

FLOW CHARACTERISTICS OF HIGH CONCENTRATION FLY ASH SLURRIES THROUGH PIPELINES

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by

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DEPARTMENT OF APPLIED MECHANICS

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सरस्वति नमस्तुभ्यं वरदे कामरूपिणि ।
विद्यारम्भं करिष्यामि सिद्धिर्भवतु मे सदा ॥ ॥

Oh Goddess Saraswati, my humble prostrations unto you, who are the fulfiller of all my wishes. I am beginning my study, let me attain perfection in that, always.

DEDICATED
TO
MY RESPECTED TEACHERS
&
MY DEAR PARENTS AND WIFE

CERTIFICATE

This is to certify that the thesis entitled “**FLOW CHARACTERISTICS OF HIGH CONCENTRATION FLY ASH SLURRIES THROUGH PIPELINES**” being submitted by **Mr. Anubhav Rawat** to the Indian Institute of Technology Delhi, New Delhi, India for the award of the degree of **Doctor of Philosophy** is a record of bonafide work done by him under our guidance and supervision.

The research reported and results presented in this thesis have not been submitted in part or full to any other Institute or University for the award of any degree or diploma.

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Akhanndda-Mannddala-Akaaram Vyaaptam Yena Chara-Acharam |

Tat-Padam Darshitam Yena Tasmai Shrii-Gurave Namah ||

(Salutations to the Teachers Whose Form is an Indivisible Whole of Presence, and By
Whom is Pervaded the Moving and the Non-Moving Beings)

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ABSTRACT

India is one of the fastest growing economies of the world and demand of energy is growing with every passing year. Thus to meet the growing energy demands India shall need to generate huge amount of electricity which in turn require huge amount of coal as till date India is very much dependent on thermal power plants. Thus it is expected that in the coming decades more and more ash shall be generated (approximately 600 million tonnes per year) as ash content in Indian coal is more. This ash not only will require large area of precious land for its disposal but will also become one of the major sources of pollution of air and water.

The coal ash today is being transported by pipelines from sumps located in the power plants to ash ponds which could be as far as 10-15 kms at concentrations between 10 to 50% (by weight) with majority of the pipelines operating below 20% concentration (by weight). These systems are highly inefficient and waste lot of water and electricity beside causing water and air pollution. To overcome these drawbacks it is desirable to transport coal ash at high concentrations ($\geq 60\%$ by weight) using high concentration slurry disposal (HCSD) systems which ensures low specific energy consumption and overcomes the problem of excessive water consumption and environment degradation.

Considering this fact, a detailed literature survey has been conducted on various aspects of high concentration ash conveying systems, so that the gaps existing between the known technologies and the present day needs in transportation of Indian coal ash could be established.

The flue gases resulting from the combustion of coal in the boilers at thermal power plants are made to pass through a series of Electrostatic Precipitator (ESP) hoppers to capture the fly ash particles carried by these gases before being released to the atmosphere. The coarser particles of the fly ash get deposited in the earlier fields of ESP hoppers and the fine ash particles in the later fields of ESP hoppers. The deposited fly ash from various fields of ESP hoppers are evacuated and transported to common sump for further disposal to the ash pond by slurry pipelines. The proportion of fly ash from different fields of ESP hoppers vary according to the evacuation sequence which inter depends on the rate of accumulation in each field. Thus the quality of slurry in terms of particle size distribution, being pumped at high concentration through pipeline would vary with time which in turn affects the head requirement for pumping.

Thus in order to understand the above, fly ash samples from different fields of ESP hoppers of a thermal power plant have been analyzed for their physical properties in particular the particle size distribution (PSD), specific gravity, settling characteristics, pH of the slurry etc and the rheological parameters namely yield stress and Bingham viscosity of the slurries in the concentration range of 60-70% (by weight). The rheological studies on different samples of fly ash have also been conducted to find out the effect of ageing, wetting, presence of un-burnt carbon, and mixing of fines to coarse fly ash samples.

Pressure drop is a very important parameter for the hydraulic design of pipelines and needs to be accurately estimated for efficient transportation. Pressure drop is a function of friction factor which in turn is dependent on various flow

parameters. In the current work CFD has been used to determine the pressure drop and thus friction factor for the flow of High Concentration Coal ash slurries in the concentration range of 60% to 70% (by weight) considering the medium to be homogeneous. Parametric study to find the effect of particle size of fly ash and effect of mixing of fine to the coarse fly ash samples on pressure drop has also been evaluated. CFD has been shown to be an efficient tool for the prediction of head loss, an important parameter for hydraulic design of HCSD pipelines.

