Energy Optimization of High Concentration Fly Ash Slurry Disposal through Pipelines in Laminar Regime

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Abstract

Safe disposal of coal ash is a major concern for the thermal power industry, as the coal ash is to be transported to ash pond, which are situated at some distance from the ash generation unit. It can be transported through various modes of transport viz. trucks, trolleys including the pipeline transportation in slurry convey mode. As the energy required for transportation of coal ash with the help of hydraulic conveying is substantially less in comparison to other transportation modes, present study has been focussed on the optimization of power requirement for the transportation of high concentration coal ash slurry disposal (HCSD) system under laminar flow regime. In current work various parameters like pipe diameter, flow velocity and solid weight concentration have been considered to evaluate their effect on the optimum energy requirement (specific) for slurry transportation using computational Fluid Dynamics (CFD) in laminar regime, with the help of commercially available CFD software Ansys FLUENT 16. It is found that the effect of the selected parameters is substantial.

Keywords. Slurry flow, Bingham plastic fluid, specific energy consumption, CFD

1. INTRODUCTION

The demand of energy is increasing day by day in today's modern world, which is fulfilled through renewable and non-renewable source of energy. Although there are many advantages of renewable energies both in terms of environment protection and their ease of handling, their high initial cost makes it unaffordable to many countries like India and they have to depend more on non-renewable sources of energy including coal based thermal power. The major challenge in such thermal systems is its residue which is fly ash. Although the utilization of ash been substantially increased in last decade, still tonnes of ash needs to be transported to the dumping sites/Ash ponds including their pipeline transportation to the nearby utilization industries like brick manufacturing plants etc. Among various transportation modes pipeline transportation of coal ash is more prevalent due to its low operating cost and less wear to the pipeline systems. That too the energy required for high concentration slurry transportation is lesser in comparison to low concentration slurry [1].

The slurry transportation can be classified into three types: low (5-20% approx.), medium (20-45% approx.), and high (50-70% approx.) (all concentrations mentioned are in terms of by weight) [2]. High concentration slurry behaves like Bingham plastic fluid and its rheological behaviour may be modelled as Herschel-Bulkley model [3]. Based on the available rheological data fly ash slurry could be suitably modelled using Bingham plastic fluid having concentration by weight in the range of 40-70% [4]. Pressure drop, for high concentration fly ash slurry can be accurately evaluated using CFD for both laminar and turbulent flow regime for the calculation of friction factor along with the effect of particle size on head loss [5-7]. The energy required for the transportation of both fine and coarse particle will be less when the ratio between fine and coarse particle is not more than 30% also the particle size ratio will be in the range of 4:1 to 3:2 [8,9]. There are many other studies available in literature which generally relates to very limited aspects of slurry transportation that too without giving due weightage to flow regime of the slurry [10-14]

Therefore, the objective of the current study is set to optimize the energy requirement for the high concentration slurry transportation with respect to various operating parameters viz. pipe diameter (D), flow velocity (V) and solid weight concentration (C_w), with the help of commercially available CFD tool ANSYS FLUENT 16, in laminar regime. The current study mainly focuses on the energy consumed for high concentration slurry disposal systems which is calculated in terms of Specific Energy Consumption (SEC) [15]. It is the amount of energy required for the transportation of unit mass to a unit distance and is given as

$$SEC = \frac{2.726\ X\ i}{C\ X\ \delta_s} \tag{1}$$

Where, i = hydraulic gradients of slurry (mm W/m),

C = Volumetric concentration of slurry (%),

δ_s = Specific gravity of solids

SEC is expressed in kW.h/t.km.

2. COMPUTATIONAL METHODOLOGY

Following are the various step wise computational strategies adopted in current work.

