Improvements in the Rheological Characteristics of the Complex Coal-Water Suspension Using Gasification Derived Waste Water

Harmanpreet Singh*1, Satish Kumar1, Saroj Kumar Mohapatra1
1Mechanical Engineering Department, Thapar Institute of Engineering and Technology, Patiala -147004, India
*harmanpreetsingh@thapar.edu

Abstract:
The area of application of coal as a source of energy is expanding to sophisticated devices such as internal combustion engines, liquid fuel-based furnaces, gasification, pyrolysis, etc. The coal reserves in the developing countries are mainly young and of low rank, which have poor slurrying and rheological characteristics. The present research presents a novel methodology to improve the slurrying and rheological characteristics of the coal water suspension using the gasification derived waste water. The gas produced by a gasifier contains a lot of tars, which are washed down along with the sprayed water; this water is known as gasification derived waste water. In the present case, the waste water is collected from the gas cleaning unit of a 10 kg/h downdraft biomass gasifier. This waste water contains some amount of dissolved tars. When this water is used for the preparation of the coal water suspension, an improvement in the slurrying and rheological characteristics of the suspension is observed. The tars are observed to choke the pores on surface of the coal particles; this checks the flow of water into the pores. So, the maximum amount of water remains in the particle’s surroundings, thereby reducing the particle to particle interaction and hence the viscosity by ~41-55%. This study thus provides a base and a novel method to utilize the waste water, which otherwise is of no use and quite harmful.

Keywords: Coal water suspension; Settling characteristics; Rheological characteristics; Gasification waste water.

1. Introduction:

In the rapidly modernizing energy generation sector, the gasification of solids is proving to be very beneficial, due to its variety of applications. The process of gasification is a thermochemical conversion technique, in which the chemical energy of solid fuels is converted in chemical energy of gaseous fuels using a thermal process. [1,2] The gaseous fuel produced is known as producer gas and has a calorific value ranging from 4200-5300 kJ/Nm³. At the exit from the gasifier the producer gas is laden with tars and soot particles, which makes it difficult to be used. [3–5] So, a gas scrubber or cleaning plant is also mounted at its end to wash down the tars and soot particles. These plants are found to have ~99.9% cleaning efficiencies. The waste water, containing the tars is either recirculated (in small plants) or detoxified using a separate water treatment plant. [6]

The gasification of coal is carried out in an entrained flow gasifier, in which pressurized coal water slurry (CWS) is fed. [7,8] The pumping system used to transport this CWS is an important area of concern. The design of slurry transport system is strongly dependent on coal properties such as particle size and shape, particle size distribution, bulk density, rank of the coal reserve, chemical composition, and surface...
The Indian coal reserves are mostly young in nature i.e. of low rank. As a result, the Indian coals possess high ash content. In the previous literature, it has been reported that the rheological characteristics of the coal water slurry are strongly related to the rank and surface properties such as hydrophobicity of the coal. The high rank coals are observed to possess high hydrophobicity index and good slurryability whereas the low rank coals show poor slurryability. This leads to a significant loss during the transportation of the low rank coal.

The previous studies have reported that the rheological characteristics of the low rank CWS can be improved using different natural and chemical additives. These additives improve the surface properties of the coal particles, which result in the improvement of rheological characteristics of the slurry.

The present study is based on the utilization of a gasification waste i.e. waste water for the production of coal water slurry. The goal of the present study is to generate a significant amount of data related to the physical, chemical and rheological characteristics of the coal waste water slurry (CWWS), which will be helpful for future implementation in coal gasification and combustion plants. This rheological data can be used to predict the flow characteristics of CWWS using previously established correlations and CFD modelling approach. This study a novel solution to effectively use the gasification waste, without any water treatment plant.

2. Materials and methods

The high ash Indian coal collected from the Makum Coal Fields of Assam is crushed in a lab scale ball mill and sieved through a 140-mesh sieve to remove particles of 106 µm size. Malvern 3601 particle size analyser is used to study the particle size distribution of the coal particles.

2.1 Chemical characterization of Coal and Waste water

The chemical characterisation of the coal is carried out using the standard procedures. The proximate analysis is done using ASTM D3173 Standard and the ultimate analysis is done using ASTM D5373 standard.

The FTIR spectra are analysed using Agilent Cary 6000 series of FTIR spectroscope. The sample in the form of a cylindrical pellet is analysed at ATR (Attenuated total reflectance) mode for wavenumbers 4000 cm⁻¹ to 400 cm⁻¹. The spectra are initially recorded as percent transmittance. These spectra are then converted to logarithmic absorbance spectra, which is helpful in highlighting the minor changes in the spectra, which are otherwise missing in the transmittance spectra.

The chemical characterization parameters are measured as per the standard procedures. These parameters include pH, TDS and COD, which are tested using bench scale instruments.

2.2 Suspension stability characterization

The suspension stability is investigated by means of gravitational settling method and zeta potential. The initial solid concentration by mass; CM of each sample is taken as 32, 41, 54%. The time required to reach the equilibrium settling condition is analysed for both the cases.

2.3 Rheological characterization:

The CWSs are prepared using tap water and the solid samples are added in 10, 20, 30, 40, 50 & 60% concentration by mass. The suspension components are stirred slowly for 15 minutes in order to avoid spillage and particle attrition. The rheological characteristics of the CWSs are investigated using RheolabQC rheometer. The bob and cup sensors are used for the present investigation. The average settling time for the CWS at 10% solid concentration is observed to be 6 hours 11 minutes, so there is no chance that the suspension will sediment in a small test time of 3 minutes. So, no correction factor is to be considered as there is no sedimentation or settling during the test.

