UNDERSTANDING THE COMPLEX INTERPLAY OF FLUID DYNAMICS BY ANALYZING VELOCITY DISTRIBUTION THROUGH A SLURRY PIPELINE

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Abstract

Slurry pipelines offer several advantages for transporting solid materials over long distances. Here are some key points elaborating on the benefits of slurry pipelines:
Slurry pipelines provide an efficient means of transporting bulk materials such as mineral ore, coal, and waste over long distances. By suspending solids in a liquid carrier, slurry pipelines can transport large volumes of material with relatively low energy consumption. Compared to other modes of transportation like conveyor belts or trucks, slurry pipelines typically require lower maintenance. Once constructed, they can operate for extended periods with minimal upkeep, reducing downtime and operational costs. Slurry pipelines offer round-the-year availability, regardless of weather conditions. Unlike railways, which may be affected by snow or flooding, slurry pipelines can operate continuously, ensuring a reliable supply of materials to processing plants or disposal sites. Slurry pipelines can offer economic advantages, particularly for transporting materials over long distances or through challenging terrain. While initial construction costs may be significant, the long-term operational savings and increased efficiency can make slurry pipelines a cost-effective transportation solution for industries reliant on bulk material transport

Slurry pipelines have emerged as a preferred mode of transport for solids in various industries due to their efficiency, reliability, safety, and environmental benefits. As technologies continue to improve, slurry pipeline systems are likely to play an increasingly important role in meeting the transportation needs of resource-intensive industries

Keywords: Slurry, suspending solids.

1. Introduction

Slurry pipelines are used to transport solid material is using water or any other liquid as a carrier fluid. This mode of transportation is suited for long distances haulage of bulk materials, like mineral ore to processing plants, coal to thermal plants, disposal of waste material like fly ash, tailing material etc. Various industries have accepted slurry pipelines as an attractive mode of transport of solids because of its low maintenance and round the year availability. This mode of transportation is extremely safe besides being eco-friendly.

Advantages of slurry transportation

1) Tremendous economy of scale
2) Relative immunity to escalation of prices
3) High degree of efficiency and reliability
4) Simplicity of installation and small place requirements
5) Ease of crossing both natural and artificial obstacles
6) Reduced storage cost at the point of consumption
7) Scan be readily automated
8) Easy to operate.

Limitations of slurry transportation

1) The initial capital cost is relatively high

2) The pipelines transportation system is solely dedicated to the transportation of solids, whereas rail, road or a highway has multi-purpose utility.
3) The pipeline transportation system requires water or other liquids as the carrier fluid in large volume, which may not be easily available at all places and all the time
4) Quality control has to be very stringent for the efficient operation at the pipeline.

Hydraulic Design of the slurry pipeline

Important design parameters

1) Hydraulic Parameters
a) Selection of the carrier fluid
b) Optimum particle size
c) Optimum concentration of solids
d) Minimum operating velocity
e) Pipe diameter
f) Pressure drop
g) Additives required for flow improvement
h) Attrition of particles due to pumping
2) Parameters of corrosion-erosion
a) Establish pipeline life (20 to 50 yrs)
b) Select corrosion inhibitor and/or additives for oxygen and pH control
c)

c) Select metal allowance
d) Abrasion
3) Parameters of operational stability
a) shutdown-start up requirements
b) Maximum allowable slope.

Details of the model for velocity distribution

Prediction as proposed by Roco and Shook (1984)

2. Literature review

[1] Multiphase slurry flow regimes and its pipeline transportation of underground backfill in metal mine: Leiming Wang, Liang ChengMini review Construction and Building Materials Volume 402, 26 October 2023, 133014 Multiphase pipeline flow and its detection of cemented backfilling slurry in metal mine is discussed.Multi-dimensional characterization and modelling prediction in the pipeline transportation of cemented slurry is systematically proposed.The wall erosion behavior, wearing reduction and controlling features in slurry transportation is summarized.

