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A analysis of various Factor Affecting Transporting Solid and Liquid Suspension through Pipelines

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ABSTRACT

An experimental investigation was carried out on the transport of solid liquid mixture through pipelines. The principal aim of this was to study how to transport slurries through pipeline systems. The experimental tests include measurements of main parameters affecting transport of solid liquid mixture, like sand slurry and mud slurry. These parameters are deduced by applying non-dimensional approach, which includes Reynolds number, Froude number, concentration, specific gravity, and ratio of particle to pipe diameter. Preliminary results include the following general trends: 1) Increasing input concentration increases the pressure gradient, whereas decreases the efficiency of solid transport; 2) As specific gravity of solid material increases, the pressure gradient increases and the efficiency of transport decreases; 3) As mixture velocity increases, the efficiency of transport increases; 4) Solids with fine grain size are preferred than with coarse grain size from the view points of pressure gradient and efficiency of transport. Also, the present experimental data has been compared with the correlations developed before by different authors. Such correlations relate the pres- sure gradient to flow velocity, specific gravity, and efficiency of transport to grain size of solid material, and input solid concentration.

Keywords: ***Sand Slurry; Solid Concentration; Pressure Gradient; Efficiency of Transport; Solid Diameter***

1. Introduction

The present study is originated in order to investigate the problem of blocking the pipelines that transport water and sold mixture. The slurry is the product of much industrial process like oxygen converter in iron and steel industries, and drilling industries.

These lines have a considerably low flow velocity, which leads to enhanced rate of deposition. As a result of this operation, pipeline systems suffer from fast blocking.

The present study is also of interest because it is applicable to problems related to the handling and trans- porting of solid raw materials and products, e.g. coal.

The experimental study for determining the pressure gradient and efficiency of transport is burdened by some different constraints arising mainly from the following three characteristics of the problem.

1) The abundance of variables which govern the flow.
2) The vast range over which most of the variables may vary.
3) The inherent limitation on accuracy and reproducibility of the data that can be obtained with heterogeneous settling slurries.

The basic problem in hydraulic transport of solids is the determination of the fluid forces acting upon the solid particles and the effects of these forces upon the behavior of such particles and upon the resultant energy losses.

2. Literature Survey

2.1. Introduction

The transport of solid particles by a liquid flowing in a pipeline is governed by a number of parameters that can be classified as follows: pipeline parameters, liquid parameters, solid particle parameters and system parameters e.g. mixture flow velocity.
It would be useful to study the effects of these parameters upon the performance characteristics such as: the pressure gradient ($\Delta P/L$) and efficiency of transport (η).

2.2. Flow Regimes and Critical Velocity

2.2.1. Flow Regimes

There are four distinct regimes of particle conveyance, (see Newit *et al*. [1]) who carried out experiments with solids of sizes from 0.062 to 4.67 mm. and specific gravity ranging between 1.18 and 4.6. The experiments were performed in a 2.54 cm. pipe and resulted in the following regimes.

1) Conveyance as a homogenous suspension in which mean mixture velocity is high to prevent sedimentation during transport process.
2) Conveyance as a heterogeneous suspension, which is maintained by turbulence heterogeneous flow.
3) Conveyance by saltation, in which the particles are alternatively picked up by the liquid and deposited fur- ther along the pipe.

4) Conveyance as a sliding bed, that is a regime in which the principal mechanism is sliding motion of sol- ids along the bottom of the pipe.

Another classification of these regimes is derived by Durand [2]. This classification depends on particle size ranges as follows:

1) Particles of a size less than 40 µm, are transported as a homogenous suspension.
2) Particles of a size between 40 µm and 0.15 mm are transported as suspension that is maintained by turbu- lence.
3) Particles of a size among 0.15 and 1.5 mm are transported by a suspension and saltation. 4) Particles of a size greater than 1.5 mm are trans- ported by saltation. The flow regimes given in this classification are re-lated having a specific gravity of 2.65.

