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Experimental Modelling of Pneumatic Conveying Capability of Dry Ash

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Abstract: Dry ash pneumatic conveying is becoming more demanding in various fly ash generating and as well as utilizing industries. Till date majority of dry ash producers are using hydraulic conveying systems due to non-availability of efficient and reliable pneumatic system. Attempts are being made to find practical uses for the dry ash on large scale due to land & water resource constraint & use as resource materials. The solution of this problem lies in developing improved model for a pneumatic conveying system which uses ecofriendly, energy efficient system which protects the potential dry ash properties for utilization on large scale. It is primary need for reliable design of a pneumatic conveying system, classical plan experimentation to model the conveying capability of dry ash conveying system to generate the design data.

This paper presents the results of an online Experimentation performed on Pneumatic Conveying system of Dry Ash for its conveying capability on important key parameters. Dry ash samples from Nine ESP field of Koradi thermal power plant according to flue gas flow direction were collected. This nine samples were reduced to three samples by mixing ESP-1,2,3, ESP-4,5,6 and ESP-7,8,9. further these Samples were tested from GEO Systems, Nagpur for mean particle size (diameter) 25-35-45 μm; loose-poured bulk density: 750—850-950 kg/m^3) and permeability Experiments were carried out on three samples for various test points and test envelope on pneumatic conveying test pipeline having diameter 0.2 and length around 300 m.

A new approach of modelling on similar pipe line configuration since scaling is not required, it has provided better accuracy and approximation when the result was compared with experimental data. This method of online experimentation is aimed to address the partial filling of pipe's cross section by the dune of dry ash which requires high volume conveying air, or sometimes chocking of section occurs due to large volume of dry fly ash. To handle these problems, online experimentation has proved to be a better method than test conducted on test rig setup for representation of the optimum flow conditions, especially such complex mode of dense-phase pneumatic conveying of fine powders like dry fly ash materials.

KEYWORDS: Classical plan, Conveying capability, Loading ratio, ESP, Permeability.

Introduction: Dry ash are produced around the world every year from the combustion of pulverized coal in thermal power stations, CEA New Delhi 2017 [1] In the report it was shown that the total no of thermal power in 18 states were of 155 and the generation of fly ash was in these stated during the year

2016-2017 was 169.2533 million tons. The table below will give the summary of fly ash generation and utilization during year 2016-2017.

Table No.1

Description		Year 2016-17
• Nos. of Thermal Power Stations from which data was received	:	155
• Installed capacity (MW)	:	157377.00
• Coal consumed (Million tons)	:	509.46
• Fly Ash Generation (Million tons)	:	169.25
• Fly Ash Utilization (Million tons)	:	107.10
• Percentage Utilization	:	63.28
• Percentage Average Ash Content (%)	:	33.22

Till date majority of ash producers are using hydraulic conveying systems due to non-availability of efficient dry ash pneumatic conveying system. Dry ash largely used in building material sector. Attempts are being made to find practical uses for the dry ash on large scale & also to avoid ground & water contamination, land & water resource constraint, it necessary to avoid the disposal of ash in wet slurry form into ash bund [2].

The solution of this problem lies in developing a pneumatic conveying system for Dry ash with maximum throughput, which uses ecofriendly, energy efficient system which protects the potential dry ash properties for utilization on large scale in various industries. In the past investigations have been carried out for dry ash pneumatic system for industrial application [3].

Nomenclature:

D	Bore of pipe
L	Length of conveying line
P_1	Supply pressure
ρ_b	Dry ash bulk density
V_p	Permeability
M_a	Mass flow rate of air
M_s	Mass flow rate of ash

Ø or LR Loading ratio

Experimental procedure

The steps involved in the planning of experimentation [4] under the classical plan of experimentation to enhance conveying capability of dry ash pneumatic conveying are discussed below: -

a) Identification of various physical quantities affecting the modelling of the system.

b) Dimensional Analysis to reduce the variables.

c) Deciding the test envelops Test points and Test sequence.

d) Selection of measuring instruments.

e) Calibration of measuring instruments.

f) Test data checking and rejection.

g) Data analysis and formulation of the model.