[2]Prediction of Critical Velocity in Pipeline Flow of Slurries Using TLBO Algorithm: Sareh Sayari,Amin Mahdavi-Meymand , Mohammad Zounemat-Kermani is one of the most important parameters to design slurry transport in pipeline systems. In this study, three standard soft computing data-driven models including artificial neural network (ANN), group method of data handling (GMDH), and neuro-fuzzy inference system (ANFIS) as well as their hybrid versions combined with the teaching–learning-based optimization (TLBO) meta-heuristic algorithm are developed to estimate the Vc through pipeline. The proposed models are built and tested for accuracy by evaluating the results of the models and the collected experimental data from the literature. The results are also compared with eight suggested empirical equations as well as the soft computing method of the gene-expression programming (GEP) model. The evaluation of the results indicates that the ANFIS-TLBO model surpasses the other models and suggested equations to determine the critical velocity of slurries. According to the finding of this study, using the TLBO algorithm improves the performance of ANN, GMDH, and ANFIS by over 15%, 21%, and 4% in terms of root mean squared error, respectively.

[3]Study on velocity distribution of large particle in vertical slurry pipeline Zhao Li-an, Wang Tieli, Han Wenqiang Velocity distribution of vertical pipes with large particle slurry plays an important role in pipeline transportation of minerals in hydraulic coal mining and ocean mining industry. The experiments of particle fluidization and particle vertical lift are conducted and the fluidization data of three kinds of large particles are analyzed. The results show that the vortex resistance prevents particles from moving as the coarse particles move in vertical pipes. An additional coefficient method is proposed to study the vortex resistance by increasing the coefficient of vortex resistance before interference. Mathematical model is established to describe the drag coefficient of the vortex by analyzing the influence factors of the experimental data and the drag coefficient of the vortex. In addition, calculation model of the velocity distribution of large particles in vertical pipe is proposed by analyzing the force, the fluid, and the solid momentum. Moreover, the experimental data of particle transport in vertical pipes are utilized to verify and analyze the proposed model.

[4]Pipeline Slurry Transportation System: An Overview The slurry pipeline system as the means of transportation is reviewed showing the process of transportation starting from the beneficiation of ore at the mine site to the dewatering stage at the process plant. A detailed analysis of the pipeline system for being the most cost-effective method of transportation in comparison with other modes of transportation like trucks, railway networks, barges, belt conveyors, and pneumatic pipeline systems was assessed. The parameters affecting the slurry flow behavior like solid concentration, the velocity of flow, pressure drop, particle size distribution, temperature, pH, different modal distributions, and additives were discussed along with their effects on the rheology. Developing a model that helps in estimating the flow behavior of high-concentration slurry has been a major concern over the years with the increasing need for transporting high-density throughput, and a few models evaluating the effects were developed in the literature and discussed here. To acquire a deeper understanding of the solid-liquid slurry flow, computational fluid dynamics is commonly used as a tool for simulating the parameters governing the motion of the flow. The solid concentration distribution, velocity profile distribution, and pressure drop as the dominant factors for estimating the flow behavior are studied, along with other parameters like skin friction coefficient, shear stress distribution, turbulent viscosity, and contours of different profiles. A comparative study of experimental and simulated results was also reviewed, measuring the randomness of asymmetry between measured and predicted data

3. Methodology

In a slurry pipe line, apart from the pressure drop and concentration distribution, velocity field at a cross-section is, an equally important parameter for the slurry pipeline design. The interrelation between various parameters cannot be fully understood without complete knowledge about the velocity field.Roco and Shook gives formula for the prediction of velocity distribution across the pipe cross section along with the modifications incorporated to improve the accuracy of the above model.