2.2.2. Critical Velocity

The critical velocity conditions have been the study of extensive research effort and yet can still be confusing, as many definitions have been used for this term. The most important critical velocities are those which another phase of flow is produced as laminar/turbulent transport velocity in case of homogenous slurry flow or the deposit velocity in case of settling slurry flow.

2.2.3. Critical Deposit Velocity

A further result of Durand's work is an empirical equation for predicting the critical deposit velocity of slurry, *i.e.* the velocity below which a stationary deposit of solids forms in the pipe. The critical deposit velocity correlation is given by:

$$v_c = F_L\sqrt{(2gD(s-1))} \qquad 1$$

where *FL* is a dimensionless function of particle diameter given by Durand and can be obtained using Figure 1, which requires only the mean particle size and concentration distribution of solids to find the value of *FL*. The result in equation is of considerable practical value for the critical velocity, if sufficiently high in a given case, may be the limiting parameter.

2.3. Pressure Drop through Slurry Pipeline

The need to predict pressure drop for flowing slurries is an eminently practical one.

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2.3.1. Durand's Equation for Pressure Losses in Horizontal Pipes

The empirical correlation published by DURAND [2] is related to the pressure drops associated with the flow of sand-water and gravel-water mixtures with particles of sizes ranging from 0.2 to 25 mm. and pipe diameters from 3.8 to 58 cm. with solids concentrations up to 60% by volume. A principal result of the work by DURAND [2] is the correlations:

$$\frac{i - i_w}{i_w C_o} = k\left[\frac{v^2}{gD}\sqrt{C_D}\right]^{-1.5}$$

where i and iw are the pressure drop of slurry and of water respectively, k is a constant and CD is the drag coefficient for the free failing particle at its terminal velocity in the stagnant unbounded liquid, assumed spherical and of diameter ds given by:

$$C_D = \frac{4gd_s\left[s-1\right]}{3v_\infty^2}$$

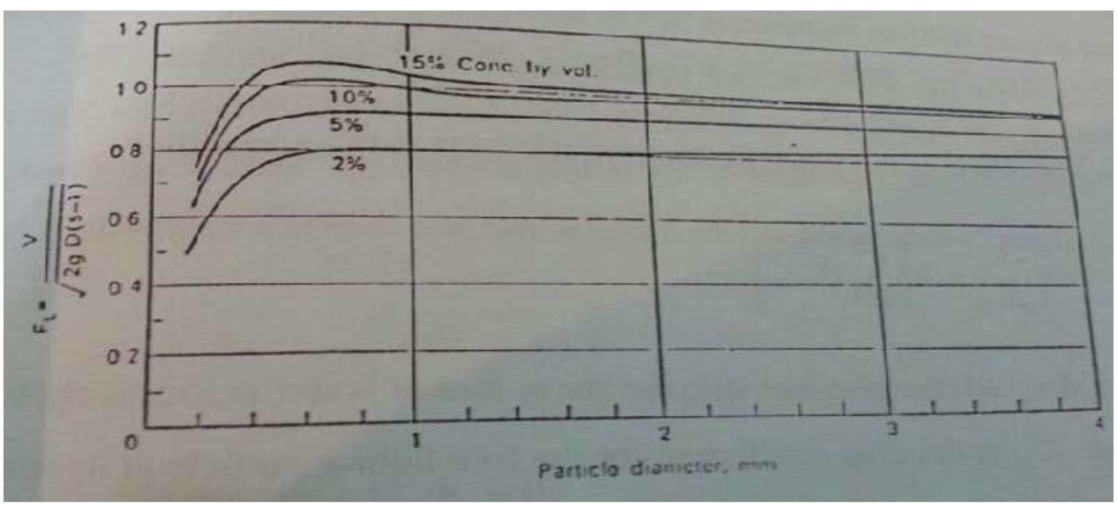

Figure 1. Values of F_L (Durand *et al*. (1953)).

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cording to WORSTER [3]. To account for the effect of particle density, moreover, a modification of Equation (1) is given by

$$\frac{i-i_w}{i_w C_o} = k\left[\frac{v^2}{gD(S-1)}\sqrt{C_D}\right]^{-1.5}$$

where S is the specific gravity of solid material. In this equation Durand's group used $(S-1) = 1.65$, and, by comparing Equation (2) and Equation (4) $k = 150$.
Durand's correlation, Equation (2) gave 18.0% absolute average deviation when compared with data by Turain and Yuan [6].

