid concentration. This research results provided data that may be useful in the consideration of charcoal slurry as a potential substitute for the conventional petroleum-based diesel oil.

Keywords: Charcoal; Properties; Slurry; Stability; Viscosity.

1. Introduction

Energy is required to do mechanical work, provide transportation, create heat, supply electricity, etc. Worldwide, the most common source of energy is from fossil fuels which are non-renewable. The energy from this source especially from petroleum and coal is not readily available, are costly and environmentally unfriendly. The utilization of fossil fuels through combustion emits hazardous pollutants and other gases that exacerbate global warming, pollute the air and cause acid rains, and many other problems. Current shift is towards renewable sources of energy which are cheap, environmentally friendly, readily available and can be replenished.

Most applications require fuels in liquid form. This has necessitated researches to convert solid fuels to liquid fuels. This line led to development of coal-liquid mixtures**.** Internationally, extensive researches were carried out over the years to establish the coal-liquid mixtures, comprising separately, coal-oil; coal-water and coal-organic solvent mixtures, as possible alternative to petroleum-based diesel oil [1, 2].

The idea of utilizing liquid charcoal as a substitute fuel for oil is receiving attention and studies are being conducted to harness the energy from this biomass as a way of reducing heavy fuel oil consumption and its concomitant pollution to the atmosphere [3].

Charcoal is the blackish residue consisting of an inorganic carbon compound obtained by removing water and other volatile constituents of animal and vegetable substances. It is usually produced from the incomplete combustion of organic material at temperatures ranging from 280 to 500^{o}C [4]. It is a solid fuel commonly used for cooking, heating, in making activated carbon and chemicals, in the iron and steel industry and for making briquettes [5].

Soloiu et al [6] prepared charcoal-oil mixture by emulsifying charcoal with heavy fuel oil. Other researchers [7] have used charcoal mixed with water and diesel oil to produce charcoal-oil mixture. Kalpesh and Sham [8] reported that some researchers from Cairo, Egypt, did research on

physicochemical characterization of emulsion fuel from fuel oil-water-charcoal and surfactants. The results of this evaluation show that the emulsion fuels are compatible with the corresponding oil.
This study presents the results on the characteristics of colloidal suspension of charcoal and water with a liquid soap as an additive to stabilize the suspension.

2. Materials and methods

The charcoal used for this study was purchased from Ogige market, Nsukka, Nigeria. The charcoal pieces were crushed, followed by grinding and screening through 250 micron sieve. The undersize charcoal was collected and packaged with plastic bags to prevent oxidation. Portions were taken from this sample for the various determinations. This work was carried out at the Laboratory of the National Center for Energy Research and Development, University of Nigeria, Nsukka between January, 2013 and July, 2013.

2.1 Proximate analysis of the charcoal

This was carried out, following modified standard methods for solid fuels [9], to characterize the charcoal for Moisture, Ash, Volatile Matter, and Fixed carbon contents.

2.2 Ultimate analysis of the charcoal

The ultimate analysis indicates the various elemental chemical constituents such as Carbon, Hydrogen, Oxygen, Sulphur, etc. This information was obtained from calculation based on the relationship between ultimate analysis and proximate analysis as follows:

Relationship between Ultimate Analysis and Proximate Analysis [10]

$$\%C=0.97C+0.7(VM-0.1A)-M(0.6-0.01M)$$
$$\%H=0.036C+0.086(VM-0.1xA)-0.0035M^2(1-0.02M)$$
$$\%N_2=2.10-0.020\,VM$$

where
C= % of fixed carbon, A= % of ash, VM = % of volatile matter, M= % of moisture

