

INVESTIGATION OF FLOW CHARACTERISTICS FOR COAL CHARCOAL SLURRY FUEL

A Dissertation

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Master of Engineering

In

Thermal Engineering

Submitted by

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CERTIFICATE

I, Anil Kumar Singh hereby declare that this thesis entitled "Investigation of Flow Characteristics for Coal Charcoal Slurry Fuel" is an authentic record of my work carried out for the award of the degree of Master of Engineering in Thermal Engineering submitted to the Mechanical Engineering Department, T.I.E.T, Patiala, Punjab under the supervision of Dr. Satish Kumar, Associate Professor in MED NIT, Jamshedpur and Dr. S. K. Mohapatra, Senior Professor in MED T.I.E.T., Patiala.

The matter presented in this report has not been submitted anywhere for the award of any other degree by this or any other University/Institute, to the best of my knowledge.

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(Anil Kumar Singh)

ABSTRACT

The rheological characteristics of uni-modal and multivariate coal-charcoal water slurry have been studied. The study aimed to investigate the physical, chemical and morphological characteristics of coal and charcoal particles. Present study also includes the experimental investigation of flow characteristics of coal charcoal slurry. The physical, chemical and mineralogical properties such as chemical composition, particle size distribution (PSD), shape, static settled concentration, HGI, proximate analysis, ultimate analysis, calorific value and pH of slurry were carried out prior to examination of rheological characteristics of coal charcoal water slurry. The surface microstructure was investigated by using scanning electron microscopy (SEM) technique. The chemical composition was determined by using electron dispersive spectroscopy (EDS) technique. Particle size distribution of coal and charcoal particles was carried out by using British standard sieves. The simulations were carried out by digital interpretations by reading the pixel and grey value information present in a particular SEM micrograph. The coal and charcoal particles were found irregular in shape and charcoal was more porous. The pH value of coal water slurries was lie in the range of 5.94 to 6.22 ,8.48 to 8.7 for charcoal water and for 6.25 to 7.2 coal charcoal water slurry. If fine charcoal particle below 53 μm is added to coal water slurry static stability was enhanced by 12%. Three Indian coal samples were procured from different thermal plants and charcoal. They were designated as C1, C2, C3 and C4 and were investigated by using Anton Paar RheolabQC rheometer to generate extensive rheological data. From rheology studies it was found that the all type of coal-water slurry shows Newtonian behaviour upto 30% solid loading and at 40% solid loading coal-water slurry shows pseudo-plastic i.e. (shear thinning) behaviour. Beyond 40% of solid loading coal-water slurry shows Herschel-Bulkley behaviour while at 30% of charcoal loading rheological behaviour was pseudo-plastic in nature and beyond 30% of charcoal loading flow behaviour was Herschel-Bulkley. At 60% of charcoal loading in charcoal water slurry the apparent viscosity is crossed the limiting value of apparent viscosity. Mono-modal of charcoal water slurry has less apparent viscosity as comparison with bi-modal of charcoal water slurry. In coal-charcoal water slurry apparent viscosity value increase as the charcoal % increases in slurry with comparison of coal water slurry while charcoal fine particles are added upto 20% by weight of total solid loading the apparent viscosity is lower with comparison of coal water slurry for 40% and 50% of total solid loading. Further, increases in charcoal percentage apparent viscosity

increases. The coal-charcoal slurry shows lower viscosity for all test at various dosages of additives and at 2% by weight addition of Triton X-100 in slurry maximum rate of reduction of apparent viscosity in the slurry for both the cases. Average reduction in apparent viscosity of slurry in which coal and charcoal was blended in equal ratio was 16 % and when ratio of coal and charcoal was 60:40 reductions in apparent viscosity was 19%.

Keywords: Additive, particle size distribution, rheology, static settling.

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NOMENCLATURES

G	Hardgrove grind-ability index
W	Mass of coal in grams
C_w	Concentration
$F(d)$	Mass distribution function
d	Particle diameter
d_{\max}	Size modulus
M	Distribution modulus
I	Mean particle size (d_{50})
V_s	Void fraction
ε	Volume of the slurry
CO_2	Carbon dioxide
H_2O	Water
CO	Carbon monoxide
H_2	Hydrogen
N_2	Nitrogen
O_2	Oxygen
τ	Shear stress
η	Viscosity
γ	Shear strain
v	Velocity
τ	Yield stress
λ	Bed density
Φ	Volume of fraction of coal
Φ_m	Maximum attainable solids volume fraction

ACRONYMS

CWSFs	Coal Water Slurry Fuels
CChSF	Coal charcoal slurry Fuels
SEM	Scanning Electron Microscopy
EDS	Energy Dispersive Spectroscopy
PSDs	Particle Size Distributions
RR	Rosin-Rammler

CHAPTER 1

INTRODUCTION

In 20th century, scientists, engineers and researchers worked extensively on various process of burning of coal in efficient manner. Finally, they reached on pulverisation process in which coal burn like gaseous fuel and its ignition and controlling is quite easy. By this coal has been transformed into extremely fine particles so its burning and energy generation by it has become easy, efficient and finally make profitable (Singer 1981). To utilised pulverised coal alternatively is to form a slurry fuel and use the coal slurry fuel in the furnace directly for combustion.

The slurry fuel contains suspension of pulverised coal particle into one or more to carrier fluids as oil, methanol or water. Advantage of doing such fuel is they possess high energy density (Choudhury 1992) and they can be used as liquefied fuel very similar to heavy fuel oil. Coal slurry fuels can be an effective option or substitute for oil in IC engines, steam production and incinerator units.

Coal slurry fuels had been analysed, studied deeply since 20th century but unfortunately, economics constraints obstructed it to become major attractive source of energy during that time. That time researchers emphasised greatly on coal oil slurry fuels because they were seeing if as replacement or alternative fuel or steam oil in steam production. However, these days, researchers have been concentration more on CWFSs as a complete replacement of oil in steam production. Utilising incinerators, diesel engines, process ovens and blast furnaces (Lee 2005). But coal is a non-renewable resource and neither uniformly distributed throughout the world and besides that the coal quality is not equal across the world, these qualities depend on so many factors. So to fulfil the requirement of energy some countries have to import it from other countries. Moreover, due to extra exploitation of the coal from long time some countries are about to finish their coal resources. As the coal is non-renewable form of energy. So day by day the cost of coal is increasing. Along with that some serious issues are related to the coal, like emission and ash handling especially in those countries where coal having more ash content by weight. So to solve such problems the science of coal slurry moved to another type of slurry where they started to work with charcoal slurry. Up to some extent this slurry has given a good performance for particular type of application like in iron making furnace in Brazil. Alone charcoal has great potential in small scale and medium scale but in large scale application, it has problems of net heating value and availability of charcoal at affordable cost.

To take the advantages of the coal and charcoal people worked on the combination of coal and charcoal slurry. Presence of coal in slurry increases the heating value and solid content in slurry and also decreases the value of viscosity of slurry. It also reduces the dependence on coal and enhancement in emission after the burning such fuel. Moreover, the charcoal is renewable form of energy.

But unfortunately in this field less work has been done. So by keeping above mentioned possibility in mind this project has been selected. Some work has been done in Brazil, France, US and Japan. But in India such type of work is not done till now. The type of coal available in India and availability of charcoal. This work has a great potential. We will try to find and analyse the flow behaviour of coal-charcoal slurry fuel as an alternative fuel source.

1.1. SLURRY FUEL

The formulations of pulverized coal slurries fuel (mineral coal or charcoal) in one or more carrier liquids, fuel or not (fuel-oil, water, alcohol, etc.), that give a stable liquid fuel. When a CWSF is combusted, after a combustion of 99% of its carbon content. CChSF is fire proof and explosion proof. CChSFs generally have higher solid (coal-charcoal) concentration by weight, forming it more energy compact.

However, the physical properties of CChSFs play a vital role in the preparation of the fuel. CChSF ought to be steady and possess less viscid in the deformation rates of atomization and pumping. The flow nature of CChSF is the function of the following factors:

- Chemical and physical possessions of coal and charcoal.
- The volume fraction (Φ) of the suspended coal charcoal particles.
- Particle size distribution (PSDs) of coal and charcoal.
- Inter-particle relations (pretentious by the nature of pH, electrolytes, surface groups, and chemical additives).
- Temperature of the slurry.

Slurry capability or slurriability is a measure of how well and easily a coal forms slurry. It can also be defined as the concentration of coal in water which at a given shear rate and gives a specific viscosity. It also measures the equilibrium moisture content of coal in the suspension. It indicates the maximum amount of coal that can be slurried viscosity of 1000cP, measured after 50s of shear at a deformation rate of 100s⁻¹ (Kissa 1999). It is the measure of hydrophilic nature of coal. A highly concentrated slurry (Kawatra et al. 2002) cannot be formed by hydrophilic coal because it will hold more water. Again, the viscosity of CWSFs is directly

proportional to hydrophilicity of coal. Hence, for preparation of coal slurry with less viscosity and more solid loadings, hydrophobicity of coal should be optimum. Higher grade coals, except Anthracite, exhibit hydrophobic tendency as they are less inclined toward acid groups and can form slurry up to 80% by wt. of solid concentration. Anthracite coal shows poor ignition characteristics (Kesavan 1985) because it is less volatile and less reactive. It is required, higher coal content in the CWSFs for better fuel efficiency and better ignition. But, as the solid loading percentage increases the viscosity value of slurry also increases and hence at higher loading coal crosses its maximum limit of viscosity. The viscosity of CWSFs depends on volume fraction (Φ/Φ_m), where Φ is the volume of fraction of coal, and Φ_m is the maximum attainable solids volume fraction. If it is increased, the solid loadings can be increased and viscosity can be decreased. With the help of polydisperse mixture of coal particles and optimizing particle size distribution. we can increase the volume fraction. Nature of electrolytes, type of coal, temperature, composition of the liquid phase, and dispersants and stabilizers (Kissa 1999) are the major factor which govern the viscosity of slurry. the ionic strength of water in the fuel is another important parameter. In a hydrophobic colloidal composition like CWSFs, suspended by electrically repulsive forces among particle, the quantity and quality of water and its ionic strength has a large effect on the stability against of coal particles mass. The rheology of CWSFs by using an anionic dispersant is governed by rate of particle dispersion which largely depends on viscosity of CWFS with low pH i.e. water which ultimately depends on amount of cation present in it. (Williams 1992).

Our primary requirement is to have minimal settling of coal particles in concentrated CWFSs. But, due to additives to cause low viscosity enhances the settling rate of coal particle. (Zakin et al. 2005). Commercially existing charcoal to be dispersed in carrier liquid was assessed by analyzing the rheological characteristics of the prepared charcoal water slurries (ChWS). The charcoal was pulverized in a ball mill and dispersed in liquid with the six different type of surfactants. A ChWS having composition of 60% of charcoal by weight, a viscosity was about to 1 Pa s and adding 1 wt.% of Zephrym 4974, an additive containing neither Sulphur nor nitrogen in its chain. The ChWS is highly stable and hence shows all the compulsory characteristics required to form a liquid charcoal. (Loureiro.2017).

A charcoal slurry fuel for a direct injection diesel engine was prepared and examined the performance. Prepared slurry showed non-Newtonian. The composition of produced of slurry below i.e. 25% charcoal and 1% of surfactants has 27 CP. A Mie scattering laser arrangement exhibited the SMD for diesel fuel was 25 micrometre. The pressure of top combustion at 1200 rpm and at 100% load (7.8 BMEP) was 79 bar for the diesel and for the charcoal slurry was 78

bar. 1.7 ms the ignition delay for diesel and for the charcoal slurry it increased to 2.1 ms. Increment in ignition delay due to the higher SMD of the charcoal slurry fuel. The highest combustion temperature was 2300 K for diesel and for charcoal slurry it was 2330 K i.e. 30 k more for slurry. Because of extra fuel uses, the NO_x emissions and exhaust temperatures were 30% more for charcoal slurry at any load condition compared to diesel fuel (Valentin and Soloiu. 2011).

1.2. BENEFITS OF COAL-CHARCOAL SLURRY FUEL

The various benefits of using the coal charcoal slurry fuel are mentioned below:

- Cost saving fuel compared to gas or oil fuels.
- Eco-friendly and low emission fuel as combustion here takes place at 100 -200°C lower than oil or gaseous fuels which reduces emission NO_x and SO_x.
- Transportation and storing is quite easy for this as it can be pumped and transported easily through pipe, wages, tank and carrier vehicle etc.
- Easily adoptable to pre-existing oil or gas fired system without much modification. Load adjusting range is also not very complex here.
- CChSF is fire proof. It does not cause that much dust pollution. It does not require much land or storage place to keep like coal yard and slag yard.
- Ash can be further used for making cement and brick etc.
- Gas or liquid fuel can be used parallel to it for preheating and also during the peak load condition.

1.3 UTILITY OF COAL-CHARCOAL SLURRY FUEL

The various utility of using the coal charcoal slurry fuel are mentioned below:

- For localized area or district level thermal energy generation or for heating purpose usually more than 1KW boiler is required and also in various type of industries like textile, sugar, cement, petrochemical refineries and pharmaceutical etc.
- As substitute of over expensive fuel like gas, oil or burned oil.
- Some pyrolysis units produce carbon wastage that can be used along with this slurry.
- Low cost coal wastage and charcoal can be used as an addition fuel heating or steam generation. Ultimately, it lowers the cost of energy.
- It also reduces SO_x and NO_x emission.
- It can also use in region where egress and access gas pipeline is not easy.

- Reduce the dependency of coal where coal is not available in ample amount, quality of coal is not good and may be the cost of coal is high.

1.4 RHEOLOGY AND ITS SIGNIFICANCE

Rheology is described as the study of motion or movement of matter, especially in liquid state, or soft solids i.e. solids that undergoes plastic flow in answer to a realistic force in lieu of being deformed elastically under certain conditions (Morrison 2001). We can say, it shows the deformation or disorder of bodies under the stresses developed on them. The term was coined by the saying of Simplicius (often recognized to Heraclitus), *panta rhei*, "everything flows" (Beris et al. 2014), and was first time used to explain the deformation of soft solids and the flow behavior of liquids.

Flow is a continuous irreversible deformation intercepted by internal and external friction possessed by the flowing substance. The internal resistance acted is known as viscosity, symbolled by η . Viscosity (internal friction) denotes as the deaccelerating action of a static fluid layer on a parallel moving fluid layers. When shear stress (force per unit area; τ), is applied to the fluid layers, each layer would move with a certain velocity depending upon the distance from the plane of applied force. Shear strain (γ) is defined as the velocity gradient perpendicular to the plane of applied stress. As par Newton's law of viscosity (Kissa 1999),

$$\Gamma = \eta \frac{dv}{dx} = \eta\gamma \quad (1.1)$$

The fluids following to Newton's law are called Newtonian fluids, where η is constant. However, for non-Newtonian fluids, the viscosities also depend on shear stress and shear rate, and hence is not a fixed value. The one-point measurement of their viscosity will give the value of apparent viscosity at a specific shear rate.

Rheology simply tells about the trend of non-Newtonian fluids by finding the minimal expanse of functions required to develop an association amid deformation rate and shear stress. A plot between deformation rate and shear stress is a straight line with slope which is the viscosity in case of Newtonian fluids. For non-Newtonian fluids, the shape of the curve projects the category and behavior of the flow. The main classifications are Power-Law, Herschel-Bulkley, Bingham, and Casson. The constitutive model equations for selected non-Newtonian fluids are stated in are mentioned in Table1.1.

Table 1.1 Constitutive relationship for non-Newtonian fluid models (Yong-Gang et al. 2009)

Type of Fluids	Constitutive equation	No. of parameters relating shear stress and shear rate
Power-Law	$\tau = K \gamma^n$	Two parameter
Bingham	$\tau = \tau_y + \mu_p \gamma$	Two parameter
Herschel-Bulkley	$\tau = \tau_y + K \gamma^n$	Three parameter
Casson	$T_{1/2} = \tau_{1/2} + (\mu \gamma)_{1/2}$	Two parameter

Figure 1.1 represents a graphical representation of the shear stress vs shear rate behavior plotted as a rheogram for a number of different continuum fluid models.

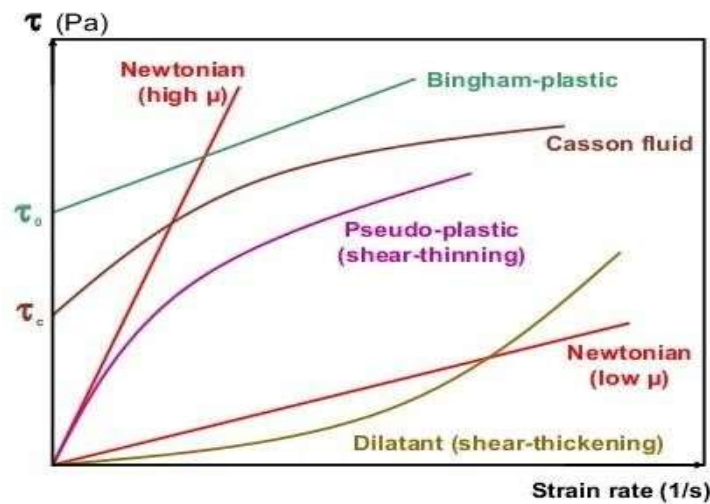


Figure 1.1: Rheogram of different fluid models (Yong-Gang et al. 2009)

1.5 IMPORTANCE OF COAL CHARCOAL SLURRY FUEL RHEOLOGY

The following points illustrate the importance and application of the rheology of CWSFs:

- Rheology controls the quality of coal and charcoal by evaluating their rheological or flow nature. The coal and charcoal material is to be accepted or rejected is estimated based on the rheological results.
- Rheology helps in determination of the mixability and pumpability of CChSFs and also helps in the designing of CChSF transportation systems.
- Rheology also helps for analysis of the frictional pressure head drop when CChSF flows through pipes and pump.
- Rheology tells the capability of slurry fuel to transport large particles. It also considers the surrounding temperature profile affecting the flow nature of CChSF.
- Rheological data helps for determining a relationship between the pump and flow in

pipelines. It also helps in selecting a particular pump that would be required to supply appropriate power for CChSFs to flow over the required distance.

1.6 COMPARISON BETWEEN CHARCOAL AND MINERAL COAL

As literature survey we come to conclusion that mineral coal slurry has not made its market which could be thought. Then we should assess the use and advantages of charcoal. Mixtures got by biomass does not contain any wood as swelling limit. Therefore, wood charcoal should be used.