2.3.2. Worster's Equation for Pressure Losses in Horizontal Pipes

Worster [3] studied flow phenomena associated with large particles in particular coal particles, and produced a similar correlation to that of Durand and his coworkers except for the inclusion of a term in take account of specific gravity of the solid material and the absence of any parameter of particle size.

$$\frac{i-i_w}{i_w C_o} = 120\left[\frac{\sqrt{gD}}{v}\sqrt{\frac{\rho_{s-p}}{\rho}}\right]^3$$

2.3.3. Improved Durand—Equation for Multiple Applications

The applicability of Durand's equation could be improved for general use by applying suitable parameters representing the grain size distribution. Thus, the Durand's equation can not only describe polydisperse (pseudo)- homogenous or heterogeneous transportation, but also solid-liquid mixtures containing a certain amount of fine particles. Even non Newtonian influences can be taken into account.

The applicability of the extended Durand's equation for polydisperse mixtures was demonstrated by measurement data. With respect to this, the transition between pseudo-homogeneous and heterogeneous transport has been considered on the basis of measured concentration profiles.

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WAGNER [4] empirically could show with special polydisperse mixtures the grain size distribution can be taken into account more efficiently by using 90*sd* and 10*sd* in the following correlation factor, *m*; viz.

$$m = 2 - \left(\frac{d_{s90}}{d_{s10}} \right)^{-0.4}$$

where 90*sd* and 10*sd* are particle diameter at 90% and 10% passing sieve, respectively.
Thus the following extended version of Durand's equation can be written for polydisperse-heterogeneous Newtonian mixture:

$$\Delta P = \left[83^{\frac{1}{m}} \left[\frac{gD}{\upsilon^2} \left(\rho_s - \rho_f \right) \rho_f \sqrt{C_D} \right]^{\frac{1.5}{m^3}} C_o + 1 \right] \cdot \lambda_f \rho_f 2\upsilon^2 \frac{L}{D}$$

3.1. Theoretical and Dimensional Analysis

In this section the dimensional analysis is used to plan experiments and present data compactly. It is noteworthy to mention that many workers also used it in theoretical studies, as well. Basically, dimensional analysis is a method for reducing the number and complexity of experimental variables that affect a given physical phenomenon, using a sort compacting technique. By applying these techniques for the problem of transporting solid-liquid mixture we proceed as follows:

Under isothermal conditions, at least 12 variables are needed to describe suspension flow behavior, provided that pipeline roughness and solids density distribution are excluded from consideration.
2. Inclination to horizontal *g*
3. Pipe length. *L*

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Liquid parameters:
1. Density. ρ
2. Viscosity. μ
Solid particles parameters:
1. Density. ρ_s
2. Size distribution (dimensionless) □
3. Shape factor □
System parameters:
1. Velocity of flow. □
2. Solid-liquid ratio of the flowing mixture at inlet.
2. Inclination to horizontal *g*
3. Pipe length. *L*
Liquid parameters:
1. Density. ρ
2. Viscosity. μ
Solid particles parameters:
1. Density. ρ_s
*s*2. Size distribution (dimensionless)
3. Shape factor
System parameters:
1. Velocity of flow.
2. Solid-liquid ratio of the flowing mixture at inlet. *C*
*i*The output variables or the performance characteristic variables are:
1. The pressure drop for pipeline flow of solid – liquid suspension
2. The efficiency of transport defined as the ratio between outputs to input concentrations per unit volume,

$$Ŋ = (C_o / C_i)$$

3.2. Experimental Test Rig

To establish the relationship stated in Equation (17) a purely experimental approach designed. The model used for test is shown in **Figure 2**.
The model was chosen in such a way to permit the observation of effects of dimensionless groups that control the rate of deposition of solids and pressure gradient through pipeline system. These dimensionless groups are, Reynolds number, Froude number, relative density, particle

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grain size, and input concentration. The model consists of two cast steel reservoirs 6 cubic meter capacity each of conical-shaped bottom, and connected to a slurry- type centrifugal pump with diameters of 5.08 cm suction and 2.54 cm discharge pipes. The pumps are connected to 7.5 Kw. A/C induced motor with variable speeds. the pipeline is 285 meter long, and the solid concentration by volume was varied between 0.027% and 10%. Average grain size range between 0.25 mm and 1 mm and specific gravities ranging from 2.65 to 3.540 the Reynolds number was varied from 10907 to 63699.