Referring theories of engineering experimentation by Hilbert Schenck Jr. [5] it was decided to use classical plan of experimentation, data was collected for dense phase pneumatic conveying system for dry ash with the use of specially designed orifice to optimize conveying condition at ash pick-up point in air supply line [6]. The model was developed to correlate dependent π term with independent variables of the system.

Mathematical Modelling:

Data collected during experimentation needs to be analyzed to develop some logical relationship between various independent and dependent parameters. Hence mathematical model needs to be formed. A mathematical model is a description of a system using mathematical concepts [7]. The process of developing a mathematical model is termed mathematical modelling. A model may help to explain a system and to study the effects of different components, and to make predictions about behavior of system components under various working conditions.

In terms of π it can be written as

$$\boldsymbol{\pi_1 = \frac{L_B}{D_B} \qquad \pi_2 = \frac{\mu_p}{D_B} \qquad \pi_3 = \frac{P1}{\rho_b V_p^2}}$$

Same method can be used to form the pi terms of the dependent variables also.

$$\boldsymbol{\pi_{01} = LR}$$

These 3 independent pi terms and 1 dependent pi terms will be used to form mathematical model. Each dependent pi term will is assumed to be the function of all independent pi terms.

$\pi_{01} = f(\pi_1, \pi_2, \pi_3)$……………………………..(i)

Initial observation hints that dependent and independent parameters have exponential relationship. Hence

$\pi_{01} = k_1 \times \pi_1{}^{a_1} \times \pi_2{}^{a_2} \times \pi_3{}^{a_3}$ ………………………………………………………..(ii)

Now forming the mathematical model means to find the value of unknowns in the above equation. Taking log [7] of the both the sides of above equation gives

$\log \pi_{01} = \log k_1 + \log \pi_1{}^{a_1} + \log \pi_2{}^{a_2} + \log \pi_3{}^{a_3}$…………………………………………. (iii)

$\log \pi_{01} = \log k_1 + a_1 \log \pi_1 + a_2 \log \pi_2 + a_3 \log \pi_3$……………………………………….(iv)

Above equation is valid for all the readings collected during experimentation. Hence putting summation on both the sides

$\sum_{i=1}^{i=n} \log \pi_{01} = \sum_{i=1}^{i=n} (\log k_1 + a_1 \log \pi_{1_i} + a_2 \log \pi_{2_i} + a_3 \log \pi_{3_i})$……………………………….(v)

Where n is number of readings

Similarly, following equations can be formed for remaining dependent pi terms

$\sum_{i=1}^{i=n} \log \pi_{02} = \log k_2 + b_1 \sum_{i=1}^{i=n} \log \pi_1 + b_2 \sum_{i=1}^{i=n} \log \pi_2 + b_3 \sum_{i=1}^{i=n} \log \pi_3$……………………….(vi)

All these mathematical equations are solved in software package MATLAB,

Index Values of Mathematical Model of Pi Terms

Pi Term	K	π_1	π_2	π_3
π_{01}	4.7034	3.996	0.029	0.000321

The same can be written as follows

$$\pi_{01} = 4.7034 \times \pi_1^{3.996} \times \pi_2^{0.029} \times \pi_3^{0.000321} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(vii)}$$

All above equations are in form of dimensionless pi terms. It is required to express them in terms of variable for the purpose of analysis of the

$$LR = 4.7034 \times D_B^{-7.7254} \times L_B^{7.6964} \times P_1^{0.00321} \times \rho_B^{-0.00321} \times \mu_m^{0.029} \times Vp^{0.00321} \ldots\ldots\text{(viii)}$$

These are the various mathematical models which are used for analysis of the process and performance of the mathematical models.

Result and Discussion

The experiments were conducted in different conditions. All the observations were recorded under steady state condition. The calculations were performed to obtain the value response variable using the log-log linear model and the results are presented in graphical form.