2.1. *Geometry*

In the current work, the study is of conducted for different pipe geometries having pipe sizes 75 mm, 100 mm, 125 mm, 150 mm, and 200 mm and pipe lengths of 6, 8, 8, 9, and 12m respectively. Figure 1 shows the straight pipe considered for computational study having variable diameter and length. For structured meshing the shown pipe is divided into five parts where the inner square is of dimension a, where a = 0.2D (D = pipe diameter). The solid cylinder is representing the fluid (slurry) domain used for computational study. The shown geometry is drawn in Design Modular, of a commercially available CFD software, ANSYS Fluent 16.

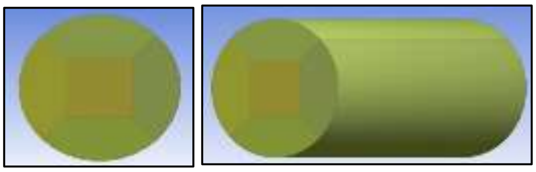


Figure 1. Cross-section and profile view of the cylindrical pipe

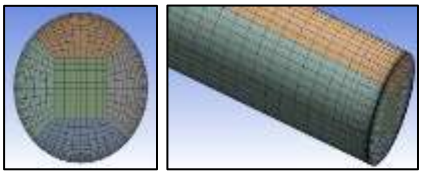


Figure 2. Cross-sectional and profile view of meshing

2.2. Meshing

Once the geometry i.e., computational domain is modelled, it is then discretized into small grids, known as elements. A structured hexahedral mesh is generated, using multizone mesh method as shown in figure 2. Edge sizing is used to control the number of elements. Inflation layer is used to capture the wall phenomenon by keeping the Y+ value equal to 1, for finding the first layer height. The governing equations are solved for each element.

2.3. Boundary conditions, solution controls, and slurry properties

For the present study the boundary condition taken into consideration are Inlet: the flow velocity Outlet: the outflow, wall: no slip having wall roughness as constant.

The first order upwind scheme is used for discretization, whereas the under-relaxation parameters are set to the default values.

The slurry rheological properties changes with respect to change in particle size, and concentrations. The slurry experimental properties are taken from Rawat et al. [16] as shown in Table 1 where displayed values are used for simulation.

Table 1 Rheological properties of slurry having d_{wm}=34.5 μm [16]

Sl. No.	**C_w (% by weight)**	**Density (kg/m^3)**	**Yield Stress (Pa)**	**Bingham Viscosity (Pa.s)**
1	55	1394.72	0.173	0.007
2	60	1446.63	0.317	0.0136
3	62	1468.49	0.484	0.0282
4	65	1502.63	0.736	0.0502
5	68	1538.23	1.6730.	0.1388

Table 2 Particle size Distribution (PSD)

Size (μm)	300	200	100	74	53	43	38	25	18	13	9	7	5	3
PSD (%)	100	97.8	88.9	84.4	75.1	69.1	67.2	53.6	45.8	36.1	24.4	16.7	7	3.1

2.4. Models and governing equations

From literature review it is clear that High concentration slurry flow behaves like homogeneous Bingham plastic fluid and can be modelled using Herschel-Bulkley equation. The current study is conducted for laminar flow regime and thus the governing equation are the continuity and momentum equation and are written in equation 2 and 3 below respectively.

$$\nabla.(\rho\vec{v}) = 0 \tag{2}$$

$$\nabla.(\rho\vec{v}\vec{v}) = -\nabla p + \nabla.(\tau) + \rho g \tag{3}$$

where, ρ is density, p is static pressure, and τ is stress tensor. The rheological equation for the Bingham plastic fluid can be written as

$$\tau = \tau_o + \mu_B D \tag{4}$$

where μ_B is Bingham viscosity, τ_o is yield stress and $D = (\frac{\partial U_j}{\partial x_i} + \frac{\partial U_i}{\partial x_j})$.

2.5. Grid Independency Test (GIT) and Validation

For the selection of optimum mesh, the GIT for 75 mm diameter pipe is shown in Fig. 3. It is observed from Fig. 3 that after the mesh M^* (having 2.88 x 10^5 elements) there is no substantial change in the values of pressure drop and therefore M* is selected as the optimum mesh for the current study. Similarly, GIT is done for all pipes having diameter 75 mm to 200 mm.