1.6.1 MERITS OF CHARCOAL

- Cost of conversion into slurry from charcoal is reduced due to lower ash content and friability. High friability leads to less grinding cost.
- Ash content in charcoal here is between 2.4 to 3.3% where as in coal greater than 10 %.
- Low sulphur content.
- Ash of charcoal does not show clinker properties which is good for burner.
- Because of high volatile matter present in charcoal its burning efficiency increases.

1.6.2 DEMERITS OF CHARCOAL

- Dispersion of biomass needs more area so its cost is increased to store.
- Charcoal energy production is reduced here half times. Because we got only 50% by weight of charcoal from wood and charcoal has also high affinity for humidity.

1.7 INTERNATIONAL STATUS ON SLURRY FUELS

CWSFs initially developed in Russia about 80 years ago, and the fuel was later used in 1950 in Europe. That time, oil prices were less due to presence of enormous oil assets, that restricted the expansion, study and the usage of the CWSFs technology. CWSFs again came into figure the 1970s, after the worldwide prices of oil increased drastically and the oil resource became rare and were diminishing fast. (Everett 1988).

Again in 1992, the US Army was asked to lessen the expenditure or consumption of crude (oil) fuel. The US Army then looked toward using CWSFs as a replacement or alternative fuel to for steam generators (Hamich et al. 1993). later, GPU Energy (PENELEC), Pennsylvania Electric Energy Development Authority (PEEDA), Pennsylvania Electric Energy Research

Council (PEERC) New York State Electric and Gas Corporation (NYSEG) and Electric Power Research Institute (EPRI) introduced activities for assessment of the consumption of CWSFs made of coal fines. They checked on large scale and laboratory-scale firing minutely of a 32 MW steam generator (Zang et al. 1993).

During 2000's China is also concerned because of environmental challenges of Beijing Olympics. So CWSFs technology in China advanced and flourished extensively. It attained the global level footage & soonly it was seen as an efficient alternative to heavy crude oil in industry and steam generator also due to japan because it had limited natural resources so they were seeking toward some substitute.

In 2014, Electricity Generating Authority of Thailand (EGAT) assessed the feasibility of retrofit the 300 MW oil fired power plant at Krabi to utilize CWSFs. The 300MW oil fired power plant at Krabi Province was a stand by unit and it was considered that the plant would be transformed to a mid-merit by utilizing CWSFs. It was also considered of CWSFs that it would enhance fuel diversity to the power producing plant that is currently utilizing approximately 70% of the natural gas. The superimposed practicability experiments of EGAT and Zhejiang University of China to use CWSFs as a substitute to the heavy oil might turn out to be an important phase for energy extension for Thailand (Daniel et al. 2014).

CHAPTER 2

LITERATURE REVIEW

A lot of research work has been completed in order to find rheology characteristics of different types of slurries fuels by keeping different aspects. Through investigation it was found that rheology behavior of slurries fuels is depend on number of factors. By keeping economics constraint, an optimum value of viscosity has been found in a particular range of shear rate for transporting the slurries fuel.

Papachristodoulou G et al. (1984) - studied the rheology of coal-oil mixtures means slurry. The preparation of slurry is done using a bituminous coal in four distinct grades of oil. The rheological behaviour of slurry was found by varying coal concentration, PSD of coal, and temperature effects. The viscosity of the slurry was measured by Ferranti-Shirley cone and plate viscometer. They observed that the coal-oil mixtures showed Newtonian behaviour for coal loading up to 30 % by weight and above them showed Bingham plastic behaviour. Also, they reported that as the median particle size got higher and the slope of PSD of coal became lower, the yield stress and the viscosity and decreased.

Hasan et al. (1986) examined the rheological behaviour of coal water slurry fuel made from sub-bituminous coal. Rheological experiments were conducted by using Brookfield viscometer with particle size varying from 0.044 to 0.223 mm. They noticed that at all concentrations, the coal water slurry showed pseudo plastic behaviour. The obtained data was fitted to the Power law model and the related parameters were evaluated. They found that the coal water slurry (CWS) prepared by hot water drying had less viscosity value as compared to the slurry prepared from as received.

Logos and Nguyen (1996) –examined the effect of (PSD) on the flow behaviour of South Australian. The coal used for the preparation of CWS was a low rank Lochiel coal procured from South Australia. The PSD was varied by introducing coarser fraction of coal with the finer fraction in different ratio. The concentric cylinder viscometer (HAAKE, Model RVI00) was used for measurement of viscosity. The solid concentration was in the range of 23 % to 50 % by weight. They observed that the slurries made by only finer fraction i.e. under 45 μ m were more viscous than the CWS made by a mixture of coarse and fine particles with coarse particles varying from 208-279 μ m. They observed that CWS upto 23% (by weight) showed Newtonian afterwards slurry becomes pseudo-plastic or shear thinning. It was also observed that introduction of coarser coal fraction lowers the viscosity of the finer CWS.

Lorenzi et al (2002) -investigated the effects of PSD on the rheology behavior of CWSFs. A surfactant was used to increase the amount of solid in slurry fuel while preparation of slurry. Solid content is inversely proportional to the settling of particles in slurry. Which helps in storing the slurry fuel. Two types of slurries were prepared mono-modal and bi-modal respectively on the basis of PSD. Bi-modal slurry has minimum viscosity as comparison of mono-modal. In this paper, also mentioned that the ratio of fine particles to coarse particles is 55:45 for minimum viscosity. Due to use of surfactant, amount of coal loading is higher as comparison of without surfactant.

Senapati et al. (2002)-studied the flow characteristics of CWS. HAAKE RV300 viscometer was used to determine the viscosity of CWS. The main aim of this work is to find the effect of ash content, solid content, temperature and pH on the flow characteristics of coal water slurry. It was seen that slurry flow behavior is pseudo-plastic. At pH 6 slurry has maximum apparent viscosity and at pH 8 has minimum apparent viscosity. The viscosity of slurry was increased as ash content and coal loading increases. Also found that the viscosity is decreases as the temperature increases.

Boylu et al. (2004)- studied the effects of PSD on rheology of coal water slurry fuel. In this study three different types of coals with different ranks were taken for making slurry fuel but Same particle sizes. Physic-chemical and zeta potential were also determined too. For the same value of volume fraction the apparent viscosity of slurries were found that higher rank coals having lower value of apparent viscosity and lower ranks coals having higher apparent viscosity. It was also observed that solid loading is increased with coal having higher ranks.in this study, it was found that the slurries viscosity increased with enhancing the pulp compactness (by wt.) for distinct PSD.

Youchi et al. (2005)- In this paper, it is mentioned that sixteen different kinds of coals were taken from various region of chinese and having different physicochemical properties. The mains ideas for this study were rheology of slurry, stability and slurryability of CWS fuel. Moreover, other factors were studied like mature ability of coal, ash amount in coals, air equilibrium moisture, petrographic, pore type, surface possessions, extreme water holding capacity etc. In this study it was found that the slurry ability is good in which coals having higher carbon amount and higher grind-ability index. Viscosity of coal water slurry is co-related positively with ash amount, pore volume, soluble ions present. which were measured by Mercury porosimeter. Moreover, zeta potential having negative impacts on flow of CWS.

Gurses A et al. (2006)- carried out an experiment on rheology of coal-water slurry by considering factors like solid loading, pH value, temperature and additives. They did the

experimentation with the help of rotating type viscometer (Model: RV8-Brookfield). And the additives surfactants were Ammonium Bromide (CTAB), Borrosperse NA-3A. They observed that viscosity of CWS increases at low speed whereas decrease at high speed with increase in temperature. From the results they mentioned that CTAB are more impressive additives up to 50% loading (by weight) as compared to Borrosperse NA-3A surfactants.

Mosa et al. (2007)- investigated the effect of temperature and pH on the rheology behavior of CWS. This experiment was performed in thermal cup at different temperatures. The temperature range was 100 to 200°F and pH limit was 2 to 12. Power law was used in this experiment to determine the non-Newtonian nature and apparent viscosities of the slurries and also Chandler Engineering Viscometer Model 3500LS+ was used for determine the above mentioned properties of slurries. In this particular study it was found that as temperature of slurries was increased the degree of pseudo-plasticity was decreased. It was also found that slurries behavior was Newtonian above 180°F. They also observed that up to pH value 6 of slurries the degree of pseudo-plasticity decreased. However, degree of pseudo-plasticity was increased from pH 7 to pH 12. Flow nature of CWS at pH value 6 was Newtonian. It was observed that as the pumping cycle was increased the apparent viscosity of CWS increased. Reason behind this phenomenon, PSD of CWS was altered during transportation of slurry through pipes.

Shukla et al. (2008)- performed experiments to analyse the rheological behaviour of CoW with different coal particle size. In this paper three different coal particle sizes were taken like 108, 75.7, and 62.9 micrometre respectively. Coal percentages during slurry preparation were taken from 10 % to 50% by weight. During experiments a bob and cup type coaxial cylinder shaped viscometer used. Their work showed a suitable particle size in CoW for improving the solid load in slurry at different conditions. In this study also mentioned for finding the relationship among percentage of coal, oil, size of coal particle and required torque.

Das (2008) - studied the rheological characteristics of CWS suspension by using natural additive. The experimentation was conducted for seeing the effect of various factor as ash content, temperature, pH value, and concentration of saponin on rheology of CWS. They took the concentration of CWS in range of 55-64 and additive was in the range of 0.4–1.2 % (by weight). It was found that 0.8 % concentration of additive give maximum enhancement in rheological properties of CWS.

Tian-ye et al. (2008) – for reporting the effect of coal blending on the rheological characteristics of coal water slurry. Three different kind of coal samples procured from Daliuta (DLT), Linhuan (LH) and Yongcheng (YH). Largest particle size of coal was as 300µm and

about 75% particles are finer than 74 μ m. Naphthalene sulphuric acid-formaldehyde condensate was taken as additive. LH and YH coal was added to the DLT coal with the weight percentage of 10-40%. It was found that addition of coal with high mature can enhance the slurry ability and rheology of the low mature coal.

Das D et al. (2009) studied the formulation, stabilization and rheological behaviour of the highly solid loaded CWS fuel and a natural additive, saponin of the Acacia concinna plant commonly called Shikakai. The samples were procured from Talcher coal fields, Odissa. HAAKE RV 30 model rotational viscometer was used for determination of viscosity of coal slurry. The slurry prepared had a coal concentration between 55-65 wt. % and the reduction in apparent viscosity was considerable when the additive concentration was less than 0.8 %.

Zhou et al. (2010)- examined the flow of CWS prepared from chine regional coal. Haake viscometer was used for viscosity measurement of CWS. Graph were fitted by taking some mathematical model. It was found that Herschel-Buckley models had very good correlation constant. Results showed that nature of flow of CWS was pseudo-plasticity and coal loading was also high. CWS also had very high tendency to behave like dilatant. Electrolytes were used while preparation of CWS to change the nature of slurry from dilatant to pseudo-plasticity. Pseudo-plasticity nature of slurry was increased while using high valence cationic electrolyte. That is good for transportation of slurry.

Buranasrisak et al. (2012) –examined the outcomes of coal PSD and packing nature of coal water slurry fuels. Particle size for coal samples were taken like less than 38 ,38 to 63, 63 to75,75 to 90, 90 to 180, 180 to 250 micrometer respectively. It was found that bi-modal had less apparent viscosity. Coal loading was maximum in bi-modal sample because of higher packing fraction.

Ganguly et al. (2012)- examined the results of PSD of pulverized coal. In which volatile matter was higher and it was less mature Indian coal. It has also low burning efficiency. The efficiency performance was find out by emission of SO_x and NO_x and amount of ash after burning. It was found that no effect of PSD on emission after burning. Another two studied had been done to determine the presence of Hg. Again no relationship was found between PSD of slurry and emission of mercury.

Shao et al. (2012) – examined the rheological behaviour and static stability of coal alcohol fermentation wastewater slurries. The viscosity of slurry was measured with the help of a rotary viscometer (NXS-4C). experiments were done at temperature of 25° \pm 1°C. The solid concentrations of coal slurries were between 45-65% (by weight) and the shear rate variation of 0-100 s⁻¹. From the experimental results it was observed that slurries of coal maize and

cassava alcohol fermentation wastewater exhibits pseudoplastic behaviour and high apparent viscosity because of the existence of carboxylic groups and lower pH. Coal-water slurry has better stability as compared to coal maize and cassava alcohol fermentation wastewater slurries.

Panda (2014)- proposed that CWS could be an alternative for fuel oil source in India. As Indian coals are less mature and having more minerals with less Sulphur. Since most of the experiments have been completed with western region countries having less ash and high Sulphur. Therefore, an effort has been done to examine certain aspects of flow nature of CWS made of by using Indian coals. An empirical connection was set among shear stress, % of ash of coal in (wt.) and amount of solid in CWS. Rheology studies help in the designing of pipeline while transporting the slurries with adequate solid loading.

Ulusoy et al. (2016) -have taken mechanical sieving (MS) and dynamic image analysis (DIA) to examine the particle size distributions (PSD) of coals (mainly lignite) those were pulverized with the help of Gy-Ro and ball mills. The PSD statistics of fine coal particles were studied on DIA and MS by log-normal scattering scheme. Mathematical models namely Gaudin-Schuhmann (GS) and Rosin-Rammler (RR) also used for PSD statistics. Generally, it was seen that the particle sizes under 100 μm showed similar PSD, for both DIA and MS principles. The RR model was seen to fit well on the complete array of particles sizes given by Gy-Ro and ball mills instead of GS model. It was also seen that DIA could evaluate the particle size arrays below 100 μm , while MS could not. Moreover, the results obtained by DIA were seen to be more accurate than those obtained by MS especially for particle sizes below 38 μm . Consequently, for PSD investigation of pulverized coal particles RR and DIA model were suggested.

Liu et al. (2017)-the influence of PSD on the rheological behaviour and stability characteristics of biochar-water suspension. The yield stress was calculated by using a Brookfield vane viscometer. Moreover, the dependence of the apparent viscosity and shear stress on the shear rate was measured with the help of Haake VT550 cone and plate type viscometer. The static stability was measured using “drop rod” method. At a given bio-char mass loading, the yield stress of the slurry first decreased when D50 value was 15 μm and then increased drastically with further increasing D50 due to high water absorbing capacity of larger particles. The slurry fuels made up with finer biochar were more stable.

Yang et al. (2016) -examined the two-grade fractal model to cause enhancement in the packing characteristics of coal particles for brown coal water slurry (BCWS). The two grade model was based on the concept of fractal theory and improvised by discriminating the coal particle size into two different ranks. Further, packing efficiency (PE) of coal particles in BCWS was

studied. Moreover, various reversion stages of the model in numerous particle arrangements were also examined. The PE of BCWS was found to be the function of fractal characteristics of sizes below 74 μm and also PE could be enhanced by setting fractal dimension near 2.6-2.7. Also, the fractal model was also found to be appropriate PSD with varied ratios of coarse (CS) to fine (FS) to ultra-fine (UFS) coal. It was perceived that the highest value of PE was obtained when the ratio of varied particle sizes was 7:0:3 (CS: FS: UFS) along with the fractal measurement being 2.7080. Taking into consideration the above mentioned fractal dimension, it was concluded that the BCWS prepared with this dimension had an increase in its solid concentration by 2.9 %.

Zhu et al. (2017) examined the influence of PSD on the flow and steadiness control of bio-char- water slurry fuels. Slurries were prepared with varied D50 values of bio-char having uni-modal in accordance with bimodal distribution including different dimension fine/coarse ratios (λ) and diverse fine portion (ξ). Brookfield vane viscometer was used for determining the yield stress of the prepared dispersions whereas Haake VT550 cone and plate viscometer was used for characterization of the dependence of the viscidness and the shear stress up on the deformation rate. Decreased viscidness and improved solid loadings were perceived for the bimodal distributed slurry. The viscidness was found to decrease proportionally with decreased λ , and was more reflective at reduced ξ . The slurry made with finer bio-char was found to be unaltered or steadier.

Loureiro et al. (2018)-Charcoal water slurries were made of an unnamed type of biomass. After the processing charcoal slurries were prepared. ChWS preparation was completed following methods mentioned in the literature for CWS fuels. The same systematic methods employed throughout the entire experiment. The viscosity and rheological characteristic of the slurries were as mentioned in the experimental procedure, a relatively high solid concentration of 58 wt.% was taken to examine the dispersion efficiency of the six different kind surfactants. While study, it was observed that in ChWS combustion the emissions decrease, as the flame temperature is reduced by water. and hence help to lower both the greenhouse effect and acid rain. For getting the best results ash in charcoal mud be below 5% by weight. A ChWS having 60 wt.% of charcoal, the viscosity of slurry is about 1 Pa s. Among the six surfactants Zephyrum 4974 is best, which is added around 1% by weight. This surfactant is helped to stabled the slurry for long period of time while preparing the slurry.

3.1 GAPS IN STUDY

A lot many of research work have been done in the previous time to examine the rheological nature of CWSFs by taking different approach, few of which were mentioned in the former section. Many factors that affect the rheological behaviour of CWSFs that have been examined by many researchers. The effects of some additives and stabilizers, highly solid loaded CWSFs, zeta potential, etc. And somewhat similar work has been done on charcoal slurry. But work on combination of both the coal and the charcoal slurry has not been studied in very well manner. In India there is no such work has done yet what is rheological behaviour of combination with Indian coal and charcoal. A gap in study show that there is still a lot many of work to be done in evaluate the influence the effects of charcoal on Indian coal when the slurry is made from charcoal and coals. Determine the flow nature of CChSF by considering the different mass ratio of charcoal and coals and find the optimum viscosity of CChSF that will help to design transportation system by conserving the criteria of slurry preparation.

3.2 OBJECTIVE

The current area of study lies in the investigation of flow behaviour of CChSFs made from three dissimilar grades of Indian coal, taken from varied region across India and one charcoal as a function of particle size distribution, varied coarse/fine ratio. The aim of the current study is stated as follows:

- Determination of physical and chemical properties of three Indian coals and charcoal like particle size distribution, specific gravity, static settling of slurry, pH, proximate analysis, ultimate analysis, SEM and EDS.
- Comparison of gridability index of charcoal with Indian coals.
- Study of rheological/flow behaviour of CChSFs with various ratio of Indian coal and charcoal
- Study of rheological/flow behaviour of CChSFs with variation of particle size distribution of charcoal.

So for reporting the flow behaviour of Indian coal and charcoal, three Indian coals have been taken from different power plant in pulverized form and one charcoal.