The rheological characteristics are analyzed for a “pre-shear and linear shear ramp step wise mode”, in which corresponding to the varying value of the shear rate, the value of shear stress is analyzed. Each test is conducted for a total of 3 minutes, including a waiting time of 10 seconds. The shear rates are varied in the range of 11 to 500 s⁻¹. The rheological experiments are carried out at room temperature of 28°C.
3. Results

3.1 Particle size distribution and morphology:

The particle size distribution and the SEM micrographs of the coal sample used in the present investigation are presented in Figure 1 and Figure 2. Almost 50% particles are less than 53 µm. The SEM micrographs show the sample contains a balanced fraction of fines and coarse particles.

![Particle size distribution of coal sample](image1.png)

**Figure 1** The particle size distribution of coal sample

![SEM micrograph of the coal sample](image2.png)

**Figure 2** SEM micrograph of the coal sample

3.2 Proximate and Ultimate analysis:

Figure 3 represents the proximate and ultimate analysis of the coal sample used in the present analysis. The coal sample is observed to contain ~31% ash, which shows that the present coal sample is of low rank. The ultimate analysis shows that the coal sample contains 58.4% carbon by mass and contains a ~24.2% of oxygen, which is a high amount. The high oxygen content in coal lessens the hydrophobicity of the coal.
Figure 3 The proximate and ultimate analysis of the coal sample

3.3 FTIR spectroscopy:

The FTIR spectrum of the coal sample is presented in Figure 4. Some distinguishable peaks are observed at 1650 cm\(^{-1}\), 2700 cm\(^{-1}\), 2900 cm\(^{-1}\) and 3400 cm\(^{-1}\) in treated coals. The peak at 1650 cm\(^{-1}\) corresponds to carbonyl (C=O) group, at 2700 cm\(^{-1}\) corresponds to aliphatic groups (RH), at 2900 cm\(^{-1}\) corresponds to aromatic groups (Ar-H) and 3400 cm\(^{-1}\) corresponds to alcohol groups. The FTIR spectra show that the coal sample contains some alcohol groups. These alcohol groups are responsible for low hydrophobicity of the coal.

Figure 4 The FTIR spectrum of the coal sample

3.4 Chemical characteristics of waste water:

The pH of the waste water is found to be 5.7. It is observed that waste has quite low pH, indicating the acidic nature of the waste water. This is due to the presence of acidic groups, which are the derivatives of benzene and other aromatic compounds. The chemical oxygen demand (COD) in the present case is observed to be 2350 mg/L. The total dissolved solids (TDS) in the present case are 1925 mg/L. These comprise of the fine soot particles dissociated from the bio-char during gasification.

3.5 Settling characteristics:
The settling characteristics of coal water slurry prepared using clean and waste water are presented in Figure 5. The particle in the coal water slurry prepared using clean water settle in a shorter duration as compared to the coal water slurry prepared using waste water. In the case of CWS prepared using waste water, the dissolved tars show great interaction with the coal particles. The coal surface shows hydrophobic properties after being covered by tars. The repulsive forces between the coal particles and water get amplified in the with waste water. So, the particles remain suspended for a longer duration in the case of waste water slurry. On average, the settling time is improved by ~30%.

![Figure 5: Settling characteristics of coal water slurries](image)

3.3 Rheological characteristics:

The rheological characteristics of coal water slurries prepared using clean and waste water are presented in Figure 6. It is observed that the coal water slurry prepared using clean water has higher apparent viscosity as compared to the coal water slurry prepared using waste water. From the pH analysis of the gasification derived waste water, it is observed the waste water contains some acidic groups, which are mostly benzene derivatives. The source of these acidic groups are the tars, which are washed down from the producer gas. In the case of CWS prepared from clean water, the coal is less hydrophobic, as a result some of the water penetrates into the particle and lesser water is available around the particle, which results into higher apparent viscosity. When the coal water slurry is prepared using the waste water, the ions present in the waste water show greater interaction with the coal surface. These ions thus cover the coal surface, as a result the hydrophobicity of the coal shows an improvement. Thus, the water is unable to penetrate into the coal particle and remains in the particle surroundings. This reduces the particle to particle contact during the flow, which is reflected in the form of reduced viscosity. The apparent viscosity is observed to decrease by 41-55% at different solid concentrations.
4. Conclusion

The present study is based on the use of gasification derived waste water for the preparation of coal water slurry fuel. This study shows that the gasification waste water has proved to be an attractive medium (fluid) for the preparation of the CWS. The CWS prepared from the waste water is found to be much better as compared to the clean water coal slurry. From the analysed results, the following conclusions are drawn:

- The gasification derived waste water is observed to improve surface properties of the coal particles.
- The particles are observed to remain suspended in the carrier medium for ~30% more time.
- The coal waste water slurry shows improved rheological characteristics.
- The apparent viscosity of the slurry is found to decrease by 41-55%, when waste water is used to prepare the CWS.

The present research is successfully able to upgrade the physical, chemical and rheological characteristics of the coal water slurry. This upgraded slurry can significantly reduce the transmission losses during its transportation. Also the cost of waste water treatment plant can be eliminated.

5. References

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