2.3 Preparation of liquid charcoal

The two main stages for producing the liquid charcoal are by grinding and by emulsification. The dry charcoal was manually crushed using a pestle and mortar and pulverized into fine powder using a grinding machine. The ground charcoal was screened through 250 micron sieve. The undersize charcoal was collected and emulsified. In the emulsification process, a measured quantity of distilled water was put into a 250 ml volume beaker followed by addition of a quantity of an anionic liquid soap (Afresh Liquid Soap, CCL, Nigeria) which was a surfactant. The water and liquid soap mixture were put in a 500 mL plastic jar of a blender and agitated for 2 minutes. The charcoal powder was added to the distilled water-surfactant mixture. The resultant mixture was vigorously stirred at an average speed of 1200 rpm for 15 minutes using the Qlink blender (Model No. QBL-15L40, Turinar Corp., China), to ensure the homogenization of the slurries. The solid (charcoal) /liquid ratios were varied for different slurries prepared. Charcoal slurries with solid concentrations of 30%, 40% and 50% were prepared. The total volume of the charcoal-water slurry in the jar was kept constant at 250mL in all the experiments to standardize the mixing. The amount of liquid soap was kept constant at 1% on the basis of the weight of charcoal. At the end of the mixing, the measurements were taken.

2.3.1 Density

The density was measured with a density bottle at room temperature of 27^0C. The density of the slurry was calculated from the simple relationship between the measured volumes of the fluid and the mass of the fluid, Density = mass/volume.

2.3.2 Viscosity

This was investigated by using Oswald portable capillary viscometer. This investigation was conducted at room temperature (31ºC) by noting the time required for the slurry to pass between two marks. The time taken to move from the first mark through the tube to the next mark was noted. This was compared to the time taken for water to move through the same distance in the orifice. The figures were used to calculate the viscosity according to the formula:

$$\frac{\text{Viscosity of water}}{\text{Time of flow water}} = \frac{\text{Viscosity of the Slurry}}{\text{Time of flow of the slurry}}$$

The rheological behavior was investigated with a rotational viscometer which measured the viscosity of the slurry. The viscosities were measured using a NDJ–5s Digital Viscometer (SearchTech Instruments, England). The viscosities of the different solid content slurries were measured at rotational speed of 6 rpm, 12 rpm, 30 rpm and 60 rpm at room temperature (27°C) to understand whether the mixtures were Newtonian or Non-newtonian; shear-thinning or shear-thickening. These were done with appropriate spindles. Also, at constant shear rate of 30 rpm, the viscosities of the different solid content slurries were measured and results were taken at 30 seconds intervals. These data showed the character of fluid. Another experiment was conducted measuring the viscosities of the 40% charcoal concentration slurry as the temperature was varied and the viscometer was in a circulating water bath using Spindle No. 2 at 30 rpm.

The stability characteristic of the charcoal slurries was determined by a sedimentation test. In this test, charcoal slurry of 30%, 40% and 50% solid concentrations were separately poured into a different 50-ml graduated cylinder and allowed to settle under gravity after agitation. The height of the supernatant liquid and the stability of the slurry were determined over a period of 30 days.

2.3.3 Flash point

The flash point is used to assess the overall flammability hazard of a material. This was measured with Pensky Martens semi-automatic multi flash closed cup flash point tester (Made in Japan).

2.3.4 Boiling point

Boiling point was determined with 0-350ºC thermometer.

3. Results and discussion

The values presented are averages of several readings per sample and of triplicate samples.

3.1 Proximate Analysis of charcoal

Table 1 shows the results of the proximate analyses for the charcoal.

Table 1. Proximate analysis of the charcoal sample

Parameter	%
Moisture content	16.0
Ash content	5.0
Volatile matter	14.0
Fixed carbon	65.0

This charcoal sample is a fuel as it has high carbon content. The main element in any fuel is carbon. In the complete combustion of fuel, carbon reacts with oxygen to produce carbon (IV) oxide and water, while giving out large amount of heat. With insufficient oxygen, carbon (II) oxide and water are produced while heat is also produced. Typical combustion equations are given below [10]:

$C + O_2 \rightarrow CO_2$ + 8084 kCals/kg of Carbon

$2C + O_2 \rightarrow 2\,CO$ + 2430 kCals/kg of Carbon

$2H_2 + O_2 \rightarrow 2H_2O$ + 28,922 kCals/kg of Hydrogen

Coal of 6.85 % ash content is considered suitable for coal-liquid mixture that can be used for boilers [11]. It follows that the 5% ash content may be appropriate for charcoal slurry fuel. The ash value is related to the inorganic material in the fuel oil. The fixed carbon content at 65% is an indication of high calorific value for the charcoal slurry fuel. The moisture will reduce the calorific value of the slurry [12].