Information of power plants is given below:

- A. Reliance Sasan ultra mega power. Sidhikhurd, Tiyara, Singrauli, Madhya Pradesh.
- B. Hindalco Renuagar power plant. Dist-Sonebhadra, Uttar Pradesh.
- C. Lanco Anpara industries ltd. Anpara, Uttar Pradesh.

Charcoal in the lump form has been taken from charcoal shop, which is in Patiala, Punjab. Charcoal has been made from wood of Keekar also known as Babool. The Latin name is Acacia.

The following notation has been used for writing this report only for samples:

- C1- Reliance Sasan ultra mega power. Sidhikhurd, Tiyara, Singrauli, Madhya Pradesh.
- C2- Hindalco Renuagar power plant. Dist-Sonebhadra, Uttar Pradesh.
- C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.
- C4-Charcoal sample.

3.3 METHODOLOGY

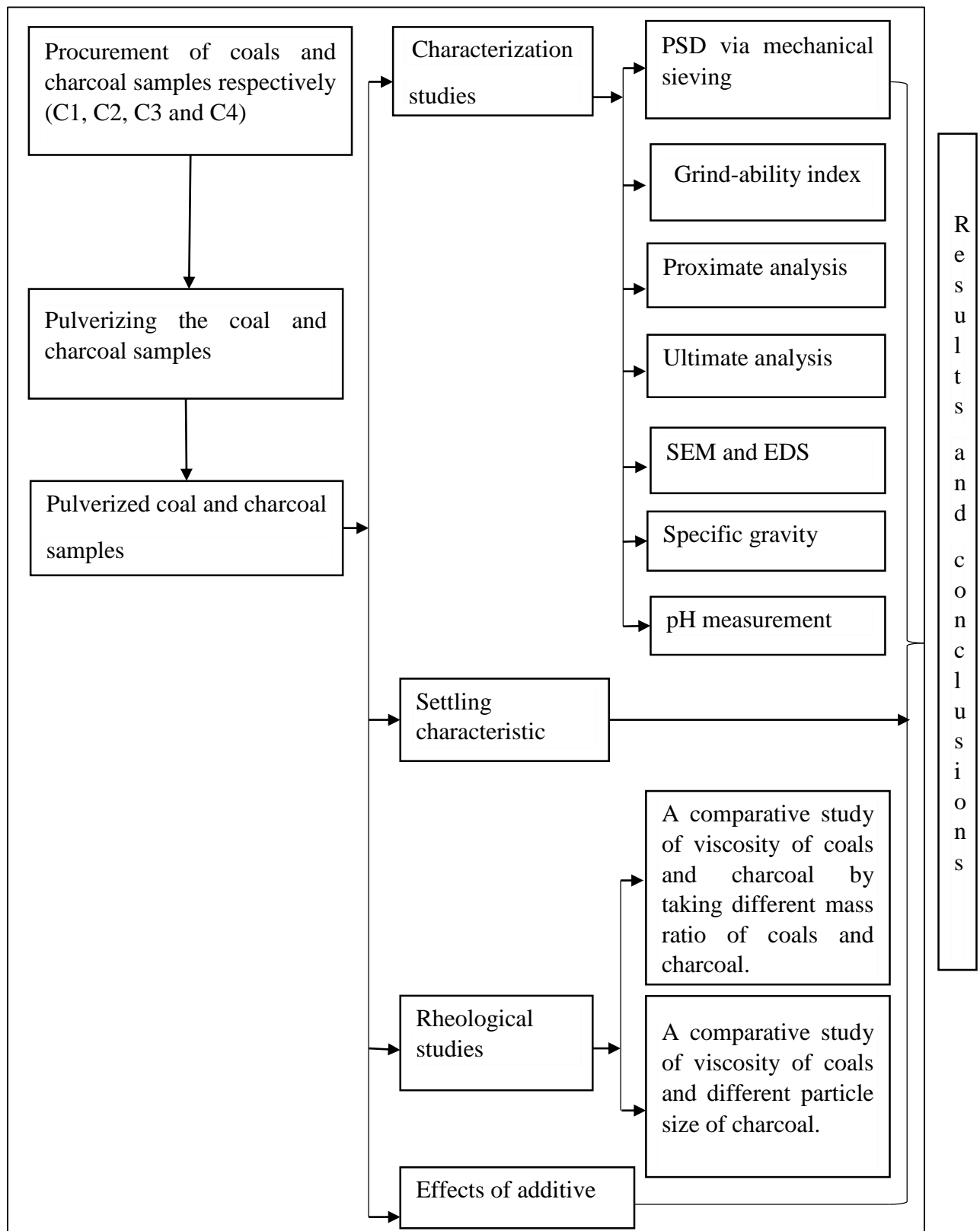


Figure 3.1: Detailed flow map of the methodology

CHAPTER 4

CHARACTERIZATION AND STATIC SETTLING

4.1 PARTICLE SIZE DISTRIBUTION (PSD)

The particle size distribution shows the percentage of solid particles present in a particular particle size range. Many factors influenced by PSD static settling and viscosity of the slurry which plays major role in variation of pressure drop during slurry transportation. In this present study, sieve analysis method is used for particle size distribution of coal and charcoal samples. The coal and charcoal sample with known mass of solids are taken and dried in an oven properly. The sample is sieved by using a set of British standard sieves (500, 355, 250, 150, 106, 75 and 53 μ m) with maximum extension of 40 on a scale of 0-100 while changes in frequency is continuous. The percentage of coal and charcoal retained on each particular sieve is collected and the mass of retained coal and charcoal samples are measured. The retained percentage for each sieve is determined by using equation

$$\text{Retained Sample} = \frac{M_R}{M_T} \times 100 \quad (4.1)$$

Where, M_R = Mass of solid particle retained (grams) and M_T = Total Mass of solid particles (grams).

The PSDs curves of the coal samples and charcoal studied viz C1, C2, C3 and C4 obtained from the data enumerated in Table 4.1.

Table 4.1 PSD analysis of coal and charcoal samples

Size limits (in mm)	Mesh size (in mm)	Cumulative mass %(undersize)			
		C1	C2	C3	C4
<0.053	0.053	14.35	8.58	7.78	19.48
0.053-0.075	0.075	43.35	24.28	38.14	62.65
0.075-0.106	0.106	67.85	54.26	55.43	81.37
0.106-0.150	0.150	84.60	70.93	77.80	92.43
0.150-0.250	0.250	97.20	83.12	89.00	99.00
0.250-0.355	0.355	100	92.12	95.11	99.26
0.355-0.50	0.500	100	100	100	100

C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renusagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4-Charcoal.

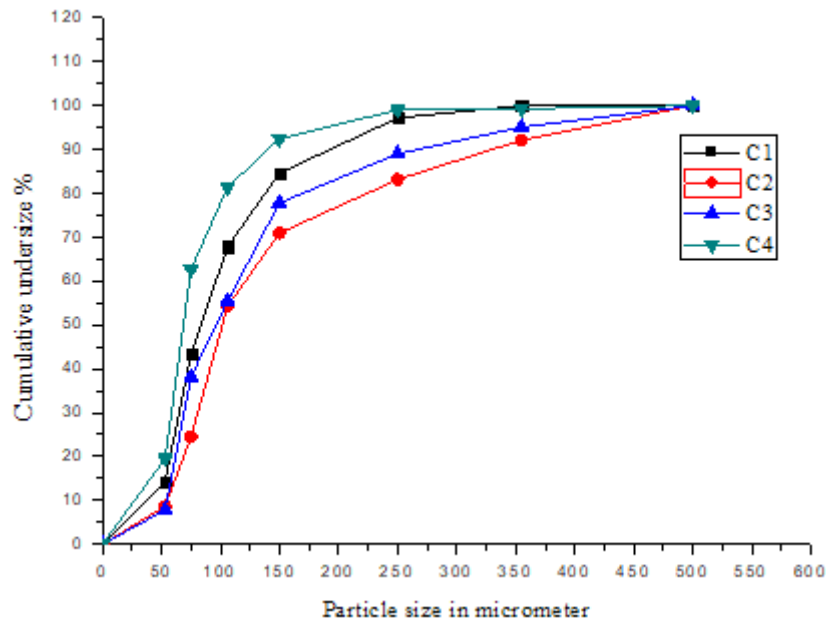


Figure 4.1: PSD curves for the three coal samples (C1, C2, C3 and C4) obtained by MS tests

The PSDs curves shows that there is continuous distribution of varied coal and charcoal particle sizes. The mass median diameters (d50) of the coals and charcoal samples were determined from the PSD curves and are shown in below Table 4.2.

Table 4.2: Mass Median diameter of samples

Coal Sample	C1	C2	C3	C4
d50 (µm)	54	75	84	63

C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renusagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4-Charcoal.

4.2 HARDGROVE GRIDABILITY INDEX (HGI)

The grindability of samples was calculated by using the Hardgrove scheme that considers for the increment in the surface area formed by certain amount of work and designated as Hardgrove grind-ability index, G (Sarkar 1990)). Grindability index also indicates properties like strength, hardness, tenacity and fracture. Coal sample having more volatile matter G value is high. The relationship for determination of grindability index is given below

$$G = 13 + 6.93W \quad (4.2)$$

Where, W is mass of solid samples in grams after passing through a 200 mesh sieve and 50g of solid sample having size 16 to 30 mesh are ground in a mill for 60 rotations.

Generally, it was observed that higher value of G for soft coals samples that means directly related to rank of coal i.e. higher the rank higher value of G. Bright coal (% carbon around 90), G value is around 105. Determination of power required for pulverized the solid samples can be related with HGI.

The results of Hardgrove grindability index (HGI) of three Indian coals and charcoal are shown in tables 4.3.

Table 4.3: Grindability index of three coals and charcoal.

Samples	C1	C2	C3	C4
HGI	63	58	54	96

C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renuagar power plant. Dist-Sonebhadra, Uttar Pradesh. C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh. C4-Charcoal.

4.3 SPECIFIC GRAVITY

Specific gravity is defined as the ratio of slurry density with respect to density of water, taken as standard reference. The specific gravity of solid materials is an important factor which specifies the settled concentration of the solid-liquid suspension.

The specific gravity of coal and charcoal is calculated by considering standard pycnometer method. Initially, a 50 ml beaker is chosen and put in hot oven for 1 hour after that cleaning is done by normal tap water. The mass of beaker (MB) is measured after removing it from hot oven. Then the beaker is filled with 30 grams of oven dried sample and together mass of beaker with sample (MBS) is evaluated by using weighing machine. In beaker distilled water is poured and stir for 5 minutes to confirm the proper mixing. The mass of beaker along with slurry sample (MBSW) is weighted again after 1 hour. The sample is taken out from the beaker and cleaned with tissue paper properly. The mass of beaker (MBW) is evaluated again after filling it with distilled water up to same height. The correlation represented in equation is used to measure the specific gravity of coals and charcoal samples.

$$\text{Specific gravity} = \frac{(M_{BS}-M_B)}{\{(M_{BW}-M_{BSW})+(M_{BS}-M_B)\}} \quad (4.3)$$

Where, M_B = Mass of beaker (grams), M_{BS} = Weight of beaker and solid (grams),

M_{BW} = Mass of beaker and water (grams) and M_{BSW} = Mass of beaker, solid and water (grams)

The value of specific gravity for coals and charcoal is given in Table 4.4.

Table 4.4: Specific gravity of coal and charcoal

Samples	C1	C2	C3	C4
Specific value	1.5	1.58	1.69	1.08

C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renuagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4-Charcoal.

4.4 PROXIMATE ANALYSIS

The proximate analysis experiment of the three coal samples and charcoal was conducted as per this analysis practice stated in IS: 1350 (I) to get the % volatile matter, % inherent moisture, % ash, and % fixed carbon by weight of samples.

Evaluation of moisture content in fuel sample: Loss in mass of fuel sample caused by heating of fuel sample for an hour at 105°C is the moisture available of fuel sample. A known quantity of fine powdered form of sample is kept in a silica crucible and kept the fuel sample in muffle furnace at 105-110°C for an hour. After that the crucible is picked out from muffle furnace, cooled in a desiccator and weigh the sample. The percentage of moisture is evaluated by
$$\% \text{ moisture in fuel sample} = \{\text{loss in mass of fuel sample} \times 100\} / \text{mass of fuel sample initially taken for analysis.}$$

Evaluation of Volatile Matter in fuel sample: It is the reduce in mass of moisture free fine powdered fuel sample is placed in a crucible after in a muffle furnace at 925°C for 7 minutes in absence of air.

$$\% \text{ volatile matter in fuel sample} = \{\text{loss in mass of moisture fuel sample} \times 100\} / \text{mass of moisture free fuel sample.}$$

Evaluation of ash in fuel sample: It is the mass of residue get after burning a known mass quantity of fuel sample in an open crucible (i.e. in presence of air) at 750°C in a muffle furnace till a constant mass is achieved.

$$\% \text{ ash in fuel sample} = \{\text{mass of residue ash formed} \times 100\} / \text{mass of fuel sample initially considered.}$$

Evaluation of Fixed Carbon in fuel sample: It is calculated indirectly by subtracting the sum total percentage of moisture, percentage of Volatile matter, and percentage of ash from 100.

$$\% \text{ fixed carbon in fuel sample} = 100 - (\% \text{ moisture} + \% \text{ ash} + \% \text{ volatile matter})$$

This analysis was completed in Department of Energy and Environment, T.I.E.T., Patiala.

The following apparatus are required for proximate analysis of a solid fuel are:

1. Weighing machine
2. Desiccator
3. Crucible
4. Hot air oven
5. Muffle furnace

All apparatuses are shown in Figure 4.2 for proximate analysis:



Weighing machine



Desiccator



Crucible



Hot air oven



Muffle furnace

Figure 4.2: Apparatuses for proximate analysis

After analysis the following results have been founded in each sample:(on air dry basis) in Table 4.5.

Table 4.5: Proximate analysis result samples (air dried basis)

Parameters(%)	C1	C2	C3	C4
Total moisture	5.00	4.72	3.41	5.20
Volatile matter	34.10	36.31	28.26	46.52
Ash	24.84	34.94	43.79	3.40
Fixed carbon	36.06	24.03	24.54	44.88

C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renusagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4-Charcoal.

4.5 ULTIMATE ANALYSIS OF COAL AND CHARCOAL SAMPLE

Evaluation of total Carbon (C), Hydrogen (H₂), Nitrogen (N₂), Oxygen (O₂) and Sulphur (S) percentages in fuel sample comprises its ultimate analysis.

This analysis has been done in Sophisticated Analytical Instruments Laboratories Society, T.I.E.T, Patiala. For the ultimate analysis an apparatus has been used which is made by Thermo Technology:

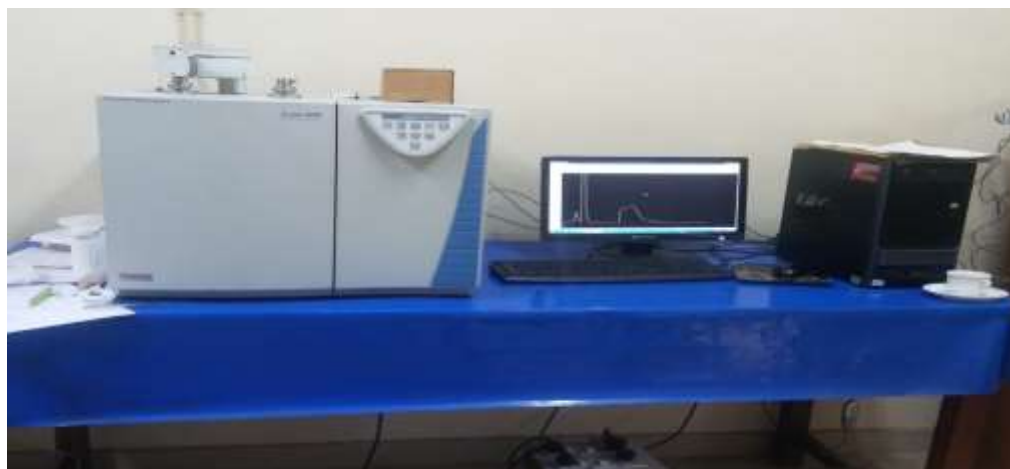


Figure 4.3: Instrument used for ultimate Analysis

Results which have been obtained after analysis is given in below Table 4.6.

Table4.6: Results of Ultimate analysis samples (air dried basis).

Parameters (%)	C1	C2	C3	C4
1. Carbon	45.94	46.31	44.01	70.91
2. Hydrogen	3.24	3.13	3.02	3.83
3. Nitrogen	0.91	0.94	1.06	0.46
4. Sulphur	0.34	0.36	0.40	Not detected

5.Oxygen	12.19	12.07	10.19	19.87
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C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renusagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4-Charcoal.

4.6 CALORIFIC VALUE BY BOMB CALORIMETER

This apparatus consists of a strong stainless steel vessel, known as bomb, capable to resist intense pressures. There is a lid which can be screwed forcefully on the bomb. Two electrodes and an oxygen inlet valve in bomb calorimeter. One of the electrodes is attached with a ring to accommodate the silica crucible. In a copper calorimeter the bomb is placed. In calorimeter there is also known mass of water. The calorimeter is covered by a water jacket and an air jacket to stop heat due to radiation and a stirrer for stirring water. A thermometer to measure the change in temperature of water. The calorific value of fuels is shown in Table 4.7.

Table 4.7: Calorific value of samples

Sample	Gross calorific value (kJ)	Net calorific value (kJ)
C1	18680	17.426.4
C2	16285.5	15031.28
C3	15236.1	13982.1
C4	13062.5	11808.5

C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renusagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4-Charcoal.

4.7 MINERALOGICAL CHARACTERISTICS

The mineralogical characteristics give idea about the structure, size and chemical composition of coals and charcoal which can be examined by scanning electron microscopy-energy dispersive X-ray spectroscope. Morphology and chemical composition of samples are determined. Through the morphology the particle shape and size are defined, which provide the information for its end utilization. The chemical composition gives the idea about different compounds present samples.

4.7.1 SCANNING ELECTRON MICROSCOPY (SEM)

The scanning electron microscopy (SEM) technique gives the meaningful information like particle size and shape through the high-resolution images. It is a kind of electron microscope which provides the information of specimen by creating very high-resolution images of a sample surface and capable up to the nanometre scale and creates image by scanning with help of electron beam. The high-energy electrons interact with the atoms of sample creates signals that give idea about surface topography and its composition. The SEM micrograph gives the 3-D appearance which is very good for understanding about nature of surface (Roy et al. 2015). The morphology of coal, charcoal samples are examined by using JEOL, 6510LV model of scanning electron microscopy-energy dispersive X-ray spectroscopy.