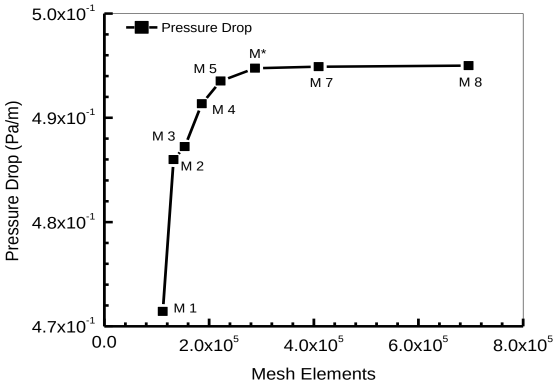


Figure 3 Pressure Drop vs No. of Mesh elements
for pipe diameter, D=0.075m

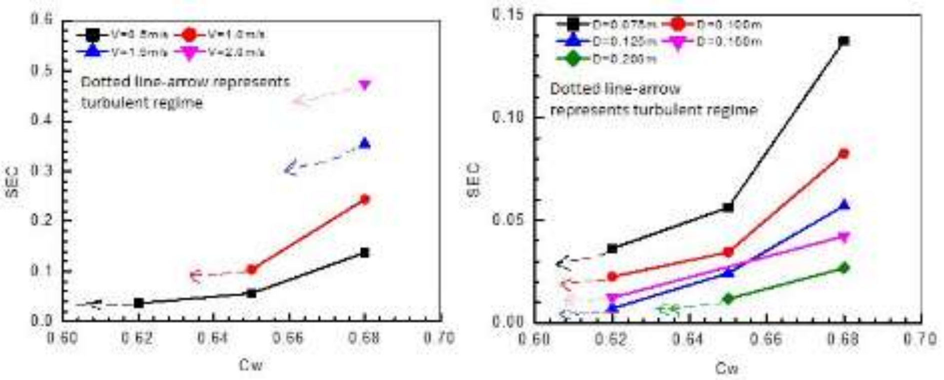
For validation the pressure drop obtained computationally is compared with the pressure drop obtained from experimental data and Buckingham-Reiner equation. Both the obtained results show close precision having very less deviation within the acceptable limits of ±1%.

3. RESULTS AND DISCUSSIONS

Various results obtained are discussed in the subsequent sections.

3.1. Effect of solid concentration on energy consumption (specific)

A graph between SEC and solid concentration (by weight) (C_w) of fly ash particles is shown in Fig. 4. Fig. 4 (a) shows that for constant Pipe diameter, the amount of energy consumed increases non-linearly with the increase in C_w for a fixed velocity. Whereas, the increase in velocity causes a related increase in energy. Fig. 4(b) depicts that the SEC increases non-linearly with the increases in C_w for a fixed pipe diameter at constant velocity. The figure also reveals that the value of SEC reduces with the increase in pipe size at a constant velocity of flow.