In a pipeline network, bends are an integral part and result in additional pressure drop. Thus a study has been undertaken to find out an optimum geometry bend (both for conventional and converging-diverging bends) for the flow of high concentration fly ash slurries using CFD. The pressure drop characteristic considered in the whole study for the bend is in terms of bend loss coefficient. Effect of flow velocity and slurry concentration for different bends has also been established for both type of bends.

Erosion is also an inseparable phenomenon associated with the slurry pipelines due to presence of solids. Erosion wear studies at in-situ conditions or in the pilot plant test loops are cumbersome, time consuming and expensive. Thus in the current work functional dependence of erosion wear on various parameters has been evaluated for the high concentration slurries using modified pot tester. It was found that the erosion wear has a strong dependence on concentration of the solids rather than the flow velocity of slurry. Also the effect of angle of impact on erosion wear has been evaluated and the results are consistent with the results obtained by previous researchers in the field of solid-liquid flow.

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NOTATIONS

B	Mass of test specimen (Fly Ash) used in grams after heating the sample until 750 ⁰ C (Equ 4.3)
C _L	end effect correction factor (Equ 3.3)
C _w	Solid Concentration (%) (By weight)
d _{wm}	Weighted Mean Diameter (mm)
D _ω	Cross-diffusion term
D _ω ⁺	Positive portion of the cross-diffusion term
f	Fanning Friction Factor
f _T	Fanning Friction Factor (Turbulent Flow)
G _b	Generation of turbulent kinetic energy due to buoyancy
G _k	Generation of turbulent kinetic energy due to the mean velocity gradient
G _ω	Generation of specific dissipation rate
g	Acceleration due to Gravity, (m/s ²)
He	Hedstrom Number
K _b	Bend Loss Coefficient
k _s	Roughness of Pipe Surface, (m)
k _s /D	Relative Roughness
L	Gap length (Height of the Bob)(Equ 3.3)
LOI	Loss on Ignition (Equ 4.3)
M	Torque, mN-m (Equ.3.3)
n	speed, min ⁻¹ (Equ 3.2)
P	Static Pressure (Pa) (Equ 5.2)
ΔP	Pressure Drop
r _e	Measuring Cup radius
r _i	Measuring Bob radius mm (Equ 3.3)
Re _B	Bingham Reynolds number
(Re _B) _C	Critical Bingham Reynolds number

S_k and S_ϵ	User-define source terms respectively
V or V_m	Mean Velocity of Flow, (m/s)
W	Mass of test specimen (Fly Ash) used in grams (Equ 4.3)
Y_k and Y_ω	Dissipation of k and ω due to turbulence respectively
Y_M	Contribution of the fluctuating dilation in compressible turbulence to the overall dissipation rate

GREEK SYMBOLS

α_k and α_ϵ	Inverse effective Prandtl numbers for k and ϵ
δ	radius ratio (r_e/r_i) (Eqs 3.1& 3.2)
ϵ	Dissipation rate
Φ	Deflection Angle, m-rad (Equ 3.1)
$\dot{\gamma}$	Shear rate, Sec^{-1}
γ	Strain (%) (Equ 3.1)
k	Turbulent kinetic energy
Ω_{ij}	is Mean rate of rotation tensor viewed in a rotating reference frame with the angular velocity ω_k
ρ_m	Density of Slurry, (Kg/m^3)
ρ_s	Density of Solids, (Kg/m^3)
τ	Shear Stress, Pa
τ_0	Yield Stress, (Pa)
$\bar{\bar{\tau}}$	Stress tensor (Equ 5.2)
μ_α	Apparent Viscosity (Pa.s) (Equ 5.1)
μ_B	Bingham Viscosity (Pa.s)
μ_r	Relative Viscosity
μ_w	Water viscosity (pa.s)
μ_0	Yielding Viscosity (Pa.S) (Equ.5.1)

μ_t	Eddy (turbulent) viscosity
ω	angular velocity (Sec ⁻¹), Specific dissipation
σ_k and σ_ϵ	Turbulent Prandtl numbers for k and ϵ respectively
σ_k and σ_ω	Turbulent Prandtl numbers for k and ω
Γ_k and Γ_ω	Effective diffusivity of k and ω , respectively

ABBREVIATIONS

ESP	Electro Static Precipitator
F-1	Field-1
F-2	Field-2
F-3	Field-3
F-4	Field-4
F-5	Field-5
LOI	Loss on Ignition
PSD	Particle Size Distribution
SSC	Static Settled Concentration