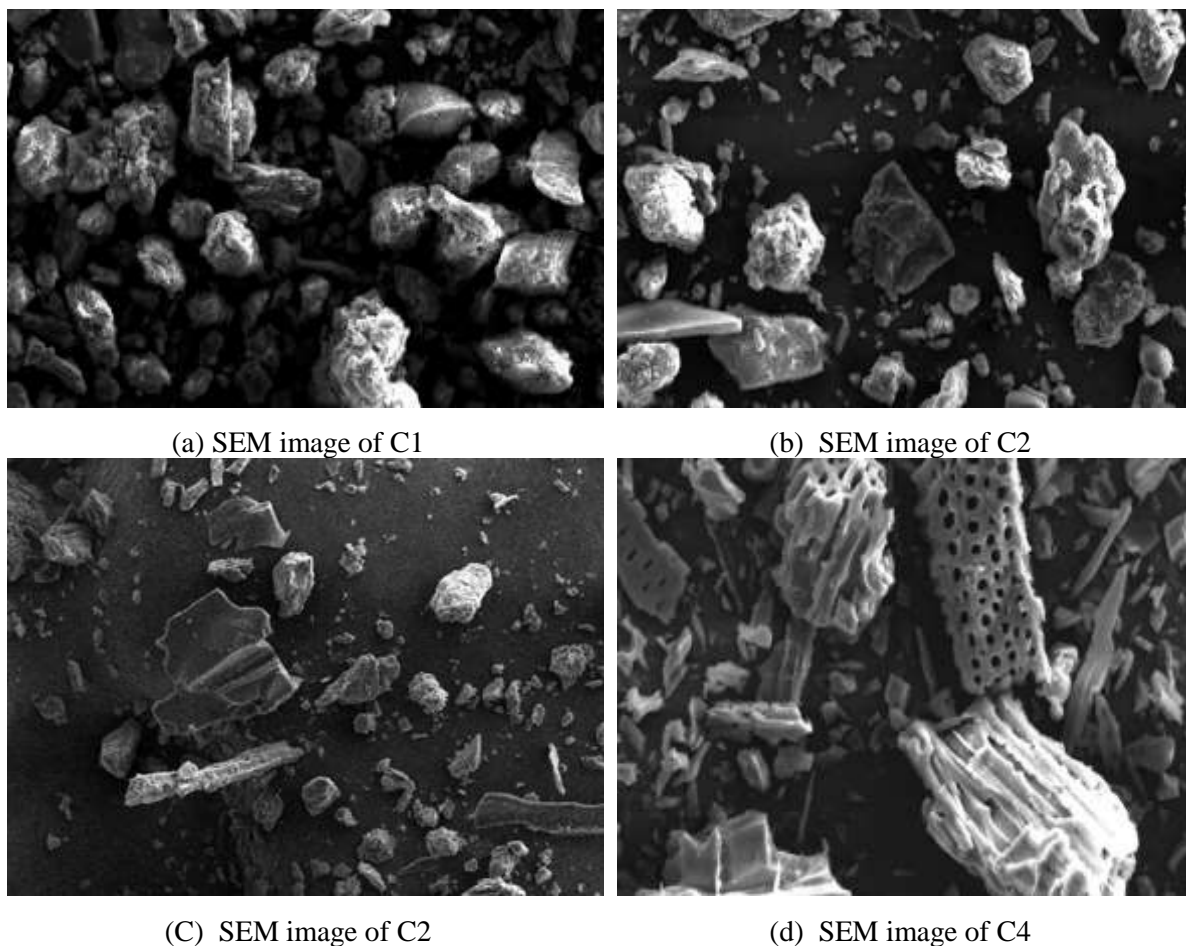


Figure 4.4: SEM images of different samples

C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renuagar power plant. Dist-Sonebhadra, Uttar Pradesh. C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh. C4-Charcoal.

The chemical composition gives idea about the presence of different type of elements and their compounds in the sample. The basic working principle of spectroscopy that there is unique atomic structure for every element and letting a unique set of peaks on its electromagnetic emission spectrum. This method permits interaction between source of X-rays excitation and the sample. The energy-dispersive spectrometer calculates the different number and level of energy produced by striking of X-rays on the surface of test sample. These differences in energies of X-rays measure the specimen elemental composition. The overlapping peaks on spectrum may decrease the accuracy of EDS spectrum and it also affected by the behaviour of sample.

For SEM imaging, samples must be electrically grounded in order to get better results, therefore the samples get coated with gold (Au) and name of coating is sputter coating. It enhances the surface resolution and signal (Loureiro et al. 2016). The results obtained for the coals and charcoal samples (C1, C2, C3 and C4) are shown in below Figures 4.4.

This test indicated that the coal and charcoal samples were mainly not in regular shape and mirrored because the presence of the grime, carbonaceous bits, alumino-silicates, etc. The small asymmetrical particles deposition was detected because of ash and soil attrition. Charcoal sample is high porous in nature.

The EDS outcomes of the samples. This is an investigative practice used for basic study of chemical composition (Roy et al. 2015). The EDS output are stated in Table 4.8.

Table 4.8: Chemical elements in the samples by EDS.

Sample	Chemical elements											
	C	N	O	Al	Si	S	Ti	Cr	Fe	Co	Cd	Hg
C1	47.69	-	36.63	3.30	10.65	0.17	0.53	0.09	0.38	0.05	0.08	0.14
C2	81.06	1.99	9.98	1.83	3.05	0.20	0.34	0.03	0.55	0.04	0.13	0.36
C3	57.8	-	3.57	2.70	3.37	.25	.41	.02	.93	.06	.15	.42
C4	72.93	-	25.93	-	-	-	-	-	0.21	0.20	-	-

C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renuagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4-Charcoal.

4.8 POTENTIAL OF HYDROGEN (PH) OF SLURRY FUELS AT DIFFERENT SOLID CONCENTRATION

The purpose of determining the pH of slurry fuels is that from literature it was mentioned that rheological behaviour of slurry fuels is influenced by their pH value. It was observed that up to pH value 6 of slurries the degree of pseudo-plasticity was decreased. However, degree of pseudo-plasticity was increased from pH 7 to pH 12. Flow nature of CWS at pH value 6 was Newtonian. (Mosa et al. 2007).

The pH of slurry fuels was calculated to see the effect of solid loading on the pH value of slurry fuels. The pH was measured by a digital pH meter. The calibration of pH meter was done before the measuring the pH of slurry fuels to ensure to get correct reading. For that firstly the electrode was put into the buffer solution with help of distilled the electrode was cleaned.

After the calibration was over the electrode was dipped into slurry for measuring the pH. Four different concentration were taken as 30%, 40%, 50% and 60% for different samples for evaluating the effect of solid loading on pH value of slurry. The pH values at different solids concentration are shown in table 4.8.

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Table 4.9: pH value coal slurry and charcoal slurry at different concentration.

Concentration(% by mass)	C1	C2	C3	C4
30	6.08	6.12	6.22	8.70
40	6.01	6.1	6.16	8.66

50	5.98	6.07	6.11	8.54
60	5.94	6.03	6.04	8.48

C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renuagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4-Charcoal.

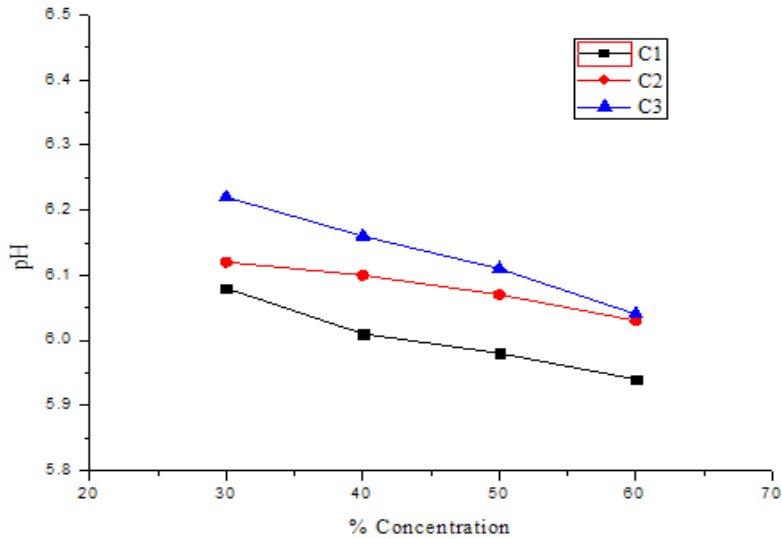


Figure 4.5: pH value of coal samples at different concentration

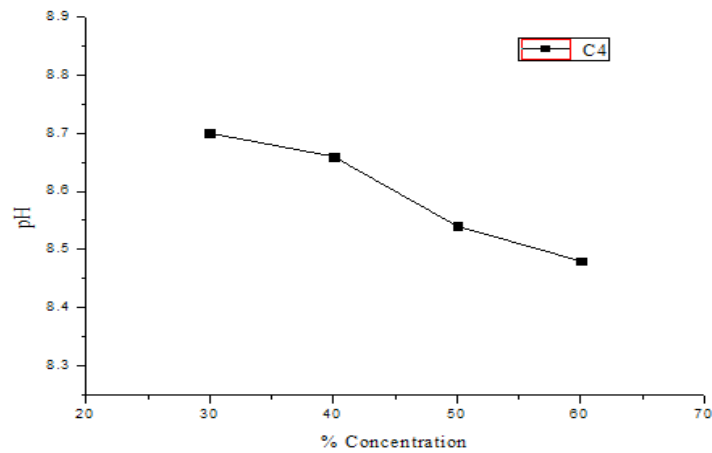


Figure 4.6: pH value of charcoal samples at different concentration

From Figure 4.5 and 4.6 shows that The pH value of the slurry fuel that decreases with an increase in the solid concentration for both coal and charcoal. The decrease in slurry pH with an increase in solid loading can be attributed to the interaction of solid particulates with the water and the interfacial properties of solid particulates and carrier liquid. It was observed that pH value of charcoal slurry is high as comparison of coal slurry.

4.8.1 EFFECT ON PH OF SLURRY WHEN COAL AND CHARCOAL MIX TOGETHER

For finding out the blending effect of coal and charcoal together this experiment was carried out. In this study coal (C) and charcoal (C4) is taken and maximum solid loading was 50% by weight. In this study, different proportion of coal and charcoal was taken like C1:C4 =90:10,80:20,70:30,60:40,50:50 and 40:60. The outcomes are shown in Figure 4.7.

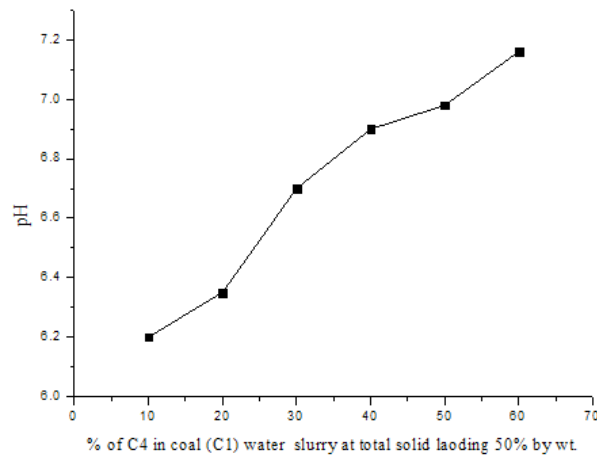


Figure 4.7: pH of coal-charcoal water slurry

From Figure 4.7, it is clear that as the percentage of charcoal (C4) increase the pH of coal-charcoal water slurry also increases and at equal proportion of coal and charcoal pH value is close to 7.

7.4.9 STATIC SETTLING

The storage of slurries fuels in storage tanks requires that slurry must to be stable for a time period, opposing sedimentation of solid particles with time after slurry preparation. The stability of slurry is influenced by various factors like- solid concentration, particle size distribution (PSD), specific gravity, particles shape, type and percentages of stabilizers that is used while slurry preparation. Static stability test on slurries fuels give an idea of their stability against sedimentation. To determine the static stability of slurries fuels the static stability test of three Indian coal and one charcoal samples was done using rod penetration method as prescribed by Usui et al., (1997). Two layers of sedimentation was found in slurries fuel, soft layer is known as Soft Pack Depth (SPD) and hard layer is known as Hard Pack Depth (HPD). The soft sedimentation can be eliminated by mild stirring of the slurries whereas the hard sediment layer is deposited at the bottom and to detected HPD this test was done.

In this present study, at the bottom of the beaker the hard sedimentation layer was accrued when it was kept for pre-assumed time periods and packed with plastic pouches to avert

vaporization of slurries fuels was examined by a steel rod having 3 mm diameter with a small disc (10 mm diameter and 1 mm thick) fitted at the tip of the rod. Static stability measuring system is shown in Figure 4.8.



Beaker with slurry sample



Measuring Rod

Figure 4.8: Static stability measuring apparatus

The total mass of the rod was 30 g. The rod was first come through into the slurry just after preparation for determine the maximum rod travel distance (d_{Max}). After that regular intervals of time, the rod was come through to determine the rod travel (d) distance. When the tip of the rod is come with contact of hard sedimentation layer, it was taken out and the depth of penetration was noted down. The percent penetration was determined as:

$$\% \text{ penetration} = d/d_{Max} \times 100 \quad (4.4)$$

where d = distance of rod travel (mm)

d_{Max} = maximum distance of rod travel (mm)

This test was carried for three different coals and one charcoal without any stabilizers and particle sizes of samples were taken below 150 μm .

The graph of percent penetration with time of storage for three coals and charcoal having concentrations of 40 % and 50 % and 60% by weight are shown in Figures 4.9- Figure 4.10.

Figure 4.9: Static stability curve of slurry fuels samples at 40% of concentration

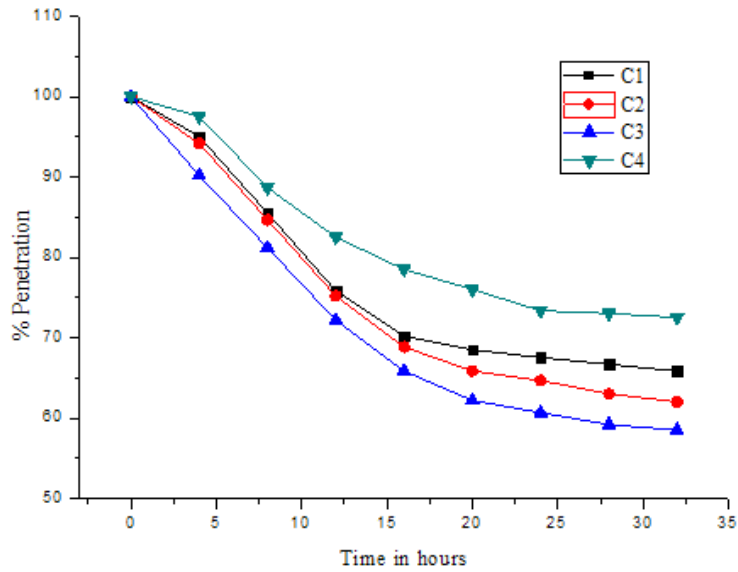


Figure 4.9: Static stability curve of slurry fuels samples at 50 % of concentration

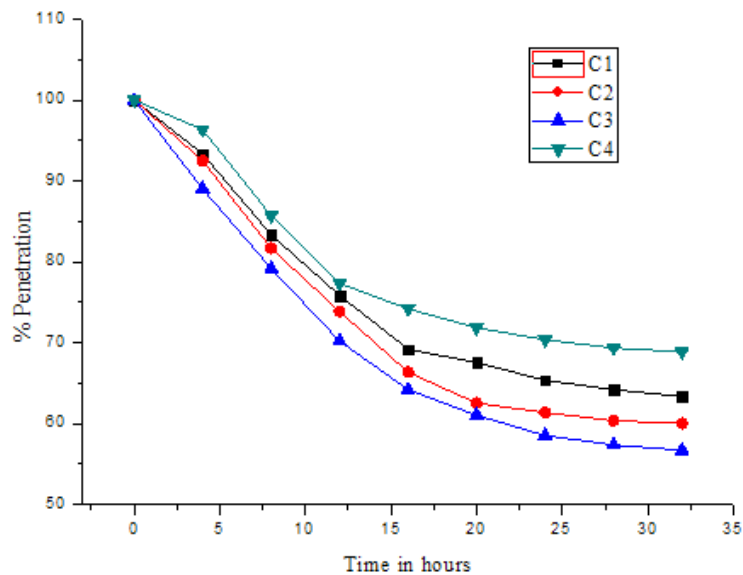


Figure 4.10: Static stability curve of slurry fuels samples at 60% of concentration

From static stability test it was observed that the coal sample C1 was more stable as compare with other coals C2 and C3 at different concentration of samples .it was found that after 20 hours' average penetration for sample were 68%,64% and 60% for C1, C2, and C3 respectively. Influence of concentration is least on % penetration for sample C1. After the 25 hours no much change in % penetration was found.

For charcoal (C4), it was observed that for first 8 hours it is quite stable but after 12 hours % change in penetration is very high. This is because charcoal is hydroscopic and from SEM analysis it was found that is porous in nature. After 20 hours the average % penetration was

74%. The average % penetration is high for C4 as compare with coals because its specific gravity is low. And also observed that effect of charcoal loading on % penetration is high.

4.9.1 Static stability of coal charcoal water slurry

This study was carried for investigating the static stability of coal charcoal water slurry. In this study, maximum solid loading was 50% by weight and ratio of blending of coal and charcoal was taken equal. From Figure 4.11, it is observed that stability is improved in comparison of coal water slurry at 50% of solid loading. This may be happened as the specific weight slurry is get lower for given solid loading.

