Coal Water Slurry As a Substitute for Fuel Oil in India

Sunita Panda, Lecturer,
Dept. of Mechanical Engg.,
IGIT Sarang

Abstract **- Due to the known abundance of fossil fuel resources in India, a deliberate mindset to change over to coal as the alternate supply is inevitable. Indian coals in general are lower in rank, have fine grained mineral matter mostly of quartz and silicate origin with low sulphur. Since most of the studies have been done with coals available in the western countries having low ash content, therefore, an attempt has been made in this study some aspects of the rheological behavior of coal slurries prepared out of coals available in India. An empirical relationship has been established among shear stress, percentage of ash by weight and concentration of solid in coal water mixture. The coal water slurry will go a long way as an alternate source of fuel considering the rheological studies in designing pipelines for transportation of slurry with optimum solid concentration.**

Keywords – Coal water slurry, Rheology, HAAKE Rotational Viscometer, Shear thinning, Slurry concentration

I. INTRODUCTION

Coal water slurry (CWS) is a fuel which consists of fine coal particle suspended in water. Presence of water in CWS reduces harmful emissions and makes the coal explosion proof thus makes it useful as a liquid fuel. The concept of coal water slurry dates back to Smith and Munsell (1879) [1] when patented for coal oil utilization as fuel were granted, but did not get significant commercial proposition. Coal oil slurries were used as fuel in the USA during 1920s and later there were some application in the other countries also. But availability of cheap oil reduced its attractiveness [2]. Coal-water slurry technology is a type of system which concern with the production, storage, pipeline transport, shipping ash removal and combustion of fuel consisting of water and fine coal powder which can be burnt directly without requiring dewatering.

This new technology has the advantages like:

1. Special port facilities are not required and loading and unloading costs are extensively reduced
2. Dusting and spontaneous firing are eliminated in storing and shipping of coal.
3. Start up and load adjustment are more readily achievable during burning.
4. Improvement of overall economy including better qualitative effects.

In a country like India, coal is available in certain parts of Orissa, Bihar, MP, Chhattisgarh, West Bengal, Maharashtra, Madhya Pradesh, and Andhra Pradesh where as coal is required across the country. Again transportation of coal by roadways & railways is costly and overburdening. Considering uneven distribution of coal, transportation in the form of coal water slurry through pipeline hydraulically can be one of the attractive possibilities. Slurry pipe lines are also amenable to automation, safe, environmentally acceptable and economically viable for long distance haulage. In the light of above, experiments on "*Coal Water Slurry As A Substitute Fuel Oil In India*" was carried out using HAAKE RV 30 Viscometer, Germany to understand the properties of coal water mixture so that the same can be used as an alternative energy sources. Varied spectrum of coals containing ash between 8 % to 42.5 % have been taken for study in this work.

II. LITERTAURE REVIEW

This section deals with literature review on rheology of coal slurries. The rheology of coal and coal ash slurries has received attention in recent years because of widespread application in industry and academic interest. The focus of investigations has mostly been on viscosity of slurries and flow behaviour and taming them to meet certain requirements such as ease of transportation and handling etc. The viscosity of slurries is dependent on many parameters such as concentration, pH, particle size distribution, chemical composition, presence of chemicals etc [3, 4, 5]. The flow behavior is Newtonian at lower concentrations (upto 30%) for both coal ash and coal water slurries above which it deviates from Newtonian behavior to mostly shear thinning/pseudo- plastic. The coal slurries made of finer particles is more viscous as compared to those made of coarser ones. Mixing coarse particles with fine particles also helps in controlling viscosity. The wider particle size distributions show lower viscosities [6]. The flow behavior and slurry characteristics are greatly influenced by the presence of surfactants/additives.

Mishra *et a1* [03] investigated the rheological behavior of Indian coal-water slurry (CWS) using a HAAKE RV30 viscometer. They studied effect of solid concentration, ash content, pH, and temperature on the rheology of CWS. The CWS was prepared on three coal samples with solids concentration varying from 50-55%. They found that all the samples exhibited shear thinning behavior with increase in viscosity at higher concentration and ash content. pH was found to have a strong influence on the viscosity with highest around pH-6 and lowest around pH-8 for all slurry samples. Small regarding quantity of fly and bottom ash transported during the time limit.