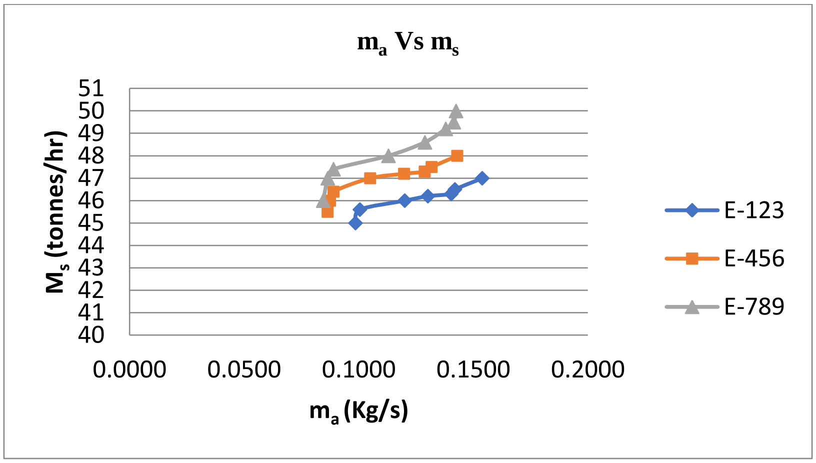

Figure1 mass flow rate of ash versus mass flow rate of air

Figure1 shows that as mass flow rate of ash increases with the mass flow rate of air. For fine ash (i.e. E-789) the mass flow rate of ash is maximum i.e.m_s=50tonnes/hr.

Figure2 shows that as mass flow rate of ash increases with increase in inlet pressure. For inlet pressure of 2.5 kg/cm^2, maximum ash collected was 50 tonnes/hr and for 1.8 kg/cm^{2}ash collected was 45tonnes/hr. Figure 6.3 shows by the same trend as shown by figure 6.1, below the velocity of 0.08m/s chocking condition was occurred and there was no flow of ash or very less collection is there.

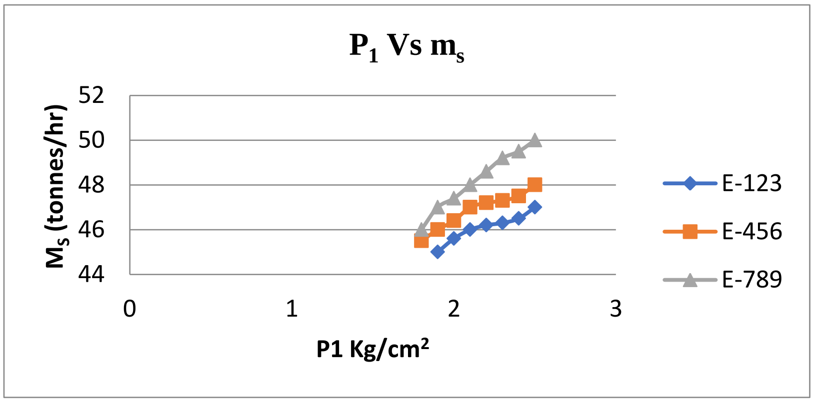

Figure2 Mass flow rate of ash versus inlet pressure

Figure 3 indicate maximum loading ratio for fine ash against the velocity of air. As velocity of air increases loading ratios are decreases, this is because of quantity of air is more than ash.

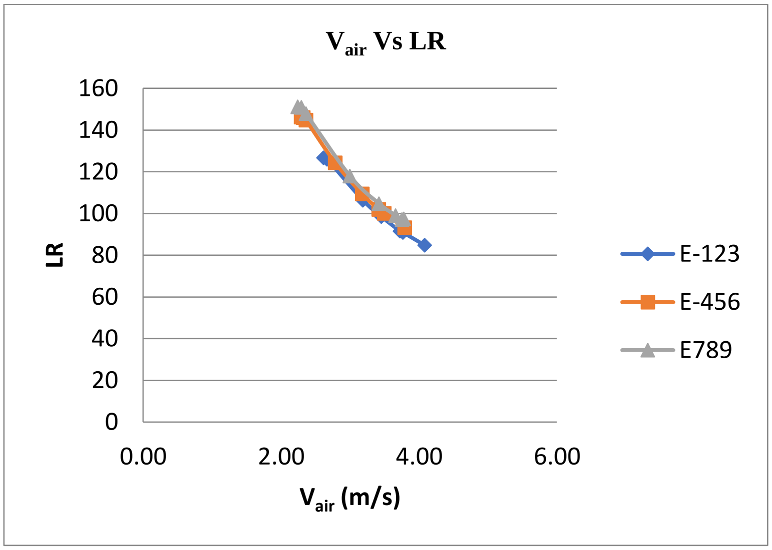

Figure3 $\mathbf{V_{air}}$ verses Loading ratio

Figure4 shows the mass flow rate of ash at various velocities point of for all three cases. It is observed that mass flow rate of ash increases as velocity increases but below 2.12m/s mass flow of ash is very low and its condition is known as chocking condition.