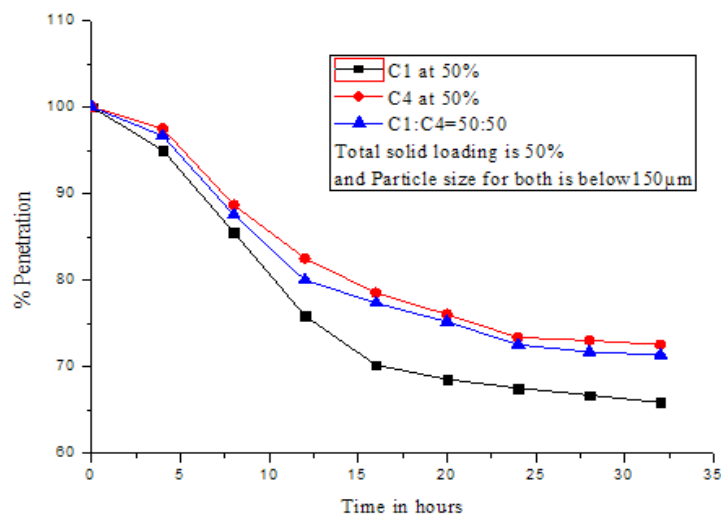


Figure 4.11: Static stability curve of coal charcoal water slurry

Further, study was extended to find out the effect of fine charcoal particles on static stability of coal charcoal slurry water. Again maximum solid loading was 50% by weight but fine charcoal like below 53 μm particle size was taken. Outcomes after the study is shown in Figure 4.12. It was observed that effect of fine charcoal particles is quite good as compare with coal water slurry and charcoal water slurry for given solid loading of slurry. Reason of enhancement in static stability of coal and fine charcoal particle is lower the value of specific weight and pore size charcoal particle is smaller hence water uptake capacity gets reduce and static stability of coal charcoal water slurry is improved (Liu et.al (2016)).

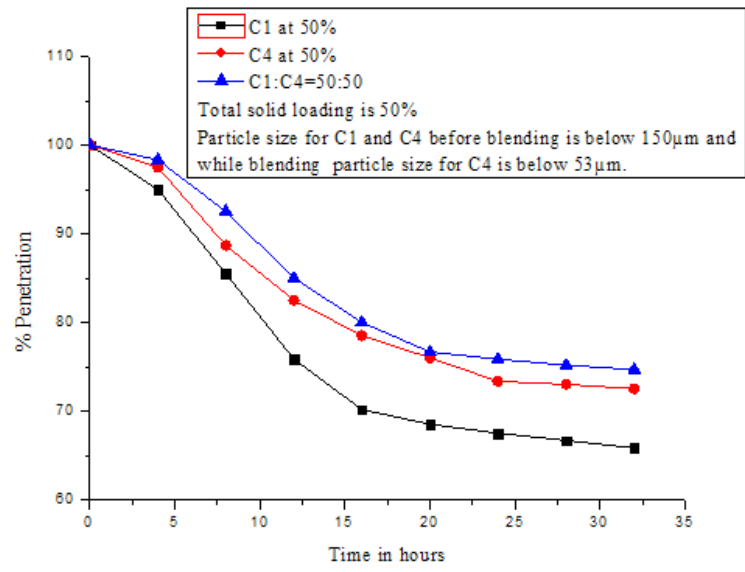


Figure 4.12: Static stability curve of coal and fine charcoal water slurry

CHAPTER 5

RHEOLOGICAL CHARACTERISTICS

The flow behaviour of solid suspension in pipeline relies on the rheological characteristics of the slurry. In power generation industries, generally the slurry fuel is being transported in pipeline for fuel generation. The maximum solid loading of slurry with appreciable viscosity enhances the efficiency of transportation system of the slurry. The energy needed for transporting slurry through pipeline mainly relies on the slurry viscosity. Thus, the study of rheological behaviour of slurries fuels necessary for their economical transportation through transporting system. So in this thesis, present work is carried out to investigate the rheological behaviour of coal water slurry, charcoal water slurry and coal charcoal water different solid loading and also the work is extended to examine the effect of particle size of charcoal, solid loading of charcoal, unimodal and bimodal particle-size distribution on the rheology charcoal-water slurry. Further, experiments are carried out in which charcoal is added in coal (C1) in different ratio by weight and different particle size of charcoal. The details of the experiment method and the apparatus used are mentioned in the following section.

5.1 RHEOMETER

Rheometer is an instrument used to investigate the flow nature of the liquids and solid-liquid slurries suspension. It generally deals to evaluate approximate way of shear rate under the action of applied shear stress. There are different kind of rheometer exist to investigate the fluid nature like Newtonian/non-Newtonian, shear stress, shear rate, viscosity, relaxation time and elongation viscosity etc. To determine the rheological characteristics of solid-liquid suspension the cone plate concentric cylinder type Rheometers are extensively used to determine the rheological characteristics of solid-liquid suspension (Al-Zahrani and Al- Fariss, 1998).

5.2 TYPES OF RHEOMETER

Concentric cylinder

There are two concentric cylinders is employed in this type of rheometer, one cylinder is stationary and second one is driven at constant torque driver (motor). The viscosity of fluid or slurry measured between two concentric cylinders. The higher spin of rotation at a particular torque lesser the value of viscosity. The elastic modulus is evaluated as function of shear stress.

In order to evaluate the elasticity, viscosity of non-Newtonian liquid and viscoelasticity concentric cylinder rheometer is employed.

Parallel plate

Parallel plate rheometer is employed for those samples which is not depend on shear rate. That means, it is not employed for non-Newtonian fluid. In the parallel plate rheometer bottom plate is fixed and top one plate is rotary. On upper plate a constant speed motor is placed and a sensor is fitted to measure the angular deflection or deformation rate.

Cone and plate

The working principle of cone and plate rheometer is very similar to parallel plate rheometer but top plate is changed with a cone. Cone has small angle and constant shear strain around the sample. Thus it is employed for non-Newtonian fluid.

Different type of rheometers are shown in below figure 5.1.

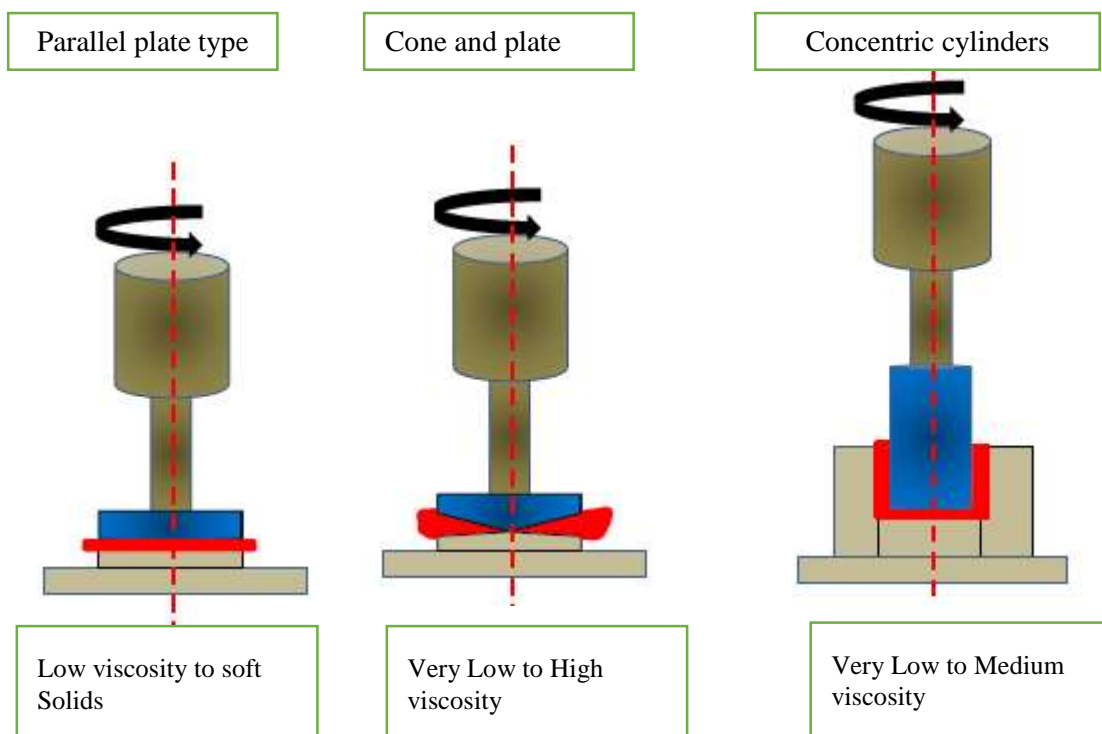


Figure 5.1: Different kind of rheometers

5.3 WORKING PRINCIPLE OF RHEOMETER

A constant torque drive (motor) is attached to the rheometer. A sensor which is employed to calculate the angular position or movement by the system, which is attached with the shaft. The torque detection system and a constant speed motor is installed with rheometer. A torsion

bar is suspended in air to give hypothetical frictionless bearing. As a consequence of rotation of driving device, the fluid sample offers resistance to the speed and forces to twist the torsion bar. The torque can be calculated as the stiffness of the torsion bar is known by determining the resultant twist with the assistance of angular position detector.

The product of torque and angular velocity with the “form factors” C1 and C2 to calculate the value of shear stress, τ and shear rate γ , respectively.

$$\text{Shear Stress} \quad \tau = C_1 \times T \quad (5.1)$$

$$\text{Shear rate} \quad \gamma = C_2 \times \omega \quad (5.2)$$

$$\text{Viscosity} \quad \eta = \tau/\gamma \quad (5.3)$$

Whereas T represents the torque value and ω represents the angular velocity value.

In some measuring rheometer device the arrangements in parallel plates type, the gap between the measuring device is changeable and that can be reset by the user. In such case the equation shear rate is:

$$\text{Shear rate} \quad \gamma = (C_2 \times \omega)/L \quad (5.4)$$

Where, L represents the gap.

Form factors are related to the various arrangements used with measuring systems and the equations are

$$\text{Cone plate:} \quad C_1 = \frac{1}{\left(\frac{2}{3}\right)\pi r^3} \quad \text{and} \quad C_2 = \frac{1}{\theta}$$

Where, r = radius of cone.

And

θ = cone angle in radius.

$$\text{Parallel plates:} \quad C_1 = \frac{1}{\left(\frac{2}{3}\right)\pi r^3} \quad \text{and} \quad C_2 = \frac{3r}{4}$$

$$\text{Co-axial cylinders:} \quad C_1 = \frac{1}{2\pi r^2 H} \quad \text{and} \quad C_2 = \frac{2r_1^2 r_2^2}{r_{avg}^2 (r_1^2 - r_2^2)}$$

Where, $r_{avg} = \frac{r_1 + r_2}{2}$, r_1 = inner radius; r_2 = outer radius and H = Height of cylinder.

5.4 EXPERIMENTAL SETUP

The Rheometer apparatus (Model: Rheolab Q-C, made by: Anton Paar Company Ltd, Germany) is taken in use to examine the rheological characteristics (i.e. relationship between shear strain rate and shear stress) of coal water slurry, charcoal water slurry and coal charcoal water slurry. The working method of Rheolab Q-C (Rheometer) apparatus is based on Searle method and It is a rotational rheometer and it has electronically commuted highly dynamic synchronous motor and also highly accurate encoder. It has torque and wide speed ranges and very petite motor response time. The pictorial view of Rheolab Q-C (Rheometer) apparatus is shown in Figure 5.1. The rheological properties are evaluated with the help of shear stress at various shear rates. The measurements can be obtained by selecting either controlled shear rates or controlled shear stress test settings. It has wide speed and torque ranges and very petite motor response time. Two different kind measuring systems can be taken as per requirement of the experiments or study. These models are DG42/SS/QC- LTD (for lesser concentrated slurry) and CC27/QC-LTD (for higher concentrated slurry). The rheometer apparatus consists of a concentric bob and cup with a little annular distance in between them. For each experiment the slurry is prepared and is filled up to the mark in the cup. The cup is then placed into the measuring cylinder after that the system is attached to the rotating spindle. The slurry is forced to shearing action in between the annular gap between the cup and bob of the rheometer and therefore shear stress is evaluated as a function of shear rate (Schramm 2000). The Rheoplus software program installed on a computer system, where the outcomes are obtained. Computer system is linked to the rheometer by LAN connection. The whole specifications of rheometer are mentioned in Table 5.1. Photographic view of rheometer is shown in Figure 5.2.

Table 5.1: Specifications of rheometer apparatus

Serial No.	Components and parameters	Specifications and range
1.	Type of motor	Synchronous electric motor
2.	Range of shear stress	0.5 to 3 x 10 ⁷ , mPa
3.	Range of shear rate	0.01 to 4000, sec ⁻¹
4.	Range of speed	0.01 to 1200, min ⁻¹
5.	Range of temperature	-20 to 180, oC
6.	Range of viscosity	0.1 to 10 ⁹ , mPa-s
7.	Range of torque	0.25 – 75, mN-m



Figure 5.2: Rheolab Q-C (Rheometer) apparatus

5.5 SLURRY SAMPLE PREPARATION FOR EXPERIMENT

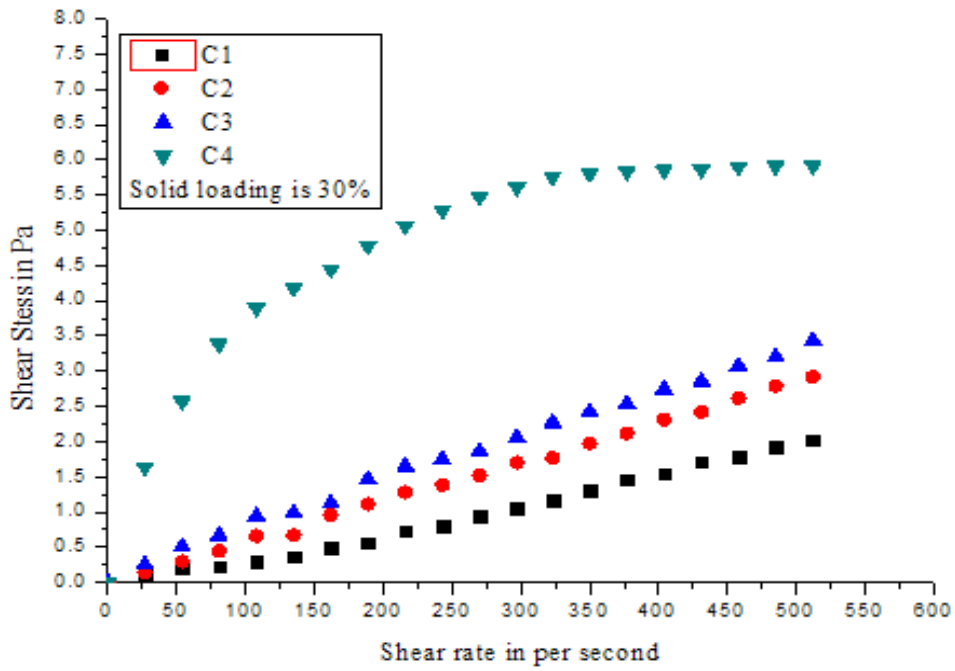
The slurry suspension sample of 100 ml is made up by the blending of needed amount of solids (i.e. coal, charcoal and coal-charcoal together) in liquid (Water) to obtain the desired concentration of solids in slurry. Laboratory-size ball mill is used to convert to raw sample into to pulverized form in different required ranges sizes 0-53, 53-75, 75-106 and 106-150 μm for the experiments. For weighing of solids the electronic pan balance with resolution of ± 0.0001 gram is taken in use and slurry is quietly prepared with the help glass rod to avoid the attrition and change in mass of solid particles while slurry preparation. Before experimentation The bob and cup assemblies are fixed with locking system. In stationary cylindrical cup the slurry is poured upto the fixed mark on cylinder and again stirred with the help of glass rod for 10-15 minutes to ensure homogenization of slurry suspension. Meantime, bob is lowered into cylindrical cup and system is assembled to the rotating spindle by forcing down the flanged coupling. At constant temperature of 25 $^{\circ}\text{C}$ rheological experiments are carried out in the shear rates range of 0-512 s^{-1} . To check the accuracy of rheological data each experiment is carried out at least three times.

5.6 FOR THE COMPARATIVE STUDY OF UNI-MODAL COAL WATER SLURRY (CWS) AND CHARCOAL WATER SLURRY (CHWS)

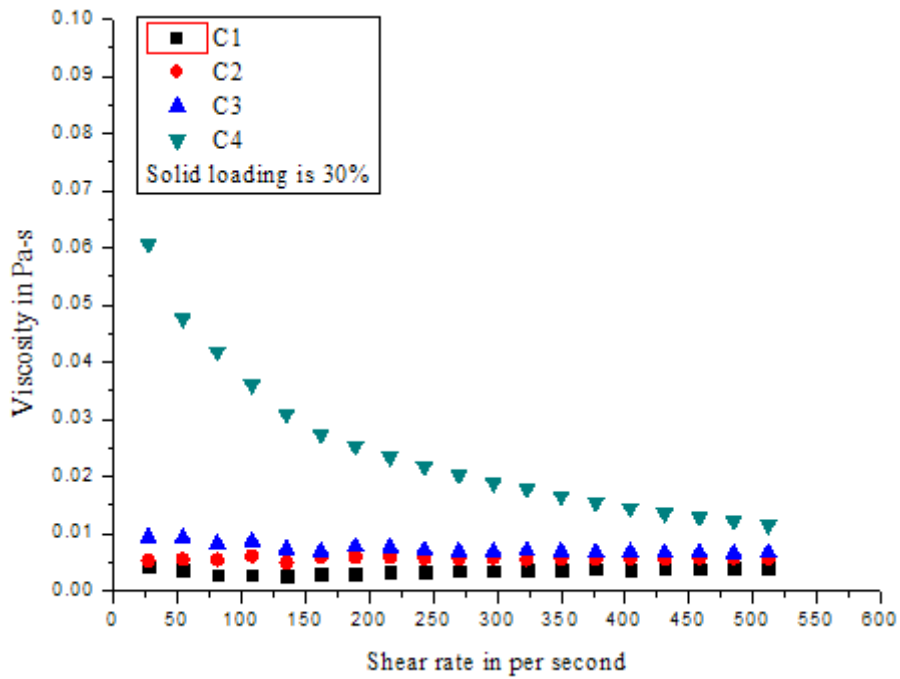
The coal water slurry and charcoal water slurry sample were prepared at different concentration 30%,40%,50% and 60% by weight of the solid loading. The uni-modal slurry suspension samples were prepared by considering the coal and charcoal particles in the size range of 0-150 μm and to examine the effect of solid loading in coal water slurry and charcoal water slurry. In Figure 5.3 prepared slurry sample is shown. The outcomes obtained are shown in the rheograms. The variation of shear stress with shear rate of the coals and charcoal samples C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renusagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4-Charcoal are shown in Figure 5.4 - Figure 5.7.