Formula for prediction of velocity profile by Roco and Shook

$$V_m(r) = -\frac{\mu_m}{2\alpha_{md}} + sqrt\left[\left(\frac{\mu^2 m}{4{\alpha_{md}}^2}\right) + \left(\frac{\xi(r)}{\alpha_{md}}\right)\right]$$

4. Experimental analysis

Experimental data to be used in the present study

Test results for water-sand mixtures flowing in circular pipelines

Run no.	**D (mm)**	**I (mH_2 O/m_{pip}**	**Cexp (%)**	**Vexp (m/s)**

		e)		
1	51.5	0.068	8.41	1.66
2		0.25	9.18	3.78
3		0.092	18.7	1.66
4		0.35	18.9	4.17
5	263	0.0312	19.0	2.9
6		0.039	18.4	3.5
7	495	0.0197	27.3	3.16
8		0.026	26.9	3.76

Comparison of Measured and Predicted (By Roco And Shook (1984) Model)

Velocity Distribution

The experimental data considered in the present study are tabulated in Table. The predicted velocity distribution is shown in Figures. The detailed calculation of velocity distribution is described in Annexure 3.1. It is observed that the experimental velocity distributions were continuous in nature. However, the predicted velocity distribution by Roco and Shook (1984) model were found to be discontinuous in nature.

4.1 Velocity distribution for run no 1 to 8

$$V_m(r) = -\frac{\mu_m}{2\alpha_{md}} + sqrt\left[\left(\frac{\mu^2 m}{4\alpha_{md}^2}\right) + \left(\frac{\xi(r)}{\alpha_{md}}\right)\right]$$

Calculation of Vm(r) for run no. 1

Y’	Vm m/s
Y’ = - 0.8 R	1.10
Y’ = - 0.6 R	1.19
Y’ = - 0.4 R	1.43
Y’ = -0.2 R	1.63
Y’ = 0	1.79
Y’ = 0.2 R	2.11
Y’ = 0.4 R	2.06
Y’ = 0.6 R	1.99
Y’ = 0.8 R	1.91
Y’ = R & -R	0

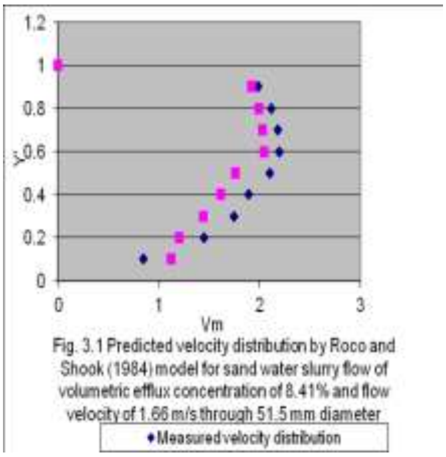

Fig. 3.1 Predicted velocity distribution by Roco and Shook (1984) model for sand water slurry flow of volumetric efflux concentration of 8.41% and flow velocity of 1.66 m/s through 51.5 mm diameter

Calculation of Vm(r) for run No. 2

Y’	Vm m/s
Y’ = - 0.8 R	3.18
Y’ = - 0.6 R	3.26
Y’ = - 0.4 R	3.46
Y’ = -0.2 R	3.77
Y’ = 0	3.94
Y’ = 0.2 R	4.27
Y’ = 0.4 R	4.19
Y’ = 0.6 R	4.12
Y’ = 0.8 R	4.10
Y’ = R & -R	0