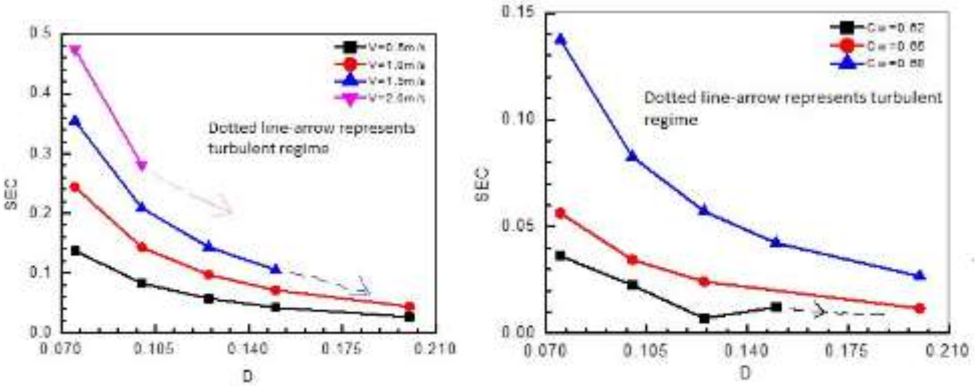
(a) D = 0.075m

(b) V = 0.5m/s

Figure 4 SEC vs C_w

3.2. Effect of Pipe Diameter on energy consumption (specific)

Ash shown in Fig. 5 (a) with the increase in pipe diameter the specific energy consumption will decrease at constant velocity for a given $C_{w.}$ Whereas, the increase in C_w causes a related increase in SEC values. Fig. 5 (b) depicts that increment in Pipe diameter causes a decrement in SEC at constant flow velocity and given $C_{w.}$ Whereas, the increase in flow velocity for a given C_w brings a related increment in the values of SEC. This can be explained based on the fact that pressure drop is inversely proportional to the pipe diameter, whereas the SEC is directly proportional to the pressure drop. Thus with the increase in pipe diameter the pressure drop decreases which in turn causes a lesser corresponding value of the SEC.



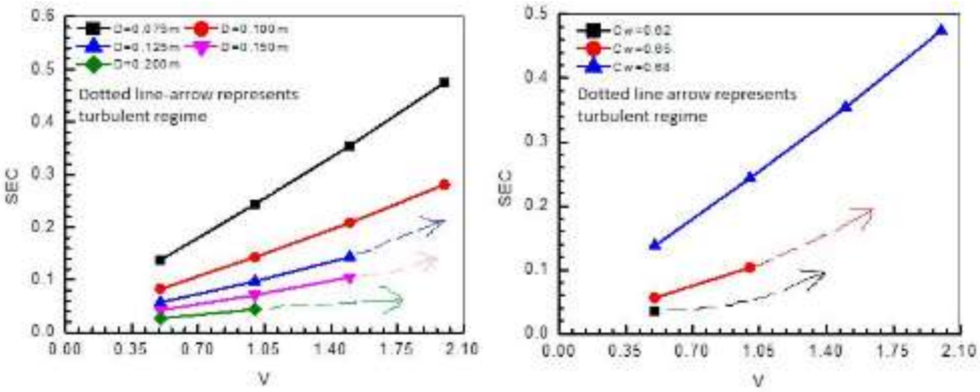
(a) $C_w = 0.68$

(b) V = 0.5m/s

Figure 5 SEC vs D

3.3. *Effect of flow velocity on energy consumption (specific)*

In this section the effect of flow velocity on SEC is evaluated with respect to constant pipe size and C_w values. Fig. 6(a) revels that for constant Pipe sizes the SEC increases almost linearly with respect to flow velocity for a given C_w. Whereas, a related increase in flow velocity for a given pipe size brings a related increment. Similar effect is seen in Figure 6 (b) where variation of SEC w.r.t. slurry flow velocity is seen at fixed C_w and given pipe size.



(a) $C_w= 0.68$

(b) D = 0.075m

Figure 6 SEC vs V

4. CONCLUSIONS

The current study i.e., optimization of HCSD flow in laminar regime by using computational method is taken up with the help of commercially available CFD tool Ansys FLUENT 16.

Herschel-Bulkley model is used for modelling of the rheological properties of HSCD system whereas the viscous model is set to be laminar. The effect of various operating parameters like flow velocity, pipe diameter, and concentration (by weight) on the energy required (specific) is studied. The following conclusion may be drawn out of the study for the flow of high concentration fly ash slurries through pipelines in laminar regime:

- With the increase in concentration and flow velocity, the SEC increases non-linearly.
- With the increase in pipe diameter, the SEC decreases non-linearly.

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