3.2 Ultimate analysis of the charcoal

The ultimate analysis indicates the various elemental chemical constituents such as Carbon, Hydrogen, Oxygen, Sulphur, etc. Table 2 gives the result of the ultimate analysis which was calculated from the relationship between proximate analysis and ultimate analysis.

Table 2. Ultimate analysis of the charcoal sample

Parameter	%
Carbon	65.45
Hydrogen	2.89
Nitrogen	1.82

3.3 Slurry fuel properties

The properties of the charcoal slurries and its comparison to some similar fuels are given in Table 3.

Table 3. Comparative properties of charcoal Slurry and diesel fuel

Properties	Charcoal-water fuel	Conventional Diesel Oil	No. 2 Diesel [13]
Density (g/cm^3)	1.01-1.08	0.840 [8]	0.67-0.74
Kinematic Viscosity (cSt)	1.25	8.31 cSt	2.6-4.1
Flash Point (^{0}C)	No flash	52-96	74
Boiling Point (^{0}C)	80-90^{0}C	150 - 343	188-343
Stability	varies	-	-

The densities of the slurries vary depending on the solid content of the slurries. It was 1.01 for the 30% solid content and 1.08 for the 40% solid content slurry. The density increased as the concentration of coal in the slurries increased. Compared to the commercial diesel oil (0.952 g/cm^3) and from the specification for typical No. 2 diesel oil, the density of the charcoal slurry is higher and the implication is that higher density results in the delivery of a slightly greater mass of fuel, hence more power [13]. The knowledge of density is useful for quantity calculations and assessing ignition quality. The unit of density is g/cm^3.

Viscosity is a measure of fluid’s resistance to flow. Fuel viscosity has influence on fuel droplet size and spray characteristics. The viscosity of the slurries which was measured in centistokes (cSt).The viscosity of the charcoal slurry was 1.25cSt. This is close to the viscosity of a typical No.2 Diesel. The implication is that it might be possible to obtain charcoal slurry that may be within the range for No.2 diesel oil.

The flash point is used to assess the overall flammability hazard of a fuel. It also gives indication of how easy a chemical may burn. The charcoal slurry did not flash. This could be as a result of the water in the slurry.

The boiling point of the charcoal slurry was between 80ºC and 90ºC. This was not within the boiling point of certified diesel oils.

The charcoal slurry of 30% solid concentration has remained stable at room temperature (about 30ºC) with no deterioration and remixes easily for the past 60 days since the slurry was prepared. The slurry with 40% solid concentration was stable at room temperature (about 30ºC) for 4 days and then caked. The slurry with 50% solid concentration was stable at room temperature (about 30ºC) for a day and then caked. Visual observation indicated that no sediment or supernant liquid on the slurries after shaking and allowing it to settle under gravity for the period Important slurry characteristics are stability, pumping, atomizability and combustion characteristics.

Viscosity is the most important rheological characteristics of slurry fuels [14]. Viscosity specification is related to atomization of the fuel, pumpability and storage. The viscosity was examined as a function of shear rate, time and temperature, respectively. The rheological characteristics of the slurries were determined from the view of whether they were Newtonian or non-Newtonian fluid.

Figure 1 which was a plot of viscosity vs. shear rate confirmed the character of fluid at 30% charcoal concentrations as non-Newtonian. The viscosity of the fluids changed as the shear rate was varied. This is a characteristic of shear-thinning suspensions, i.e., the viscosity decreases moderately with increasing shear rates The slurries with 40% and 50% solid concentrations exhibited non-newtonian behavior at below 12rpm shear rate but Newtonian at above 12rpm shear rate. This behavior may be attributed to the higher particle interactions at low shear rates. It is possible that higher shear rates will break the interactions and closeness thereby reducing the viscosity [2].

Figure 2 shows that shear stress increased with shear rate at 30%wt charcoal up to shear rate of 10 rpm. The shear stress increased shear rate after 10 rpm. This behavior could be like a Bingham fluid. The slurry characteristics changed with solid concentration and shear rate.