Figure 5.3: Prepared slurry sample

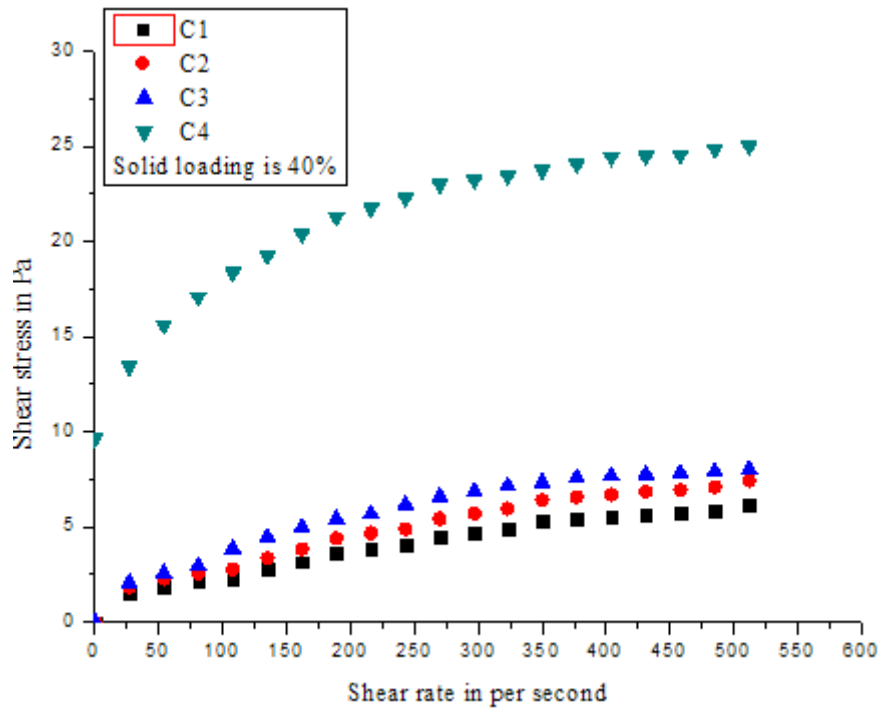


(a)

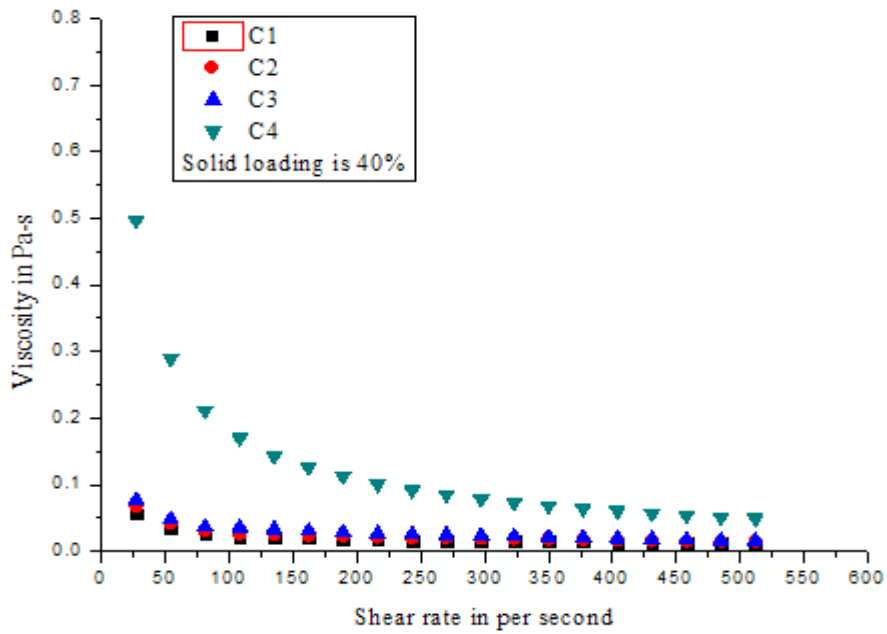


(b)

Figure 5.4: (a) Shear stress (in Pa) vs. shear rate (per second); (b) Viscosity(Pa-s) vs. shear rate (per second), C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renusagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4- Charcoal at 30% by wt. solid loading.

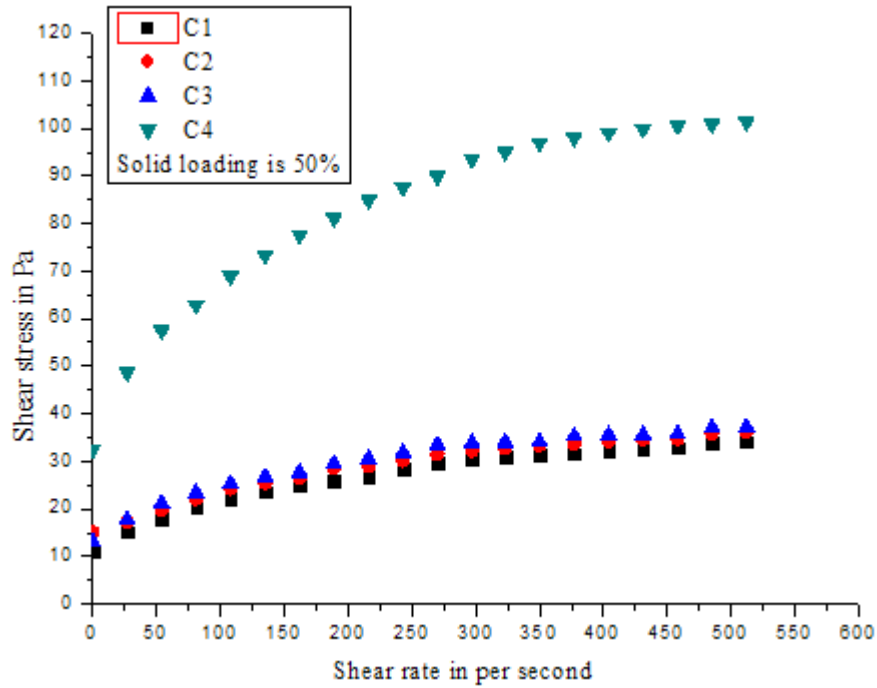


(a)

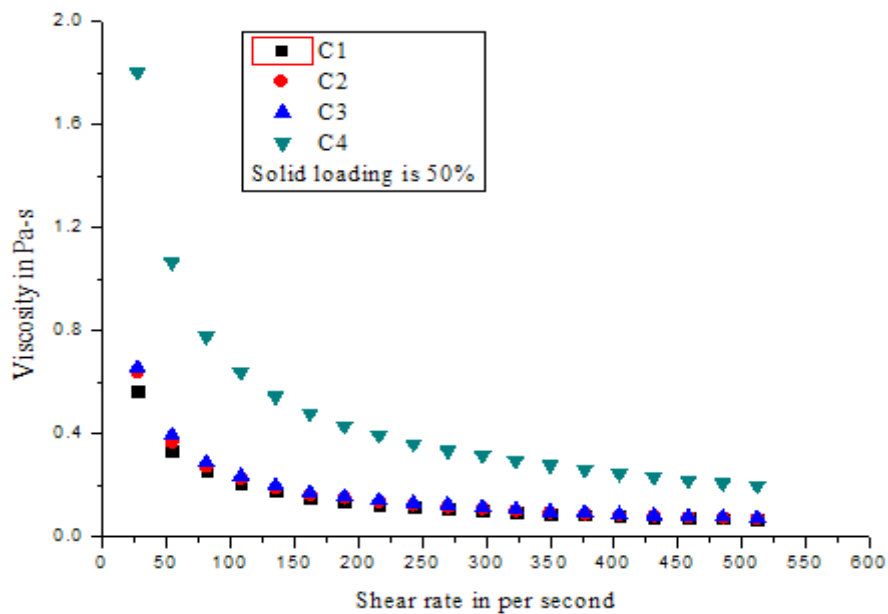


(b)

Figure 5.5: (a) Shear stress (in Pa) vs. shear rate (per second); (b) Viscosity(Pa-s) vs. shear rate (per second), C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renusagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4- Charcoal at 40% by wt. solid loading.

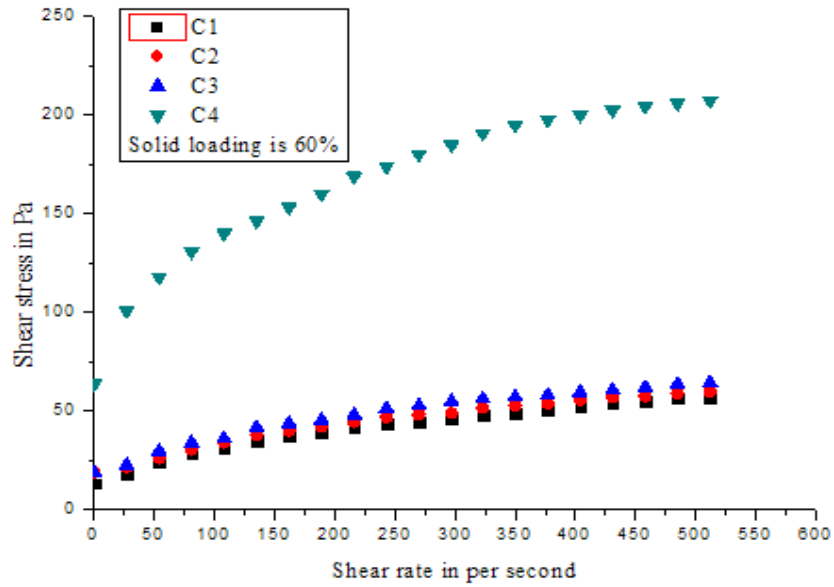


(a)

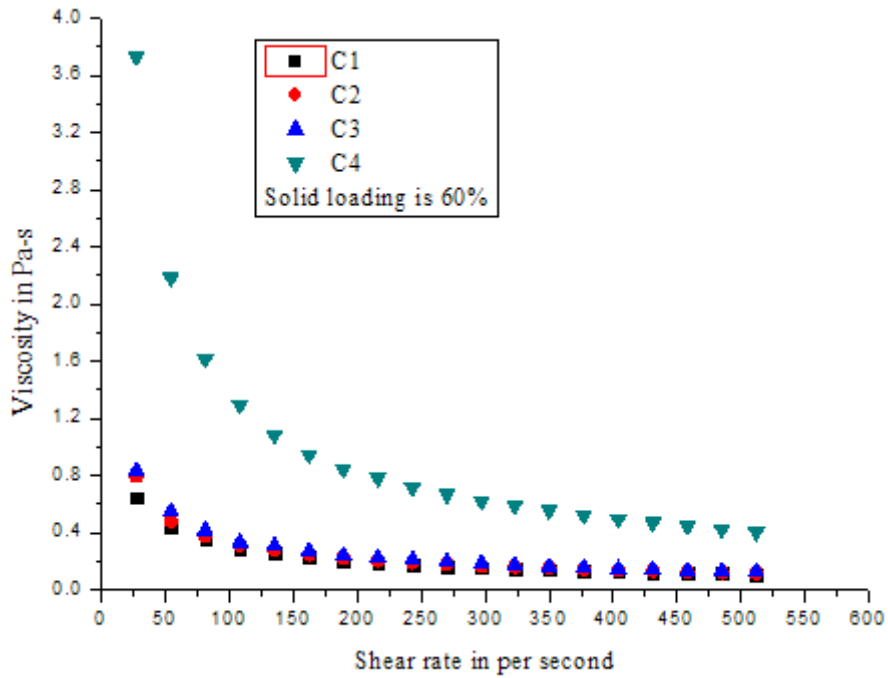


(b)

Figure 5.6: (a) Shear stress (in Pa) vs. shear rate (per second); (b) Viscosity(Pa-s) vs. shear rate (per second), C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renusagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4- Charcoal at 50% by wt. solid loading.



(a)



(b)

Figure 5.7: (a) Shear stress (in Pa) vs. shear rate (per second); (b) Viscosity(Pa-s) vs. shear rate (per second), C1-Reliance sasan mega power, Singrauli, Madhya Pradesh. C2- Hindalco Renusagar power plant. Dist-Sonebhadra, Uttar Pradesh.C3- Lanco Anpara industries ltd. Anpara, Uttar Pradesh.C4- Charcoal at 60% by wt. solid loading.

From rheograms of coal water suspension and charcoal water suspension, it can be said that the flow behaviour of slurry suspension was highly affected by variation solid loading. From

Figure 5.4- Figure 5.7, it was found that both shear stress and apparent viscosity are enormously influenced with solid loading for both coal water slurry and charcoal water slurry. As the solid loading is increased, the apparent viscosity of the coal-water slurry and charcoal water slurry is also increased. The rise in the apparent viscosity with solid loading may be due to more interactions among particles. The frictional force between particles becomes significant thus accompanying resistance is reflected with the increase in viscosity (Mishra et al. 2002). The all type of coal-water slurry shows Newtonian behaviour upto 30% solid loading and at 40% solid loading coal-water slurry shows pseudo-plastic i.e. (shear thinning) behaviour. Beyond 40% of solid loading coal-water slurry shows Herschel-Bulkley behaviour. That means the apparent viscosity is does not depend on shear rate upto 30% solid loading of coal-water slurry. Beyond 30% solid loading, apparent viscosity decreases with rise in shear rate because of shear thinning behaviour of coal water slurry.it was also found for CWS there is marginal drop in apparent viscosity after certain shear rate like for 40% solid loading shear rate is about 200 S-1, for 50% solid loading shear rate is 275 S-1 and for 60% solid loading shear rate is 325 S-1 for all type of coal water slurry. It was also found that as the % of ash contain increases in coal sample the apparent viscosity is also high for a particular shear rate. Similar results were found by (Senapati et al. 2002). For charcoal water slurry apparent viscosity is quite high as comparison Indian coal water slurry at particular shear rate. This is due high porous particle of charcoal and hydrophilic nature of charcoal particles Pengfei Liu et al. (2016). At 30% of solid loading it was found that flow behaviour of charcoal water slurry is pseudo-plastic in nature and beyond 30% of solid loading flow behaviour is Herschel-Bulkley. For ChWS the apparent viscosity is highly influenced by solid loading.

5.7 FOR THE STUDY OF CHARCOAL WATER SLURRY(CHWS) UNI-MODAL AND BI-MODAL

The charcoal water slurries were prepared at a concentration of 40% by weight of the solid loading. The uni-modal charcoal water slurry samples were made by taking the charcoal particles in the size range of 0-53,53-75,75-106 and 106-150 μm and the bi-modal charcoal slurry samples were prepared by varying the concentration of the charcoal particles in the size ranges of 0-53 μm (fine) and 53-75 μm (coarse).

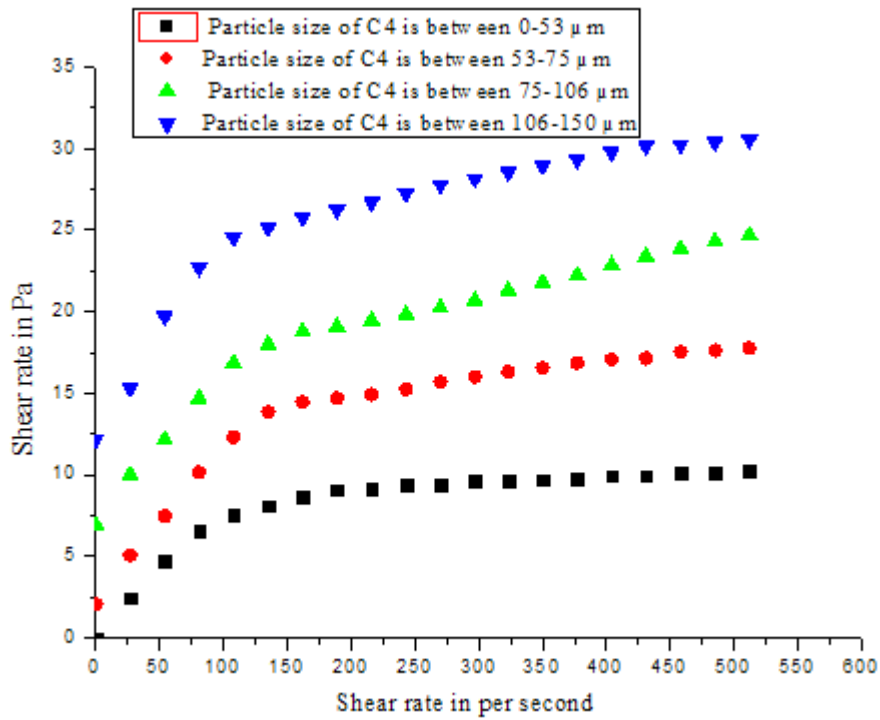
Table 5.2: Mono-modal charcoal water slurry at 40% concentration of charcoal by % wt.

Serial No.	Slurry samples	Maximum solid loading	Particle size range
1.	Mono-modal	40%	<53 μm
2.	Mono-modal		53 to 75 μm
3.	Mono-modal		75 to 106 μm
4.	Mono-modal		106 to 150 μm

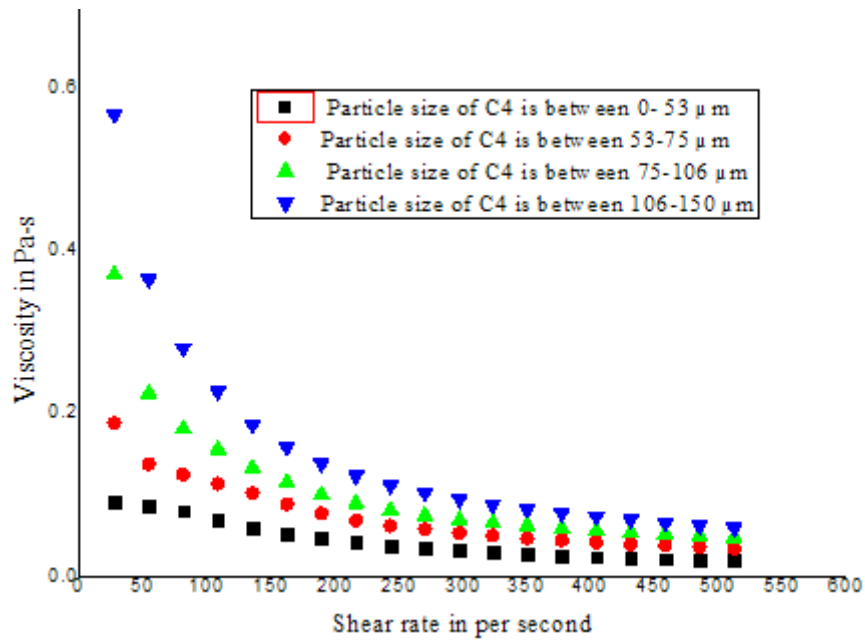
Table 5.3: Bi-modal charcoal water slurry sample at 40% concentration of charcoal by % wt.