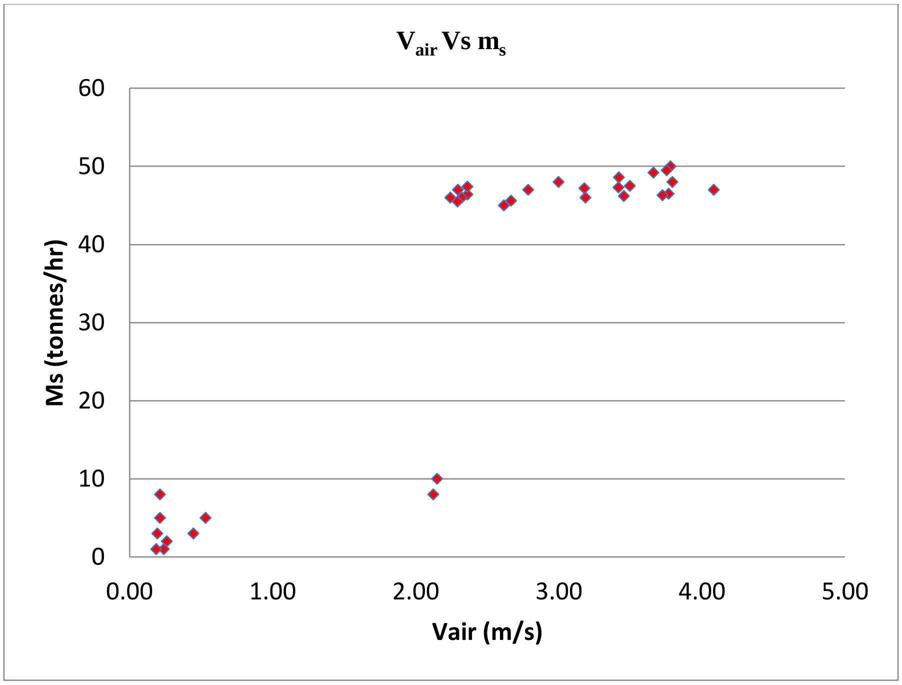

Figure 4 scatterplot of $\mathbf{V_{air}}$ verses m_s

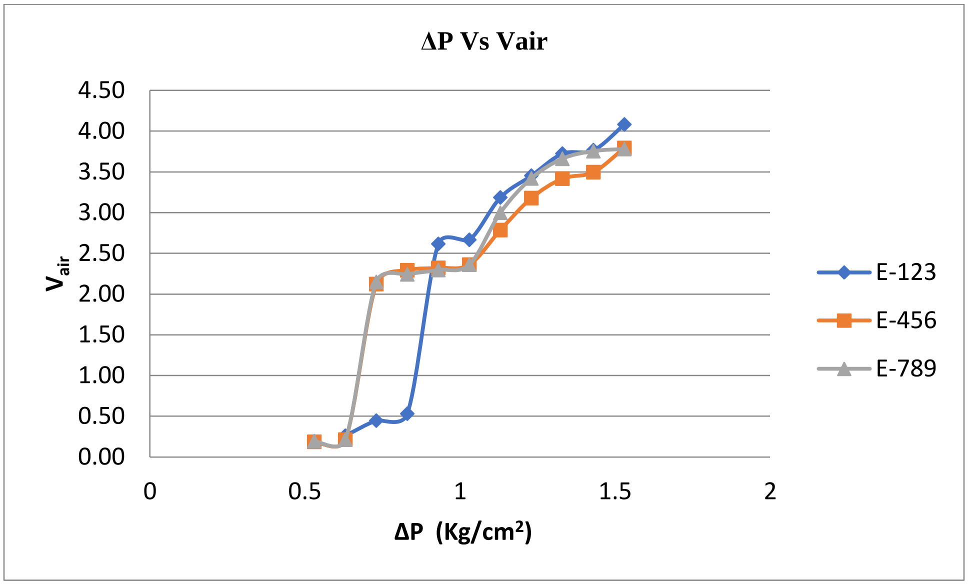

Figure 5 ΔP verses V_{air}

Figure 5 shows the velocities at different condition with respective change in pressure. As change in pressure decreases respective velocity are also decreases. If changing pressure below 0.8 Kg/cm^2, very small velocities are getting (2.21 m/s to 0.19 m/s).