Panda *et al* [7] have established the pressure loss in horizontal pipes for transportation of fly ash up to 60% concentration (by weight) by correlating it with the rheological behavior of the slurry. They have also reported that the pressure loss could be estimated reasonably well using pressure loss models developed for Newtonian fluids in the range of 20-25% concentration by weight

Parida *et al* [8] investigated the rheological behavior of fly ash samples. They found that viscosity of the fly ash slurry shows Newtonian nature up to a solids concentration of 50% (by weight). Above this concentration the behaviour is non- Newtonian. They used the pseudo-plastic model to estimate the head loss for the pipe flow and found that the transportation cost of fly ash slurry decreases drastically if it is transported at high concentrations instead of low concentrations

Knezevic *et al* [10] studied the influence of ash concentration on change of flow and pressure in slurry transportation. The results indicate that the transport should be accomplished with ash and bottom ash concentration below 50% but above 40% of solids. In this concentration range there is decrease of both flow (per volume) and pressure. However this decrease is considerably small regarding quantity of fly and bottom ash transported during the time limit

III. BENEFITS OF COAL WATER SLURRY

1. Makes the coal explosion-proof.
2. Presence of water in CWS reduces harmful emissions into the atmosphere by converting the coal into a liquid form, delivery and dispensing of the fuel can be simplified.
3. Because of the relatively low cost of coal when compared to other energy sources, CWS is a very competitive alternative to heating oil and gas. Depending on geographical area the price per unit energy of CWS may be 30% to 70% lower than the equivalent oil or gas.
4. Low emissions and low BTU (Gcal or MWh) make CWS as very cost effective and environmental friendly fuel for heat and power generation.
5. One side effect of the Coal Water Slurry making process is the separation of non carbon material mixed in with the coal before treatment. This results in a reduction of ash content to as low as 2% for the treated Coal Water Slurry Fuel, making it a viable alternative to Diesel fuel for use in large stationary engines or Diesel Electric Locomotives.
6. The demand for transport in India is increasing very rapidly due to increased social interaction between people and economic development. This has increased passenger and freight movement across the country. Pipelines form a unique mode of transportation. They can move large quantities of commodities, mainly fluids, over long distances at relatively low cost. The operations are environmentally friendly, dependable and continuous. The pipelines can be laid on a wide variety of terrains without much difficulty. Compared to normal surface mode like railways and road vehicles, the following advantages are particularly attractive:

i) They do not require the return of 'empties' to the starting point and as such are ideal for unidirectional traffic.
ii) They are insensitive to surface conditions such as storms, inclement weather, etc.
iii) Operating costs are low.
iv) Capital cost being the major cost of transportation, inflationary influences have a small effect on transport cost.
v) They are environmentally friendly.

IV. HAAKE ROTATIONAL VISCOMETER:

A rheometer is a kind of viscometer that measures viscoelastic properties of materials beyond just Viscosity. A rheometer, therefore, measures material behavior such as yield stress, kinetic properties, complex viscosity, modulus, creep, and recovery. Most rheometer models belong to three specific categories. These are the rotational rheometer, the capillary rheometer, and the extensional rheometer. The most commonly used of these is the rotational rheometer, which is also called a stress/strain rheometer, followed by the capillary rheometer. The HAAKE Rotational Viscometer, Germany (model RV 30) used for this study was supplied by M/s Haake mess Technik, Germany.

V. EXPERIMENTAL SET UP

Material & Methods

Coal Type: Three types of coal A, B & C were selected for carrying out experiments.

Type "A" – Imported coal from Indonesia as collected from Paradeep. It is low ash coal having very high calorific values.

Type "B" – Coal from West Bengal has been collected and used in this type. It is a medium ash coal having medium calorific values.

Type "C" – Coal from Talc her area has been collected and used in this type .It is a high ash coal having low calorific values.