Serial No.	Slurry suspension (in term of PSD)	Maximum solid loading	Composition	Fraction (% by wt.) Coarse: Fine
1.	Bi-modal	40%	Coarse (53-75 μm) Fine (0-53 μm)	90:10
2.	Bi-modal		Coarse (53-75 μm) Fine (0-53 μm)	80:20
3.	Bi-modal		Coarse (53-75 μm) Fine (0-53 μm)	70:30
4.	Bi-modal		Coarse (53-75 μm) Fine (0-53 μm)	60:40

Experiments have been completed to study the comparison of uni-modal of charcoal slurry in different particle size range (PSD) and bi-modal particle size charcoal slurries and at 25 °C constant temperature. Variations on the flow properties like viscosity, shear stress, etc. and on a computer screen the rheological data were obtained. The outcomes obtained are shown in the rheograms. The outcomes of the data obtained by the rheological test of the charcoal samples.



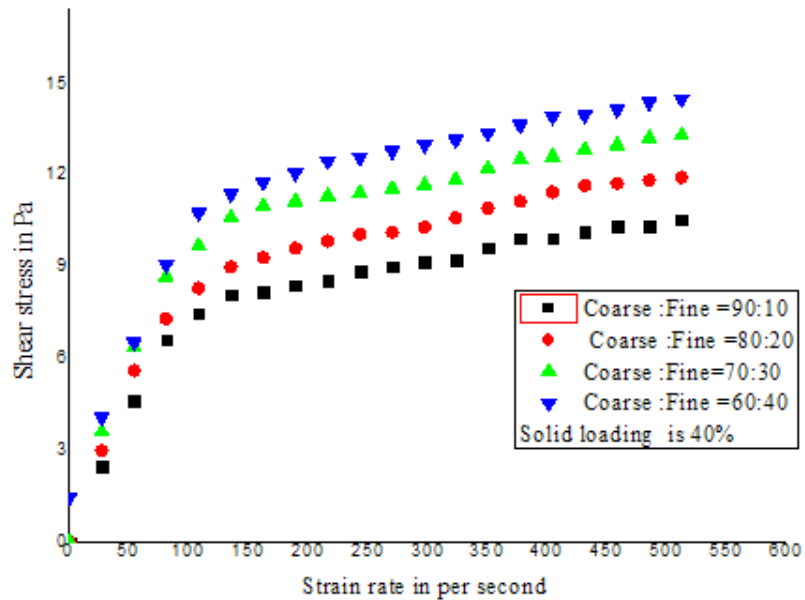
(a)



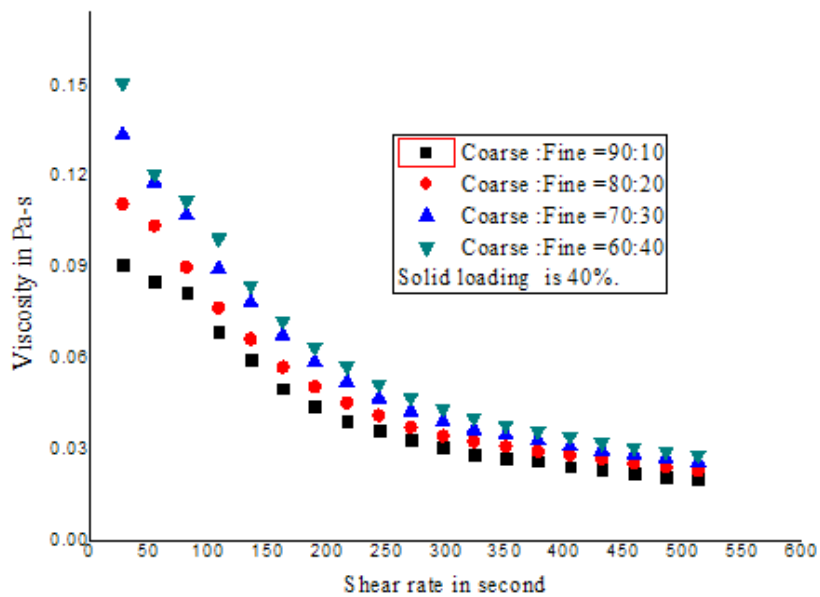
(b)

Figure 5.8: (a) Shear stress (in Pa) vs. shear rate (per second); (b) Viscosity(Pa-s) vs. shear rate (per second), C4-Charcoal at 40 % by weight solid loading. For uni-modal slurry samples in different particle size range.

From Figure 5.8 (a) and (b), it was observed for mono-modal samples that as the particle size reduces the apparent viscosity gets reduce for given shear rate value this is because of pore size is small in fine charcoal particles. Also observed that for particle size range between 0-53 μm apparent viscosity more less stable for shear rate 350 S-1.



(a)



(b)

Figure 5.9: (a) Shear stress (in Pa) vs. shear rate (per second); (b) Viscosity(Pa-s) vs. shear rate (per second), C4-Charcoal at 40 % by weight solid loading. For modal bi-modal slurry samples.

From Figure 5.9 (a) and (b), it was observed for bi-modal samples that as the coarser particles % by wt. increases the apparent viscosity is increased this because of pore size of charcoal

particles is larger in as comparison with fine charcoal particles. Moreover, apparent viscosity is less for mono-modal in comparison with bi-modal charcoal water slurry sample at a given solid loading. In literature, it was seen that for coal water slurry bi-modal has less apparent viscosity (Buranasrisak et al. 2012) and others.

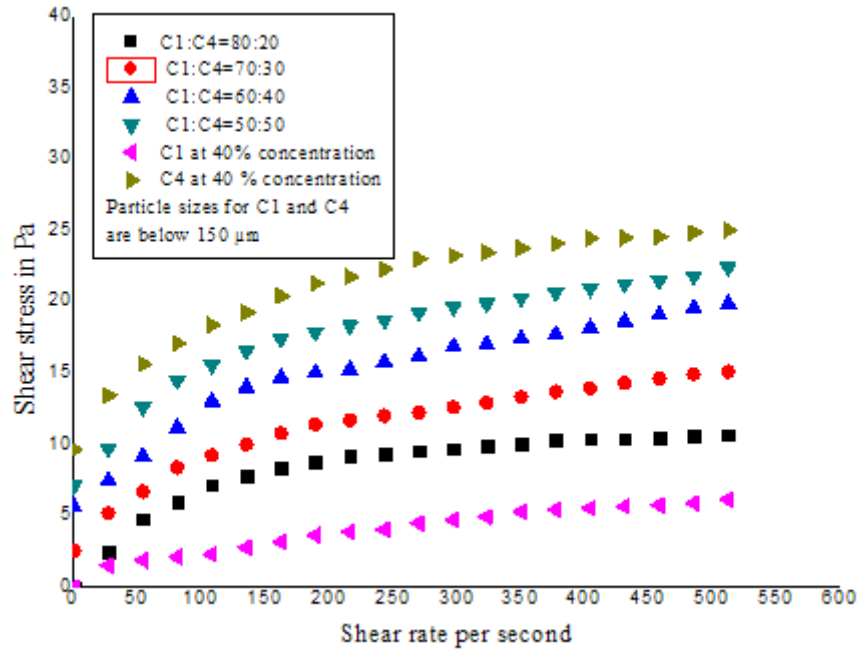
5.8 FOR THE COMPARATIVE STUDY OF COAL-CHARCOAL WATER SLURRY (CCHWS), COAL WATER SLURRY (CWS) AND CHARCOAL WATER SLURRY (CHWS)

The coal-charcoal water slurry sample were prepared at different concentration. The maximum solid loading was 40 and 50% a by weight. Coal (C1) and charcoal (C4) together added to preparation of coal-charcoal slurry. For this experiments different ratio of coal and charcoal were taken. Particle size range for both coal and charcoal was taken 0-150 μm and at 25 °C constant temperature. The goal of this study was to investigate the viscosity of coal charcoal water slurry suspension when coal and charcoal is mixed together in different ratio.

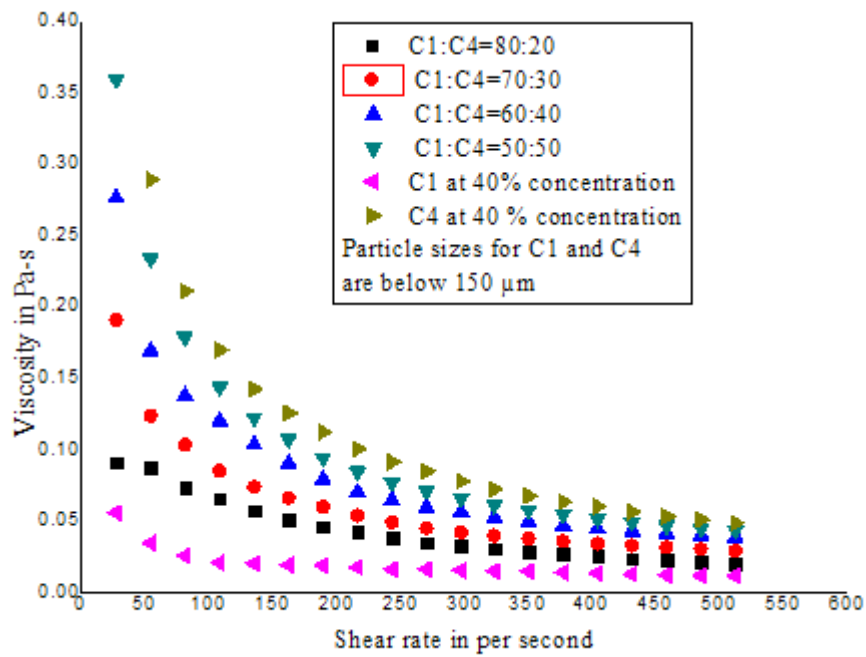
Table 5.4: Coal-charcoal water slurry (CChWS) samples at 40% maximum solid loading

Serial No.	Slurry suspension (in term of different kind of solid)	Maximum solid loading in (% by wt.)	Solid composition (% by wt.)
1.	Bi-modal	40%	C1:C4=80:20
2.	Bi-modal		C1:C4=70:30
3.	Bi-modal		C1:C4=60:40
4.	Bi-modal		C1:C4=50:50

Similar sample composition of coal-charcoal water slurry was taken at 50% (by wt.) for maximum solid loading in CChWS. Variations on the flow properties like viscosity, shear stress, etc. and on a computer screen the rheological data were obtained. The outcomes obtained are shown in the rheograms. The outcomes of the data obtained by the rheological test of the coal-charcoal water slurry (CChWS), coal water slurry (CWS) and charcoal water slurry(ChWS).

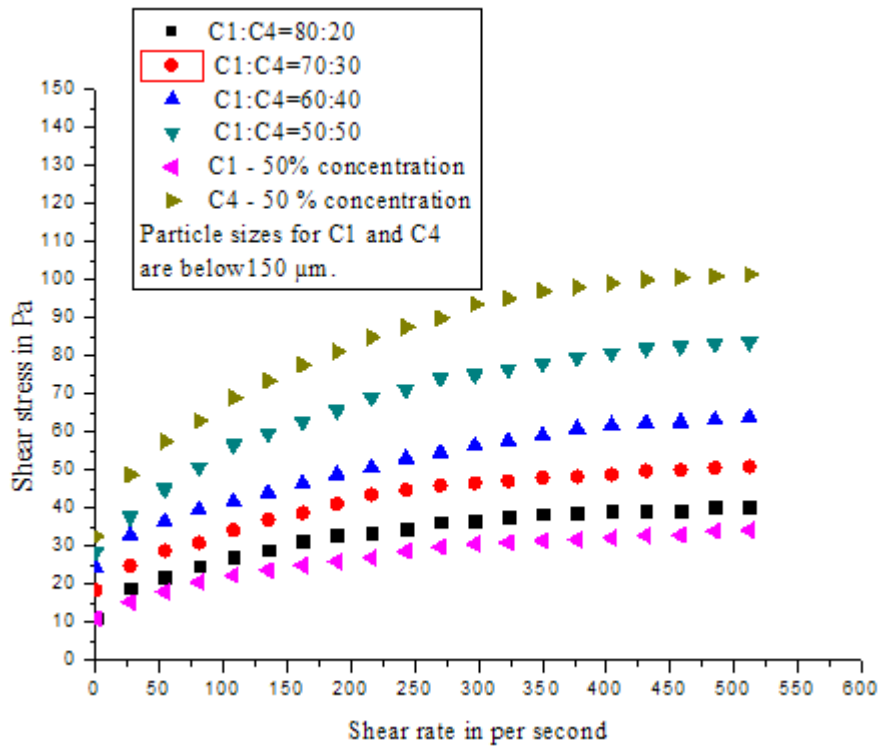


(a)

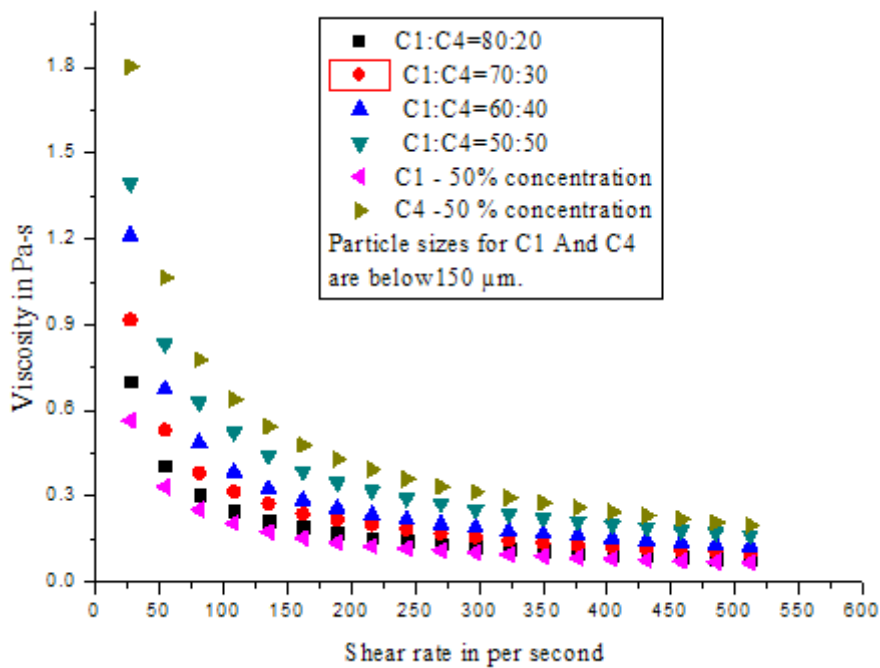


(b)

Figure 5.10: (a) Shear stress (in Pa) vs. shear rate (per second); (b) Viscosity(Pa-s) vs. shear rate (per second), C1-Reliance sasan mega power, Singrauli, Madhya Pradesh, C4-Charcoal at 40% by weight solid loading.



(a)



(b)

Figure 5.11: (a) Shear stress (in Pa) vs. shear rate (per second); (b) Viscosity(Pa-s) vs. shear rate (per second), C1-Reliance sasan mega power, Singrauli, Madhya Pradesh, C4-Charcoal at 50% by weight solid loading.

From Figure 5.10 (a) and (b), it was observed that for a given solid loading apparent viscosity is high for charcoal water slurry with comparison of coal water slurry. Further, observed that when coal and charcoal is blended together the apparent viscosity is within the range of coal water slurry and charcoal water slurry. Moreover, it was observed that as the percentage of charcoal increases the apparent viscosity increases. Similar results are found at 50% solid loading too.

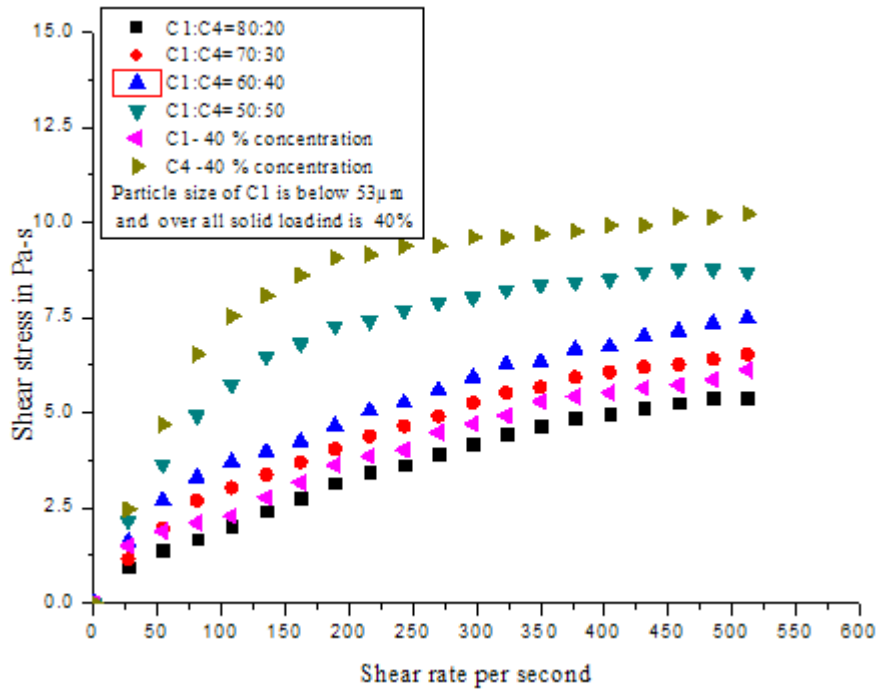
5.9 EFFECTS OF FINE CHARCOAL PARTICLE ON RHEOLOGY: A COMPARATIVE STUDY OF COAL-CHARCOAL WATER SLURRY (CCHWS)

The coal-charcoal water slurry sample were prepared at different concentration. The maximum solid loading was 40% and 50% a by weight. Coal and charcoal together added to preparation of coal-charcoal slurry. For this experiments different ratio of coal and charcoal were taken. Particle size range for coal (C1) and charcoal (C4) was 0-150 μm and 0-53 μm and at 25 °C constant temperature. The goal of this study was to investigate the viscosity of coal charcoal water slurry suspension when fine charcoal particles are mixed together in different ratio.