Figure 3 which was a plot of viscosity with time at constant shear rate of 30 rpm, the slurries exhibited a thixotropic behavior with 40%wt at below 270s when the fluid exhibited rheopectic behavior. This rheopetic behavior was also exhibited at 210s.

Figure 4 is the viscosity-temperature relationship for 40% w/w charcoal-water slurry. In this figure, the viscosity of the fluid decreased as temperature increased. It follows therefore that the viscosity can be regulated by controlling the temperature.

Figure 5 gives the result of the relationship between viscosity and density for the charcoal slurry. The density increased as the concentration of charcoal in the slurries increased. Similarly, the viscosities increased with increase in density for room temperature measurements conducted at 30 RPM. The correlation between viscosity and density is: Density= 0.012 * viscosity +0.166 with coefficient of regression value of 100, based on the 30% and 40% solid concentration slurry. No result was obtained for the density at room temperature for the 50% solid concentration charcoal slurry. There is therefore high regression between viscosity and density for charcoal slurries.

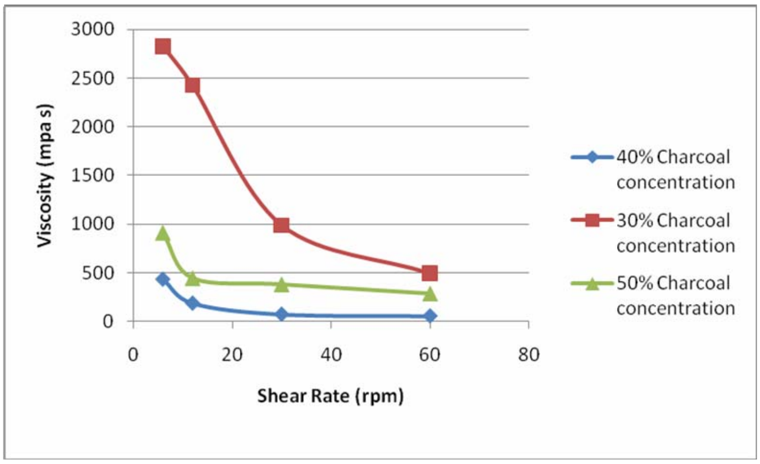

Figure 1. Viscosity as a function of shear rate for charcoal slurries at room temperature (27 ºC)