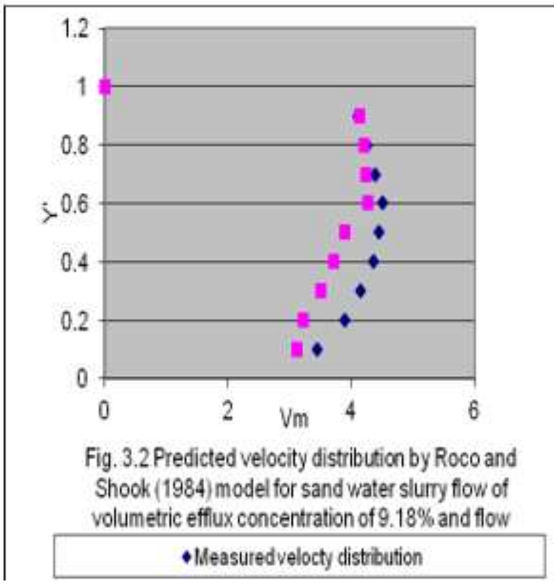

Fig. 3.2 Predicted velocity distribution by Roco and Shook (1984) model for sand water slurry flow of volumetric efflux concentration of 9.18% and flow

Calculation of Vm(r) for run No. 3

Y’	Vm m/s
Y’ = - 0.8 R	1.10
Y’ = - 0.6 R	1.13
Y’ = - 0.4 R	1.26
Y’ = -0.2 R	1.43
Y’ = 0	1.57
Y’ = 0.2 R	2.04
Y’ = 0.4 R	2.03
Y’ = 0.6 R	2.03
Y’ = 0.8 R	2.02
Y’ = R & -R	0

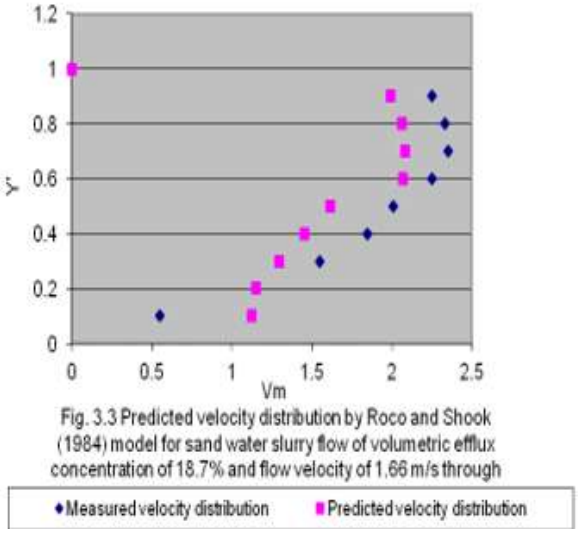

Fig. 3.3 Predicted velocity distribution by Roco and Shook (1984) model for sand water slurry flow of volumetric efflux concentration of 18.7% and flow velocity of 1.66 m/s through

Calculation of Vm(r) for run No. 4

Y’	Vm m/s
Y’ = - 0.8 R	3.28
Y’ = - 0.6 R	3.32
Y’ = - 0.4 R	3.58
Y’ = -0.2 R	3.79
Y’ = 0	4.06
Y’ = 0.2 R	4.52
Y’ = 0.4 R	4.48
Y’ = 0.6 R	4.42
Y’ = 0.8 R	4.38
Y’ = R & -R	0

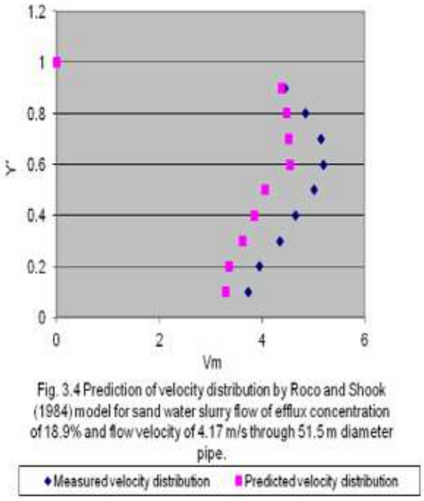

Fig. 3.4 Prediction of velocity distribution by Roco and Shook (1984) model for sand water slurry flow of efflux concentration of 18.9% and flow velocity of 4.17 m/s through 51.5 m diameter pipe.