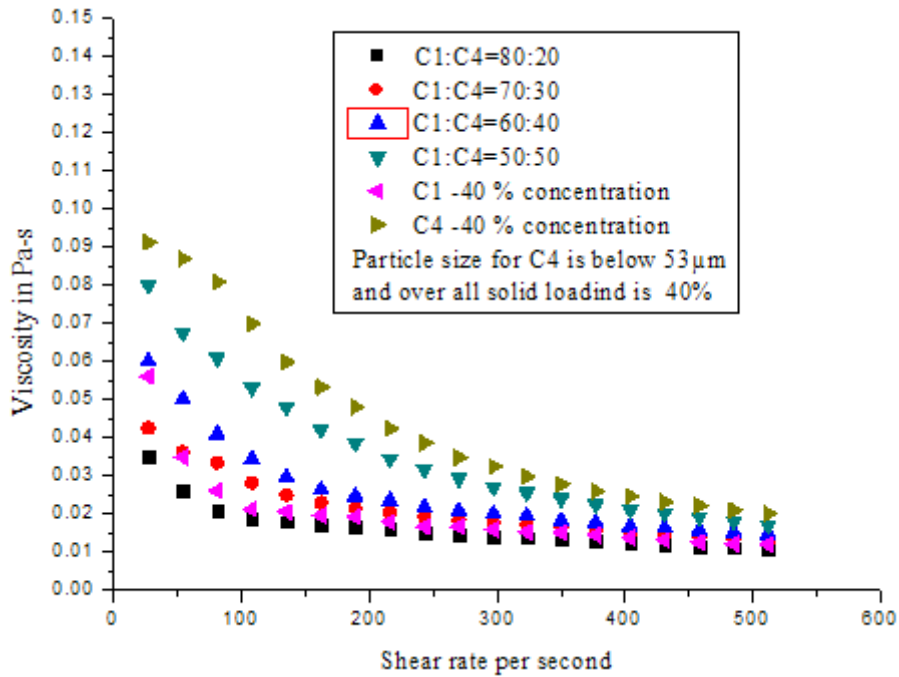
Table 5.5: Coal-charcoal water slurry (CChWS) samples at 40% maximum solid loading when particle size of charcoal particle is below 53 μm .

Serial No.	Slurry suspension (in term of different kind of solid)	Maximum solid loading in (% by wt.)	Solid composition (% by wt.).
1.	Bi-modal	40%	C1:C4=90:10
2.	Bi-modal		C1:C4=80:20
3.	Bi-modal		C1:C4=70:30
4.	Bi-modal		C1:C4=60:40

Similar sample composition of coal-charcoal water slurry was taken at 50% (by wt.) of maximum solid loading in CChWS. Variations on the flow properties like viscosity, shear stress, etc. and on a computer screen the rheological data were obtained. The outcomes obtained are shown in the rheograms. The outcomes of the data obtained by the rheological test of the coal-charcoal water slurry (CChWS), coal water slurry (CWS) and charcoal water slurry(ChWS).

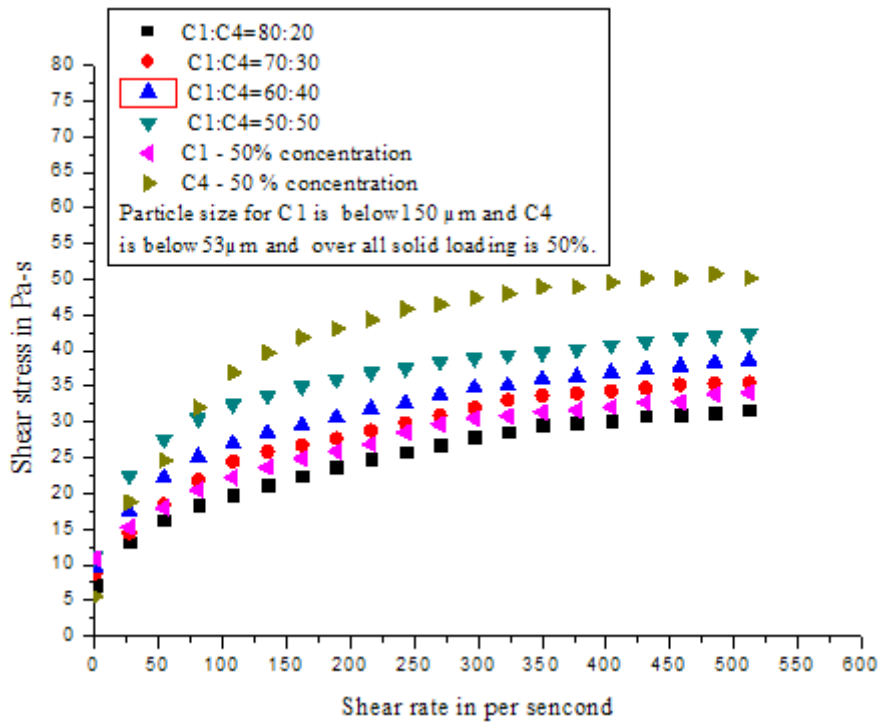


(a)

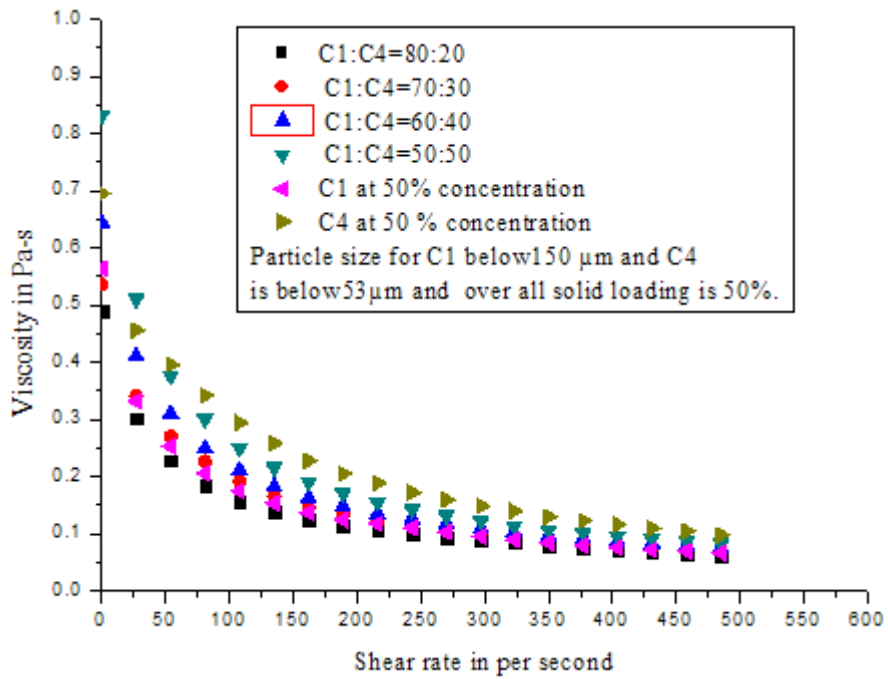


(b)

Figure 5.12: (a) Shear stress (in Pa) vs. shear rate (per second); (b) Viscosity(Pa-s) vs. shear rate (per second), C1-Reliance sasan mega power, Singrauli, Madhya Pradesh, C4-Charcoal at 40% by weight solid loading.



(a)



(b)

Figure 5.13: (a) Shear stress (in Pa) vs. shear rate (per second); (b) Viscosity(Pa-s) vs. shear rate (per second), C1-Reliance sasan mega power, Singrauli, Madhya Pradesh, C4-Charcoal at 50% by weight solid loading.

From Figure 5.12 (a) and (b), it was found that when 20% by wt. charcoal fine particle is added with coal the apparent viscosity lower as comparison with coal water slurry. This is because fine charcoal particle take space available between coal particle that form smoothness coal-charcoal slurry. Further, increment in charcoal upto 40% by wt. apparent viscosity increases quietly. Beyond 50% by wt. addition the apparent viscosity increases sharply. Reason of increment in apparent viscosity is as % of fine charcoal particles increases the hydrophilic nature of charcoal particle may play role in rheology behaviour of coal-charcoal water slurry.

CHAPTER 6

RHEOLOGY STUDY OF COAL-CHARCOAL WATER SLURRIES WITH ADDITIVE

6.1 SURFACTANTS

The term surface – active agent or “surfactant” shows heterogeneous and chain molecules having both hydrophobic moieties and hydrophilic.

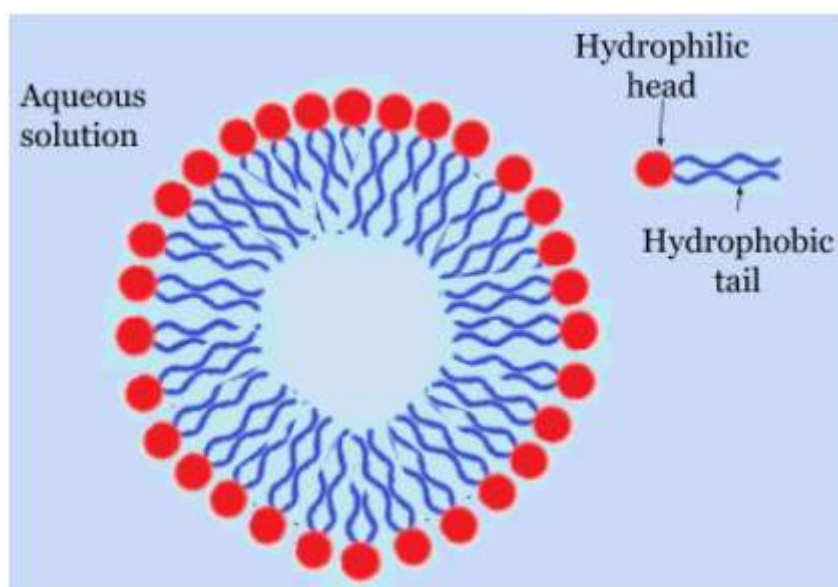


Figure 6.1: Surface-Active Agents or Surfactants

Micelle-In an aqueous solution, molecules have both charged groups or polar and non-polar zones (amphiphilic molecules) construct aggregates known as micelles. In a micelle, ionic heads construct an outer shell when they link with water, while nonionic ends are stay in the interior. Thus, the core of a micelle, being formed of long nonionic ends. The length of the non-ionic ends, the nature and size of the ionic head, the pH of the solution, the presence of added salts and the temperature are the most crucial factors for determining the kind of the acquired aggregate. it is possible to alter size and shape of the micelles if above mentioned parameters are changed, the rheological behaviour of slurries is a strong function of the surface charge/characteristics of solids. This surface character can be altered by chemicals called surfactants. They normally stop aggregation/flocculation by providing net charge on the surface of particles (in case of ionic surfactants) and by steric repulsion in case of nonionic additives. These changes often manifest in the form of altered.

6.2 TRITON X-100

(C₁₄H₂₂O(C₂H₄O)_n): A non-ionic surfactant which contains hydrophilic polyethylene oxide chain (on average it has 9.5 ethylene oxide units) and other part is an aromatic hydrophobic group. The hydrocarbon part is a 4-(1,1,3,3-tetramethylbutyl)-phenyl group. It is link to the Pluronic range of detergents marketed by BASF. Triton X-100 is frequently warmed prior to use due to it is more viscous at room temperature.

Figure 6.2 shows molecular structure of triton X-100.

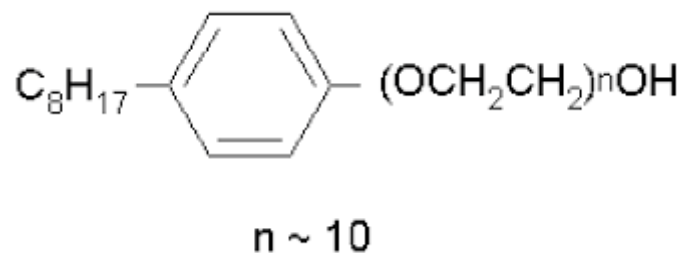


Figure 6.2: Triton X-100

Uses: it is a commonly used detergent in laboratories.

Permeabilizing unfixed eukaryotic cell film.

Solubilizing film proteins in their native state in conjunction with zwitterionic detergents such as CHAPS.

6.3 EFFECT OF TRITON X-100 ON COAL-CHARCOAL WATER SLURRY RHEOLOGY

The non-ionic additive TRITON X-100 was bought from Loba Chemie Pvt.Ltd, Mumbai and it is used to analyse the effect of surfactants on the rheology of coal charcoal slurries. Its chemical name is iso-octyl phenoxy polyethanol and pH value (5% aqueous solution) is between 6-8.

The experiments setup and methodology is the same as in chapter 5 and slurry was prepared by coal, charcoal, additive and water. particle size for both coal and charcoal were below 150 μm and maximum solid loading was 50% by weight. Coal (C1) and charcoal (C4) was blended in equal ratio. Rheology tests were conducted in presence of various dosages of additive. The results of rheology are shown in Figure 6.3.

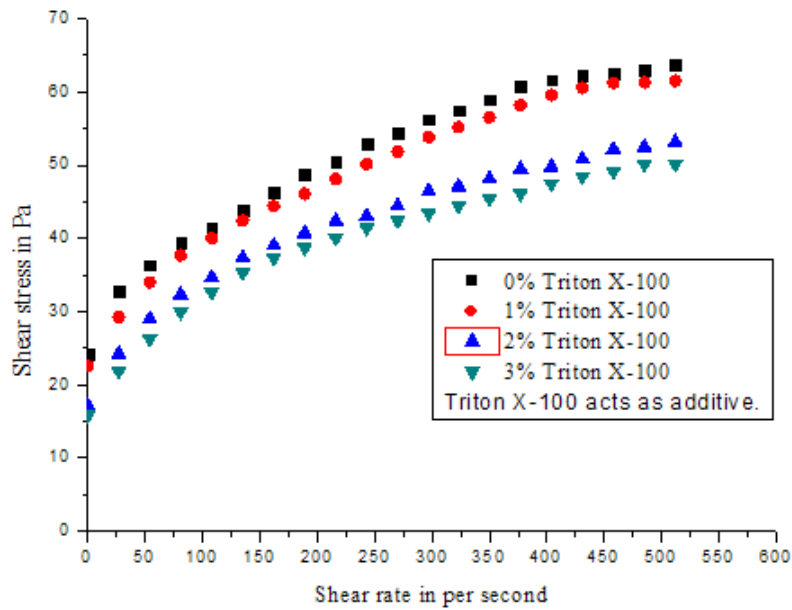


Figure 6.3: Shear stress (in Pa) vs. shear rate (per second) of coal charcoal water slurry with additive at solid loading 50% by wt. and coal and charcoal is blended in equal ratio by wt.

Further, another tests were carried out and there is one change was made in this test coal and charcoal ratio was 60:40 by weight of total solid concentration. Rheology tests were conducted in presence of various dosages of additive. The results of rheology are shown in Figure 6.4.

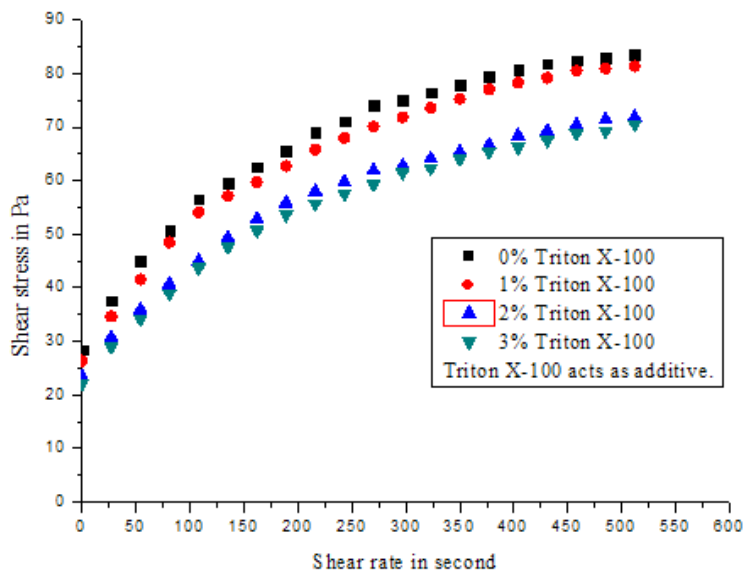


Figure 6.4: Shear stress (in Pa) vs. shear rate (per second) of coal-charcoal water slurry with additive at solid loading 50% by wt. and coal and charcoal is blended in 60:40 ratios by wt.

The above two Figure 6.3 and 6.4 clearly indicates that triton X-100 has profoundly affected the rheology of coal-charcoal water slurry. The following points can be made from Figure 6.3 and 6.4.

The coal-charcoal slurry shows lower viscosity for all tested at various dosages of additives. The additive is effective in both cases and also found that at 2% by weight addition of Triton X-100 in slurry maximum rate of reduction of apparent viscosity in the slurry for both the cases. Further, increase in additive (Triton X-100) percentage i.e. from 2% to 3% in slurry, viscosity does not reduce too much.

7.1 CONCLUSIONS

The following conclusions have been made on the basis of present work:

- From rheology studies, the all type of coal-water slurry shows Newtonian behaviour upto 30% solid loading and at 40% solid loading coal-water slurry shows pseudo-plastic i.e. (shear thinning) behaviour. Beyond 40% of solid loading coal-water slurry shows Herschel-Bulkley behaviour while at 30% of charcoal loading rheological behaviour is pseudo-plastic in nature and beyond 30% of charcoal loading flow behaviour is Herschel-Bulkley. At 60% of charcoal loading in charcoal water slurry the apparent viscosity is crossed the limiting value of apparent viscosity.
- From static stability test it was found that after 20 hours' average penetration for slurries samples were 68%,64% ,60% 74%. for C1, C2, C3 and C4 respectively. Further, static stability of coal (C1) water slurry is after 20 hours' average penetration when charcoal is added 75%. If fine charcoal particle below 53 μm is added to coal (C1) water slurry static stability after 20 hours' average penetration was 77%.
- Mono-modal charcoal water slurry has less apparent viscosity as compared with bi-modal charcoal water slurry.
- In coal charcoal water slurry apparent viscosity value increases as the charcoal % increases in slurry with comparison of coal water slurry while charcoal fine particles are added upto 20% by weight of total solid loading the apparent viscosity is lower with comparison of coal water slurry for 40% and 50% of total solid loading. Further, increases in charcoal percentage apparent viscosity increases.
- The coal-charcoal slurry shows lower viscosity for all test at various dosages of additives and at 2% by weight addition of Triton X-100 in slurry maximum rate of reduction of apparent viscosity in the slurry for both the cases. Average reduction in apparent viscosity of slurry in which coal and charcoal was blended in equal ratio was 16 % and when ratio of coal and charcoal was 60:40 reductions in apparent viscosity was 19%.

7.2 FUTURE SCOPE

A lot of work required to be done in the present work. It could be possible to suitably manipulation of particle size distribution (PSD) in coal as well as charcoal, pH value to meet a given requirement. The influence of additive on the stability of slurries could be done and it might be possible to develop an additive which could together lower viscosity/yield stress and enhanced stability of the slurry. Also some pre-treatment of coal and charcoal might be an option for optimization of rheological behaviour of the coal charcoal water slurry.

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