The measured velocity was varied from 0.5 m/s to 2.5 m/s.

In the tests five variables were determined namely:

1. Pressure gradient along the pipeline system.
2. Flow rate measurements.
3. Input concentration to pipeline. C_i
4. Output concentration from pipeline. C_0
5. Input grain size.

3.2.1. Pressure Measurement

Pressure measurements were determined by means of bourdon tube manometers that were calibrated by means of dead weight testers. The bourdon gauges are fitted to the pipeline at an equal distance of 16 meter between any two successive manometers.

To avoid wrong readings of manometers as a result of existing solid material through the flow field, special connections were made by mounting a helical-shaped pipe full of oil that is lighter than water.

3.2.2. Flow Measurements

Flow measurements were determined by measuring the flow rate during one hour operation from suction tank to discharge tank.

During the experimental work, the flow rate controlled by means of adjustment of delivery valves only while keeping the suction valves fully opened.

3.2.3. Concentration Measurement

In this experimental work, the following steps have been carried out to determine the input and output concentrations,

1. Prepare a clean, empty bottle and weigh it.
2. Fill the empty bottle with 50 cm3 sample from the homogenous mixture of the suction tank.

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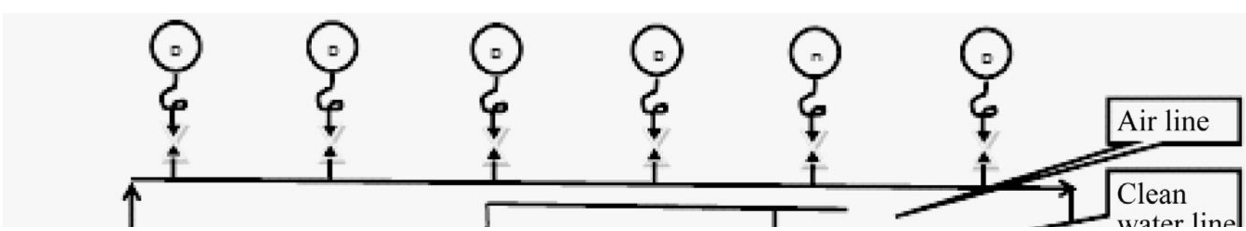
3. Put the bottle on a heater until water is completely evaporated and hence the solids are completely dried.
4. Put the solid sample into cold dryer to cool it.
5. Weigh the solid sample.
6. Subtract the two weights in steps 5 and 1 respectively.
The difference is the total solid existed in the sample (suspension solid + soluble solid).
7. Take another 50 cm3 sample from the same mixture of the suction tank and filter it, so as the water constitutes the soluble solids only.
8. Repeat the steps from (3 to 4) listed before to determine the weight of soluble solids.
9. Subtract the result of step number 8 from that of number 6 to obtain the T.S.M (Total Suspended Material) which represents the transported material through the pipeline system.

3.2.4. Input Grain Size Measurements

The input grain size was determined using a set of standard screen meshes that are available in the laboratories of the factory.

3.3. Experimental Procedure

Preliminary measurements were made to ensure that the system produces a stable (no pulsation), with no leakage from test devices. The Reynolds number (ReD) for the tests is varied from (10907 to 63699). The model was provided with 18 pressure gauges, fitted at locations of equal distance of 16 meter apart to ensure precise plotting of the pressure drop variation with length and velocity.