Calculation of Vm(r) for run No. 5

Y’	Vm m/s
Y’ = - 0.8 R	2.11
Y’ = - 0.6 R	2.20
Y’ = - 0.4 R	2.38
Y’ = -0.2 R	2.58
Y’ = 0	2.74
Y’ = 0.2 R	3.69
Y’ = 0.4 R	3.66
Y’ = 0.6 R	3.57
Y’ = 0.8 R	3.55
Y’ = R & -R	0

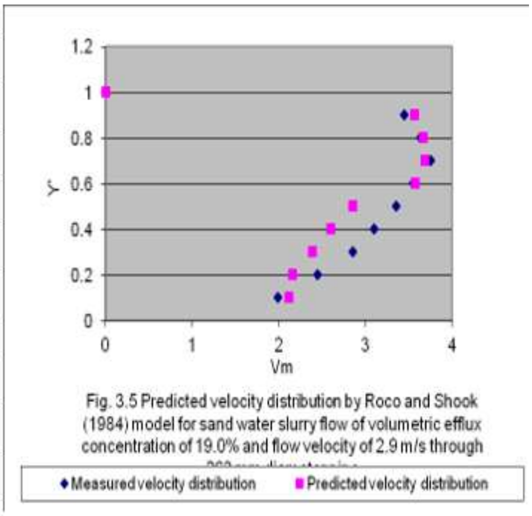

Fig. 3.5 Predicted velocity distribution by Roco and Shook (1984) model for sand water slurry flow of volumetric efflux concentration of 19.0% and flow velocity of 2.9 m/s through

Calculation of Vm(r) for run No. 6

Y’	Vm m/s
Y’ = - 0.8 R	2.50
Y’ = - 0.6 R	2.55
Y’ = - 0.4 R	2.79
Y’ = -0.2 R	3.02
Y’ = 0	3.26
Y’ = 0.2 R	3.92
Y’ = 0.4 R	3.99
Y’ = 0.6 R	3.86
Y’ = 0.8 R	3.81
Y’ = R & -R	0

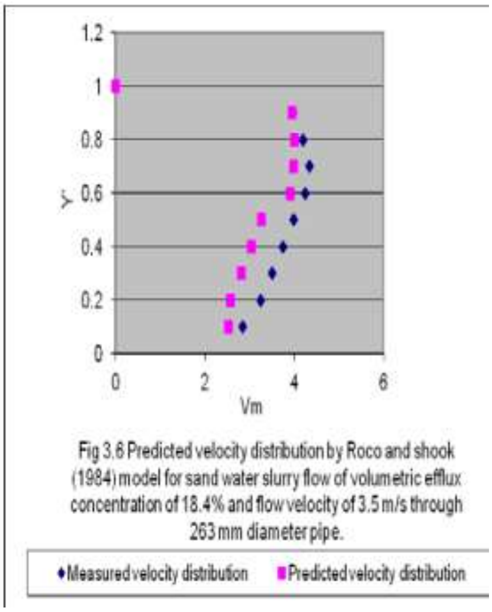

Fig 3.6 Predicted velocity distribution by Roco and shook (1984) model for sand water slurry flow of volumetric efflux concentration of 18.4% and flow velocity of 3.5 m/s through 263 mm diameter pipe.

Calculation of Vm(r) for run No. 7

Y’	Vm m/s
Y’ = - 0.8 R	2.55
Y’ = - 0.6 R	2.71
Y’ = - 0.4 R	2.82
Y’ = -0.2 R	2.95
Y’ = 0	3.15
Y’ = 0.2 R	3.73
Y’ = 0.4 R	3.91
Y’ = 0.6 R	3.87
Y’ = 0.8 R	3.82
Y’ = R & -R	0