VI. COAL SLURRY PREPARATION AT RHEOLOGY LABORATORY

In the laboratory a known amount of coal sample i.e 30g was taken in a beaker. To make slurry of 100gm, required amount of water (70g) of water was added to it. Then it was well stirred for 10 minutes for proper mixing and thus slurry of 30% concentration by weight was prepared. The same procedure was followed to prepare slurry of concentration 40%, 45%, 50%, 55% and 60%. Rheology of coal water slurry was studied at different concentration by using Haake Viscometer. The PH of the mixture was adjusted between 6 & 7 by adding 1.5 % solution of lime by volume.

Following formula was used to calculate weight concentration:

C_w = (weight of solid/weight of solid + weight of suspending medium) * 100.

The volume fraction was calculated by:

Ø = volume of solids/volume of solids + volume of suspending fluid.

Ø= (Cwt/ρ)/(Cwt/ρ+(100-Cwt)/ρ)

Where Ø = volume fraction
P = density of solid
Cwt = weight of solid

VII. EXPERIMENTAL PROCEDURE

Experiment in HAAKE RV30 Viscometer:

For rheological study, suitable sensor system i.e. MV-1 was chosen for given concentration in order to provide accurate results. The rotor was inserted through temperature vessel from below into the measuring drive shaft and screwed tight. The cup to be used was filled up to the mark with this prepared slurry sample of 30% weight concentration and fitted into the temperature vessel from below and slowly pushed up as far as the stopper. The cup is secured using the union nut. Temperature was set to 30^0C and shear stress was measured on varying shear rate ranging from 0-200(1/s). The HAAKE Viscometer was operated for one minute and readings were taken. The data on shear rate, shear stress, viscosity were displayed on the computer screen and these data were transferred to a printer. Similar procedure was followed for 40%, 45%, 50%, 55% and 60% concentration as the case may be.

VIII. DISCUSSIONS ON THE EXPERIMENT

1) Rheogram of coal water mixture was prepared (Fig-1) from the results obtained from Haake Viscometer (Table 1) by plotting shear stress against shear rate at 30^0c. It can be observed from these data that the slurries upto 30% concentration by weight for coals A, B and C coals behave like Newtonian fluid and then transition occurs.. At high shear the viscosity tends to approach an asymptotic value in which case the internal structure of the suspension become stabilized and no further changes in viscosity due to the increase in shear rate occurs.

2) The yield stress values have been calculated by extending the experimental shear stress – shear rate line to zero shear axis (Fig-2). Yield stress values obtained from the rheograms have been tabulated in Table 2. From the data variation of yield stress with ash content at different concentrations, C_w of solids in slurry are drawn in a semi log plot and shown in Figure-4. It may be seen that the relation is linear but deviates parallel with the parameter C_w. The slopes of these lines are equal to 4.76. For finding the effect of C_w on shear stress, the intercept values for each obtained from the figure are plotted against Cw^2 as shown in figure(Fig-5). The relation is straight line hence ζ_y for particular slurry can be related to C_a and C_w by the following equation.

ζ_y= Exp(4.76C_A +11.169Cw^2 - 3.2 ---------------- (1)

Where 11.169 is the slope of the line and -3.2 is the intercept value in the Fig-2.

Morgan *et al.* [11] observed the difference in rheological properties of various coal slurries and in particular the yield stress values are due to the difference in the structure of coal. As the low rank coals (high ash) contain more oxygen, their surface is easily hydrated and spontaneously wetted by water and a hydration shell is formed around the particles. These shells generate gel network structure because of hydrogen bonding. These structures develop very rapidly and are responsible for the time independent yield stress. On the other hand high rank coal contain less oxygen and therefore no hydration shell is formed easily thereby causing lower yield stress and in some cases no yield stress at all.

IX. CONCLUSION

Following important conclusions may be made from the above results:

1) The slurries up to 30% concentration by weight for coals behave like Newtonian fluid (Fig-1) and there after the transition occurs.

2) At a shear rate below 100 s^{-1}, there is sharp decrease in viscosity (Fig-3) which approached to an asymptotic value at higher shear stress.