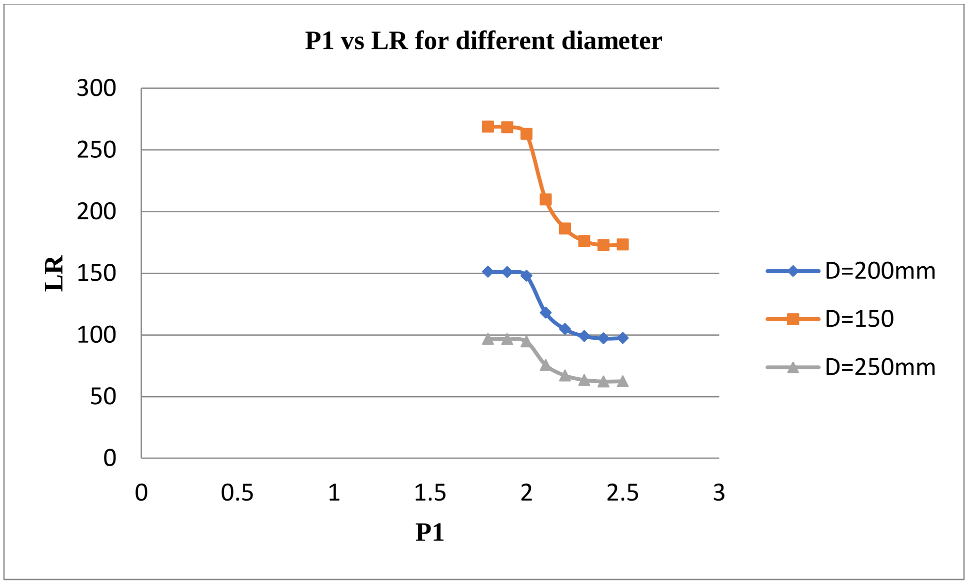

Figure 6 P1 verses LR for different bore diameter

Figure 6 shows predicted trend of loading ratio for different bore diameters. If the diameter is increase to 250mm then loading ratios are decrease and vice versa by considering the same air velocity, pressure range and same material condition.

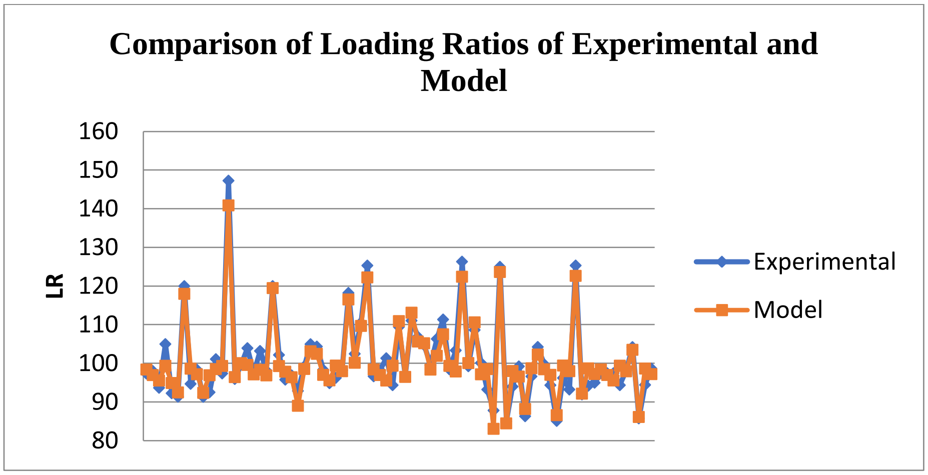

Figure7 Comparison of Loading Ratio of Experimental and Model

Figure 7 shows comparison of loading ratios of model and experimental values and it is found that these values are within 5% error.

Conclusion

Based upon the experimental data the various parameters were compared with the response variable. The other parameters such as mass flow rate of ash, velocity of air, pressure drop, loading ratios and inlet pressure was represent graphically. From above it is conclude that loading ratio increase with decreasing in inlet pressure

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