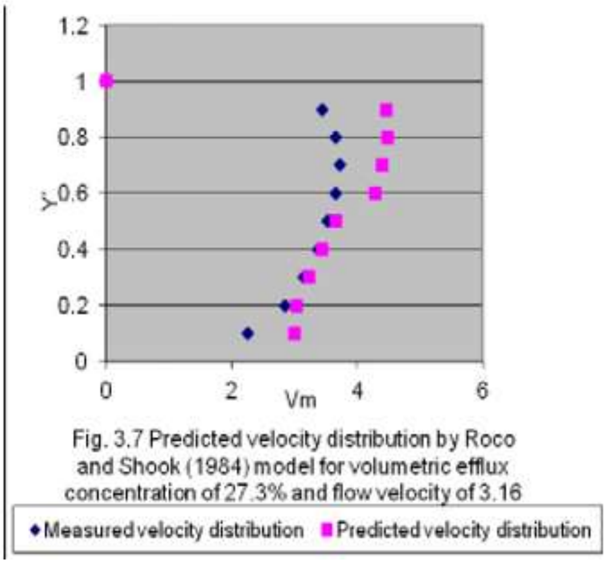

Fig. 3.7 Predicted velocity distribution by Roco and Shook (1984) model for volumetric efflux concentration of 27.3% and flow velocity of 3.16

Calculation of Vm (r) for run No. 8

Y’	**Vm m/s**
Y’ = - 0.8 R	3.47
Y’ = - 0.6 R	3.61
Y’ = - 0.4 R	3.96
Y’ = -0.2 R	4.26
Y’ = 0	4.53
Y’ = 0.2 R	5.11
Y’ = 0.4 R	5.13
Y’ = 0.6 R	4.85
Y’ = 0.8 R	4.84
Y’ = R & -R	0

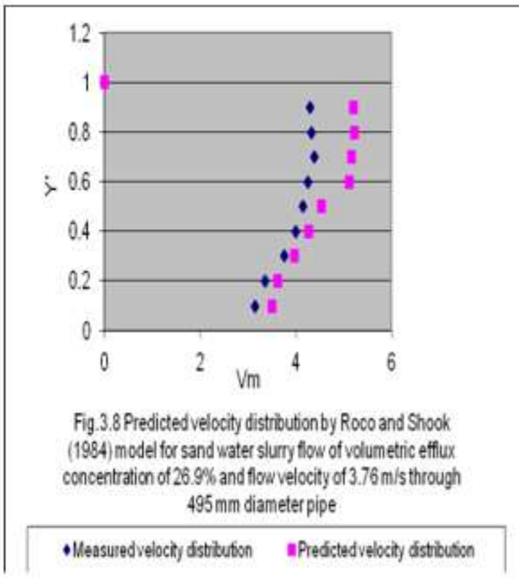

Fig.3.8 Predicted velocity distribution by Roco and Shook (1984) model for sand water slurry flow of volumetric efflux concentration of 26.9% and flow velocity of 3.76 m/s through 495 mm diameter pipe

5. Conclusions:

This experimental study gives the broad and general observations for the overall characteristics of the flow of equi-sized particulate slurry.

1. On the basis of extensive literature review, it was found that Roco and Shook [1] model has great promise for the velocity distribution prediction.
2. Roco and Shook [1] model has been used to predict the velocity distribution for experimental data available in literature.
3. It was observed that however the average velocity calculated on the basis of Roco and Shook [1] model is similar to the measured value, the shape of the velocity distribution is not according to the shape of measured velocity distribution. the model might not capture the nuances of the velocity profile within the pipeline
4. The reason for irregular shape of velocity distribution predicted by Roco and Shook [1] is attributed to the use of Peckenkin [2] equation for liquid and solid turbulence intensities in their model.
5. Roco and Shook (1984) model is modified by using a very recently and well tested formula for liquid and solid turbulence intensities proposed by Kaushal et.al [3].
6. The proposed modified Roco and Shook [1 he model accurately predicts the average flow velocity, replicates the shape of the velocity distribution, and matches the location of maximum velocity observed in experimental data, it suggests that the model is performing well overall

6. References

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