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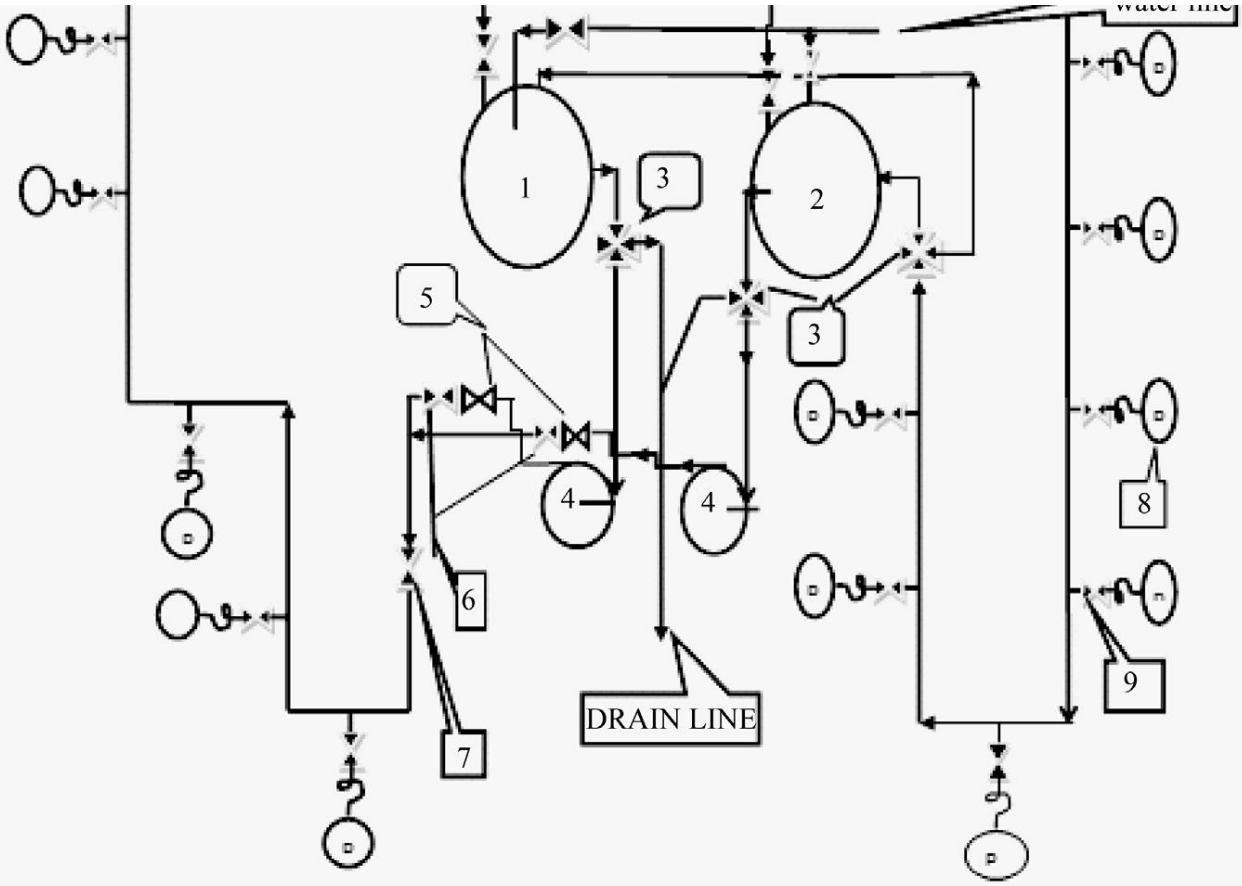

No	Description	No	Description
1	Tank 1	6	Delivery valves
2	Tank 2	7	Control valve
3	Three way suction valves	8	Pressure gauges
4	Centrifugal pumps	9	Pressure gauge valve
5	Non return valves		

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Figure 2. Schematic outline of experimental test rig.