3) The relation between yield stress and ash content is linear but deviates parallelly with the slurry concentration. Further it has been found that the yield stress increases with the increase in ash content. A correlation of the following type has been proposed to predict the yield stress variation taking into consideration ash content (C_A) and slurry concentration (C_w).

The correlation is ζ_y=Exp(4.76C_A +11.169Cw^2 -3.2)

The above coal water slurry will go a long way in its usage as an alternate source of fuel considering the rheological studies will be helpful in designing pipelines for transportation of slurry with optimum solid concentration which has become an attractive mode of transportation from economic point of view.

TABLE I

Concentration by wt	Shear Stress	Shear Rate	Viscosity	Shear Stress	Shear Rate	Viscosity	Shear Stress	Shear Rate	Viscosity
%	Pa	s^{-1}	mPaS	Pa	s^{-1}	mPaS	Pa	s^{-1}	mPaS
	COAL "A"			COAL "B"			COAL "C"		
30	0.65	54.12	12.01	1	106	9.43	1.14	63.14	18.05
	1.017	81.18	12.5	1.8	180	9.4	1.299	94.71	13.71
	1.68	135.3	12.41	2	218	9.27	1.525	126.28	12.07
	2.034	189.42	10.7	2.5	252	9.1	1.92	157.85	12.16
	2.203	216.48	10.17				2.18	189.42	11.53
40	0.678	27.06	25.1	1.05	54	19.44	1.887	45.1	41.84
	1.017	54.12	18.8	1.35	82	16.46	2.1	67.65	25.67
	1.2	81.18	14.78	1.95	135	14.44	2.316	90.2	22.52
	1.42	108.24	13.12	2.4	188	12.76	2.54	112.75	20.46
	1.78	135.3	13.15	2.75	216	12.73	2.768	135.3	20.458
	2.305	189.42	12.2				3.22	180.4	17.85
	2.644	216.48	12.2				3.367	202.95	15.89
45	1.017	27.06	37.6	1.6	90	17.78	4.294	45.1	95.21
	1.525	54.12	28.2	1.9	110	17.27	4.97	67.65	73.46
	1.695	81.18	20.9	2.25	150	15	5.535	90.2	61.38
	2.034	108.24	18.8	2.4	160	15	6.068	112.75	53.82
	2.441	135.3	18				6.55	135.3	48.41
	3.119	189.42	16.5				7.68	180.4	42.57
	3.39	216.48	15.7				8.02	202.95	39.52
50	1.354	27.06	50.06	2.45	67.65	36.22	9.537	45.1	211.46
	2.181	54.12	40.31	3.02	100	30.20	11.345	67.65	167.7
	2.437	81.18	30.03	3.6	140	25.71	12.769	90.2	141.56
	3.036	108.24	28.04	3.81	160.5	23.74	14.125	112.75	125.27
	3.526	135.3	26.06				15.436	135.3	114.08
	4.86	189.42	25.72				17.967	180.4	99.595
	5.04	206.48	24.3				19.097	202.95	94.097
55	6.615	45.5	145.3	7.01	45.5	153.8			
	8.9	67.7	131.45	8.76	67.73	130.88			
	10.9	108.3	100.64	11.66	108.5	108			
	12.7	135.3	157	12.94	135.5	95.5			

TABLE II

	Change Of Yield Stress With Coal Concentration,Temperature-30Degree			
Coal Type	Concentration By Weight, Cw	Yield Stress ,τ_y (Pa) Experimental Value	Yield Stress ,τ_y (Pa) Calculated By Equn (1)	Ash Content
A	0.4	0.35	0.359	8.2
	0.45	0.60	0.578	8.2
	0.5	1	0.99	8.2
	0.55	2.8	1.9	8.2
B	0.4	0.45	0.501	15.1
	0.45	0.85	.806	15.1
	0.5	1.4	1.364	15.1
	0.55	3.8	2.651	15.1
C	0.4	1.5	1.8	42.5
	0.45	3.2	2.95	42.5
	0.5	5.2	5.02	42.5