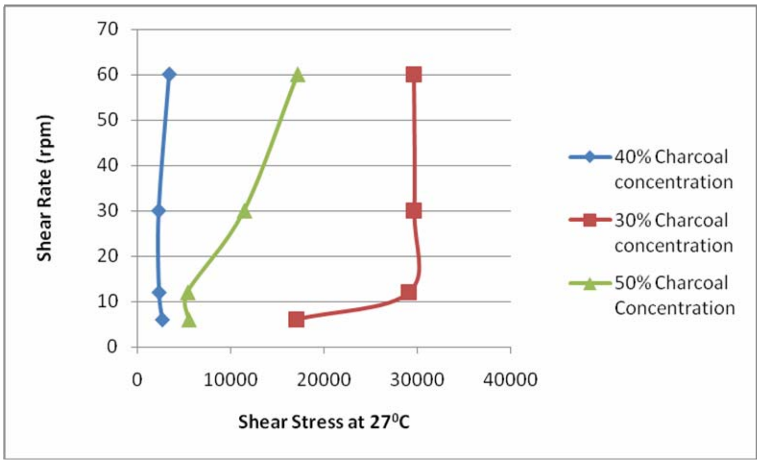

Figure 2. Shear stress vs shear rate

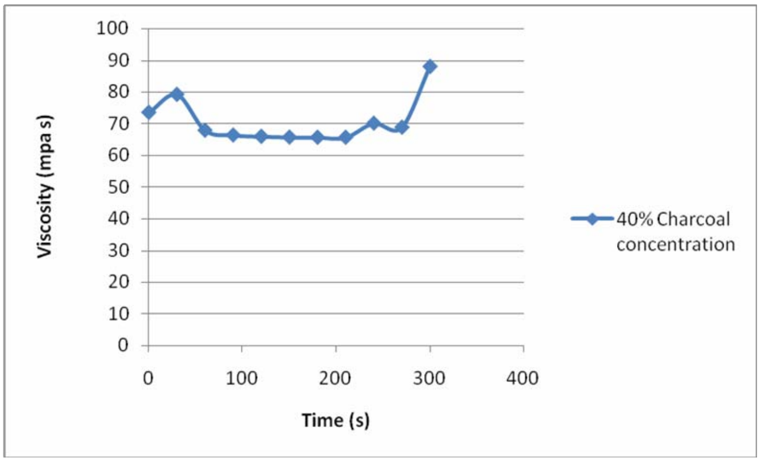

Figure 3. Plot of viscosity vs time at 30 rpm

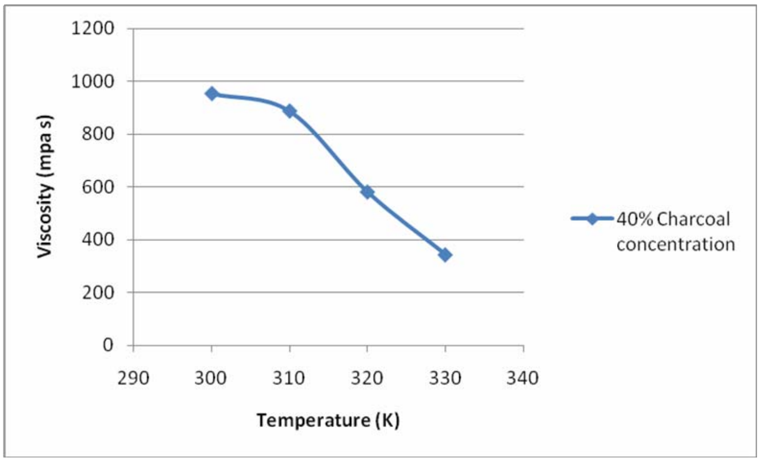

Figure 4. Viscosity temperature relationship for charcoal-water slurry (40% w/w)

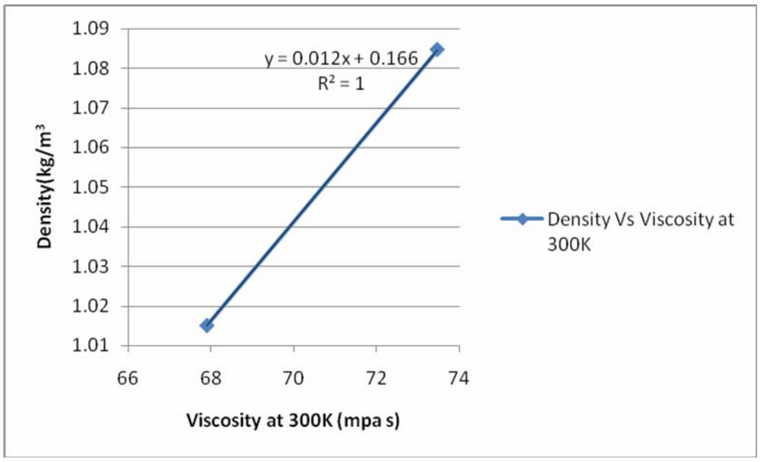

Figure 5. Correlation between density and viscosity

4. Conclusion

Charcoal slurries were prepared from the hydration of charcoal. A surfactant was used as an additive to stabilize the colloidal suspension. The properties of the slurries were evaluated and compared to those of conventional diesel oils. The results indicated that the density and the viscosity of the charcoal slurries were comparable to those of the diesel oils. The charcoal slurries exhibited different flow characteristics depending on the solid concentrations of the slurries. The viscosities decreased with increase in temperature. The slurries were relatively stable with no visible sediments over a 30-day period for slurries with less than 40% solid concentrations. These findings on the flow characteristics and stability of the charcoal slurries prepared provided vital information that would be useful for designing of appropriate system for the utilization of the slurry in diesel engines and its storage. The use of a surfactant may have aided the relative stability of the slurries.

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