4. Results and Discussions

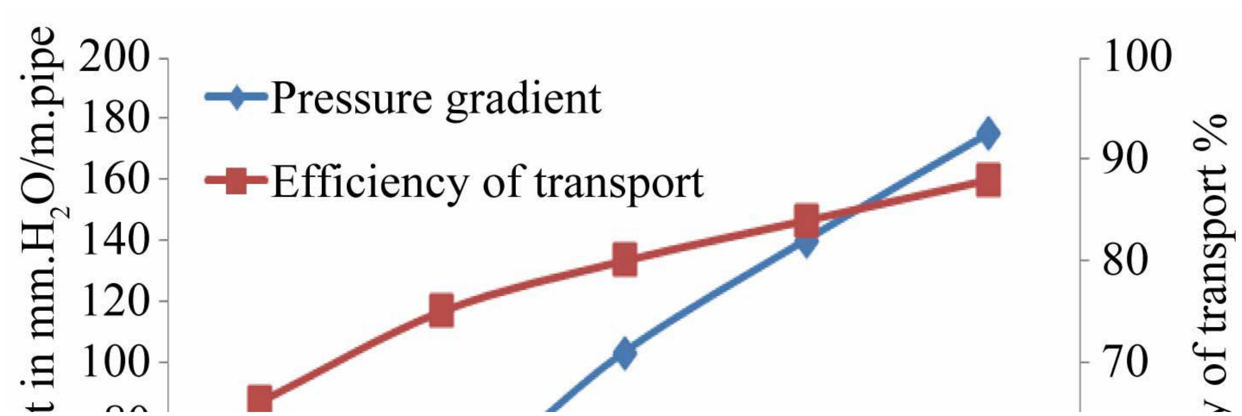
In the present section the results obtained from the experimental model are presented and discussed.

4.1. Effect of Varying Reynolds Number Re and Froude Number upon the Performance Characteristics.

In the present experimental work, it was found that the simplest way to vary the value of Reynolds number would be through adjustment of the flow velocity. Therefore, Reynolds number as well as Froude number vary together.

1) Effect of varying Re, Fr, upon pressure gradients

The Reynolds number has been varied from (10907 – 63699) and Froude number from (0.5 - 17). It has been noted from **Figures 3** to **8** that as Reynolds



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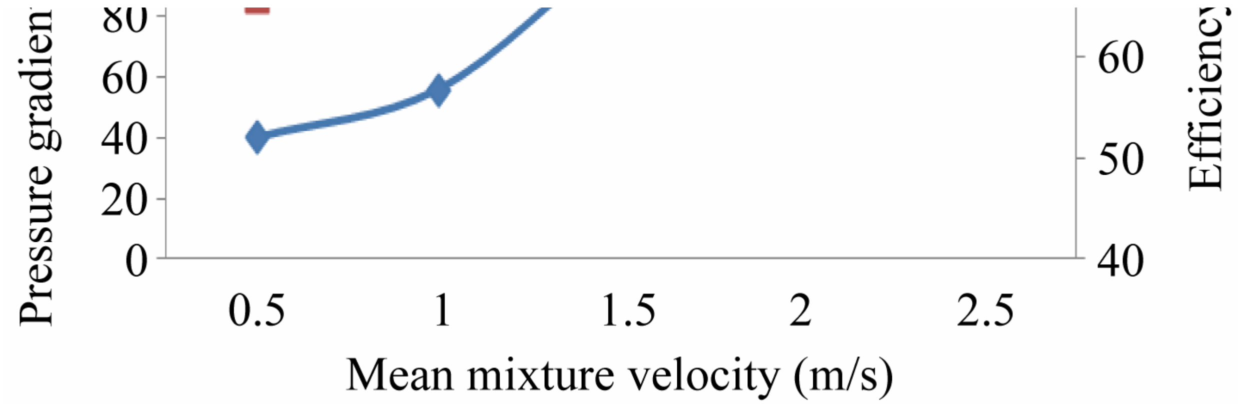

Figure 3. Variation of slurry performance characteristics for sand slurry with solid concentration 1% by volume and particle diameter *ds* = 0.25 mm. versus mean mixture velocity.