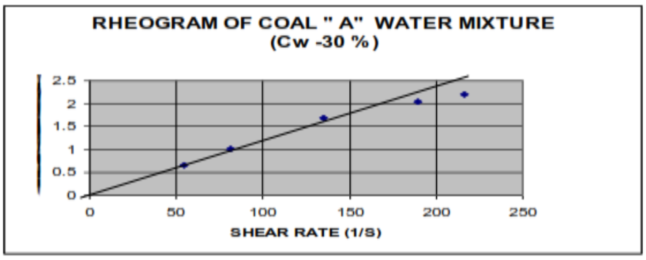

Fig. – 1

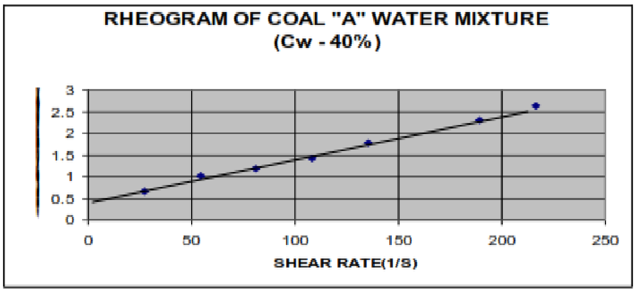

Fig. - 2

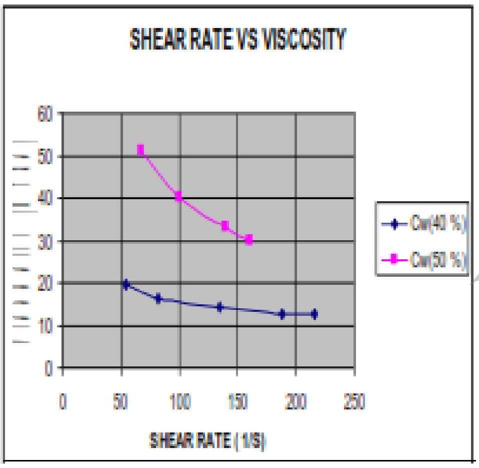

Fig. - 3

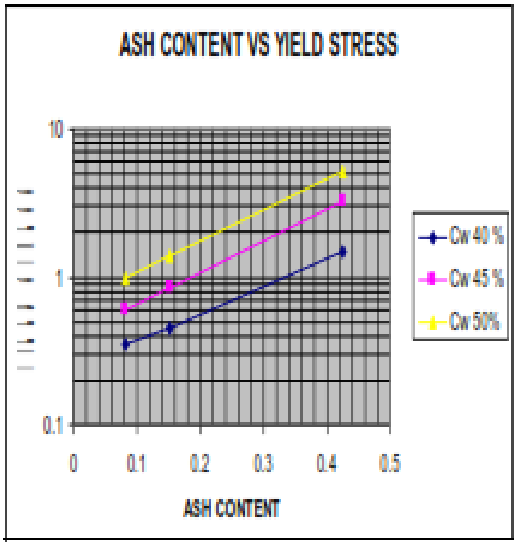

Fig. - 4

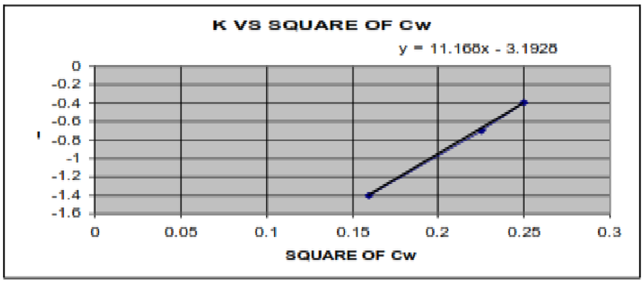

Fig. - 5

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Mrs S. Panda belongs to Ganjam district of Odisha. She passed her BTech in Mechanical Engineering in the year 2004. Then she completed her Masters degree in Thermal Engineering in the year 2009. She has more than 7 years of experience in research and teaching. At present she is continuing her PhD in eco-friendly fuel.