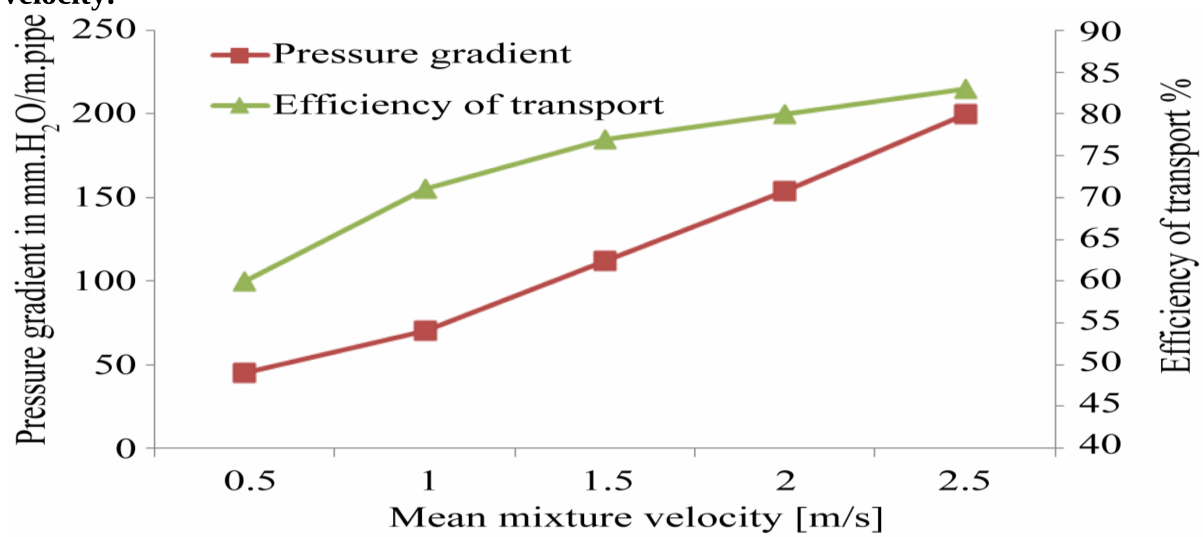

Figure 4. Variation of slurry performance characteristics for sand slurry with solid concentration 1% by volume and particle diameter *ds* = 0.5 mm. versus mean mixture velocity.

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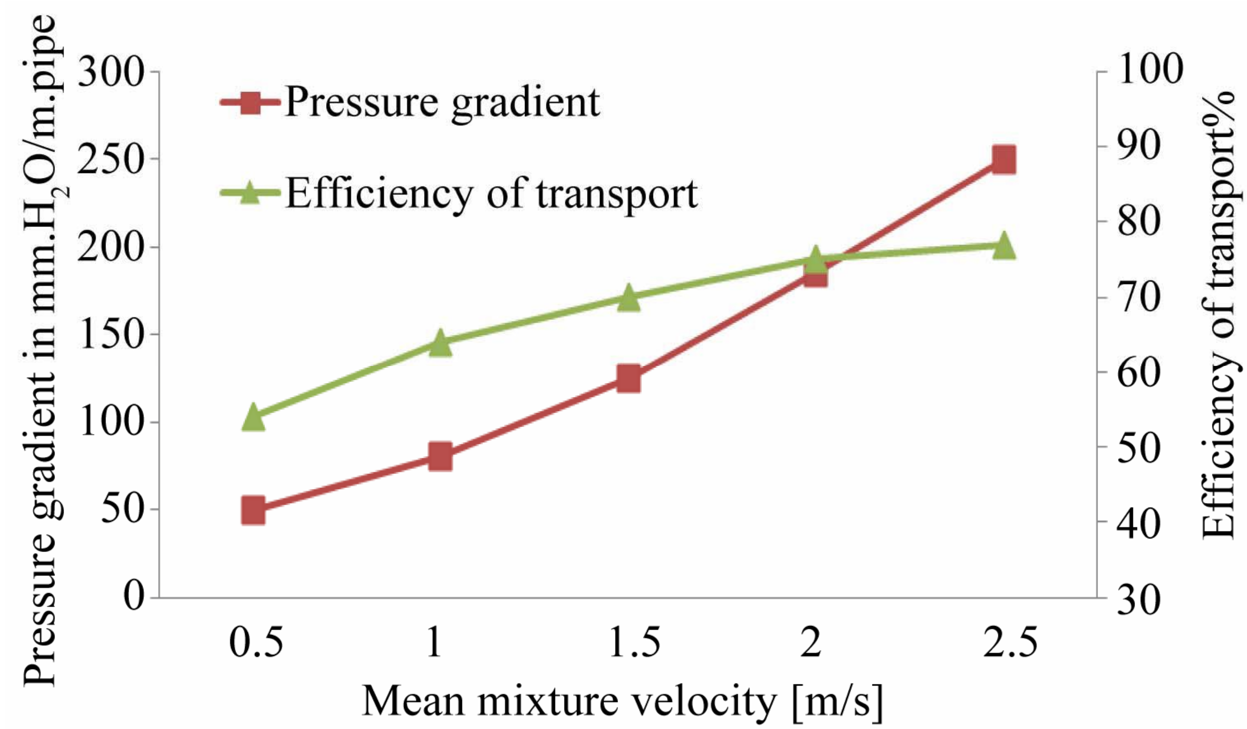

5. Conclusions

The main conclusions that can be extracted from the results and observations of this work are mentioned below:

1) The input concentration plays an important role in the slurry transportation process. Increasing input concentration causes an increase in the pressure drop and a decrease in efficiency of transport, probably due to ag- glomeration and flocculation of solid particles.

2) Increasing the grain size increases the pressure loss and decreases efficiency of transport.

3) As the Reynolds number increases, transport efficiency increases with an increase in pressure drop, and subsequently input power increases as well.

4) The process of transportation can be improved by using fine materials rather than course materials.

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5) The specific gravity of solid materials plays an important role in efficiency of transport and also in pressure gradient. As specific gravity increases, the tendency to settle down increases, which can lead to decrease in efficiency of transport and increase in pressure drop.

6. Recommendations

1) The present work was carried out to investigate and deduce the dimensionless groups that affected the trans- porting process, but the functional dependence was still unknown. So it's recommended to use the data summed up here and define the governing equations.
2) It is also recommended to carry out experiments to investigate how the slurry transport affects the characteristics of the pumps.

REFERENCES

[1].D. M. Newitt, J. F. Richardson, M. Abbot and R. B. Tur-tle, "Hydraulic Conveying of Solids in Horizontal Pipes," *Transactions of the Institution of Chemical Engineers*, Vol. 33, 1955, pp. 93-113.

[2].R. Durand, "The Hydraulic Transport of Coal and Solid Materials in Pipes," *Proceedings of Colloquium on the Hydraulic Transport of Coal*, National Coal Board, Lon- don, 1952, pp. 39-55.

[3].R. C. Worster, "Proceedings of Colloquium on Hydraulic Transport of coal, National Coal Board, London, 1952.

[4].K. Wagner, "Investigations on the Influence of the Grain Size Distribution for Horizontal Hydraulic Conveying of Solids in the Heterogeneous Regime," Thesis, Karlsruhe, 1982.

[5].M. Weber, "Improved Durand–Equation for Multiple Application," *International Symposium on Slurry Flows*, 1986, pp. 61-66

[6].R. M. Turain, T. F. Yuan, *et al*., "Pressure Drop Correla- tion Pipeline Flow of Solid Liquid Suspensions," *AICHE Journal*, Vol. 17, No. 4, 1971, pp. 809-817. doi:10.1002/aic.690170409

[7].H. C. Hou, "Investigation of Optimal Grain Distribution for Transport with High Concentration," *Hydraulic Trans- port of Solids in Pipes*, city, 29-31 October 1986, pp. 177-183.

[8].M. S. Lee, V. Matousek, C. K. Chung and Y. N. Lee, "Pipe Size Effect on Hydraulic Transport of Jumoonjin Sand: Experiments in a Dredging Test Loop," Terra et Aqua-number 99, Hamburg, June 2005, pp. 1-10.