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Parameter affecting of slurry flow in perforated pipe on fluidization method to maintenance of channel

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Abstract. Slurry flow in pipes is one of the techniques in developing the method of fluidization, especially in the work of sand by passing for the maintenance of estuary channel, port channel, and others. The slurry flow in the pipe determines the fluidization performance, therefore many researchers have studied the slurry flow system in various approaches. This analysis focuses on the factors that influence the flow of slurry in the perforated pipe based on literature studies. The results of the study indicate that several factors are grouped into main parameters such as pipeline parameters, liquid parameters, solid particle parameters and system parameters. All parameters are concluded through the approach of dimensionless numbers such as Reynold Numbers, Froude numbers, concentration, ratio of settling particle to pipe diameter, ratio of hydraulic gradient to mean flow velocity. These parameters have an effect on head loss, friction, drag reduction which controls the flow of slurry in the pipe media. In addition, the constant pressure distribution is a factor that affects the discharge in the slurry flow in the perforated pipe.

1. Introduction

Channel maintenance with the fluidization method was first carried out on a waterway maintenance project in Anna Maria, California for the operation of sand by passing work in 1994 [1]. However, research into the application of fluidization for sediment transport was first carried out in 1977 [1]. The form of fluidization proposed by both Wisman and Kelley is a form of fluids with pipes embedded under a layer of sediment (non-cohesive material). Both Kelley, Weisman and Lennon have similarities in fluidization research, namely their emphasis on the hydraulic aspect to obtain maximum fluidization and geometric elements of the grooves formed. In addition, Kelley also conducted research on the structure of sediment grains eroded by water bursts in the initial conditions of fluidization until full fluidization was achieved. It is explained by Weisman and Lennon that the phenomenon of fluidiation generally explains Darcy's law which applies at the beginning of fluidization due to obstacles to flow velocity by sediment grains [26]. The flow velocity through the media in the initial fluidization phase is hereinafter referred to as the minimum fluidization velocity V_{mf} [2].

The fluidization method has been developed through various methods and various interests. Specifically in the field of navigation channel maintenance the fluidization method develops by fluidization using the sediment agitation method with perforation pipes embedded under the sediment layer and fluidization by the suction method using a jet slurry pump commonly used in the sand by passing method [3]. This method emphasizes on achieving minimum [27]quire of velocity at holes of perforated pipe (v_{mf}) [4], pressure distribution in the sediment bed and the hydraulic gradient (d_h/z) for incipient fluidization [5]. Fluidization with the suction pipe method in principle uses the fluid flow [28]thod in the pipe which is sucked through the hole by using the suction pressure from the pump. Fluid flow in the pipe is influenced predominantly by the viscosity (thickness) of the liquid. Therefore the relationship of fluid to its viscosity value divides fluid flow into Newtonian fluid and Non-Newtonian fluid. Especially for jetting in pipes that are not resistant to shear stress, velocity gradient



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and temperature, the viscosity of the fluid changes with time, which means that viscosity is a function of time such as slurry, paper pulp, lubricating oil and others [6].

2. Statement of problem

Slurry flowing in the pipeline has been investigated in various interests, one of which is the development of fluidization methods in channel maintenance work both in channels, harbor from sediment piles both originating from river streams and the influence of waves and tides. Slurry flow uses a pipe medium especially with a slurry suction pump system with a perforation pipe allowing several factors to influence its flow behavior. Therefore some research results state that the performance of drainage through perforated pipes is influenced by several factors that cause blockages in perforated pipe holes [6], the characteristics of particle solids along the pipe from since entering the inlet to the outlet [8], the pipe roughness factor [9] to the particle size [10] and many other influencing factors. The factors that includes of the main parameters that usually known as the transport of solid particles by a liquid flowing in pipeline that can be classified as follow : pipeline parameters, liquid parameters, solid particle parameters and system parameters [11]. Therefore this article discusses the factors that influence the flow of slurry in the perforation pipeline sourced from literature studies with the factors mentioned above.

3. Previously published theories

The forces acting on a pipe cylinder can consist of pressure, shear stress and weight. Therefore, if the flow goes through a pipe without changing the dimensions of the pipe, then the Bernoulli equation applies to the flow at the starting point and end point of the pipe that can be written through the continuity equation (1).

$$z_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g} = z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + h_f \quad (1)$$

Head loss equation due to the flow friction along the pipe wall can be write (2).

$$h_f = \left(z_1 + \frac{p_1}{\gamma} \right) - \left(z_2 + \frac{p_2}{\gamma} \right) \approx h_f = \Delta z + \frac{\Delta p}{\gamma} \quad (2)$$

The Darcy-Weisbach equation is used to determine the energy loss in a circle pipe where f is the coefficient of friction. The value of the coefficient of friction f is a function of the surface roughness factor in the pipe, pipe diameter and flow that depends on the Reynold number Re [9]. For laminar flow with Reynold value $Re < 2000$ the coefficient of friction f can use the Hagen-Poiseuille equation, which is written in the following equation (3).

$$\frac{1}{\sqrt{f}} = \sqrt{\frac{Re}{64}} \approx f = \frac{64}{Re} \quad (3)$$

However, for turbulent flow conditions and transition where the value of $Re \geq 2000$, the friction coefficient which is usually a major concern for the Darcy-Weisbach equation with the friction coefficient equation formulated by Blasius (1913) known as the Blasius equation (4).

$$f = 0.32N_R^{-0.25} \quad (4)$$

N_R is the Reynold Number or Reynold number (Re) so that this equation can also be written down (5).

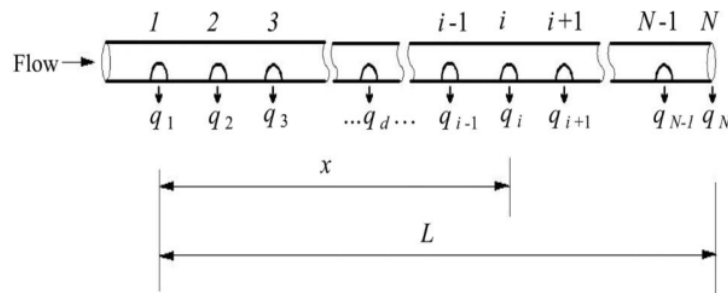
$$f = 0.32R_e^{-0.25} \quad (5)$$

For the perforated pipe, the friction coefficient f is related to the sidewall roughness and the tube structure in addition to the reynold number [12, 13]. The pipe material or surface finish will affect the value of the dimensionless friction coefficients in the governing equations. The experimental results indicate that the friction factor can be calculated under the assumption that the branch points do not affect the friction pressure loss characteristics of the header. Two dependent variables that considered

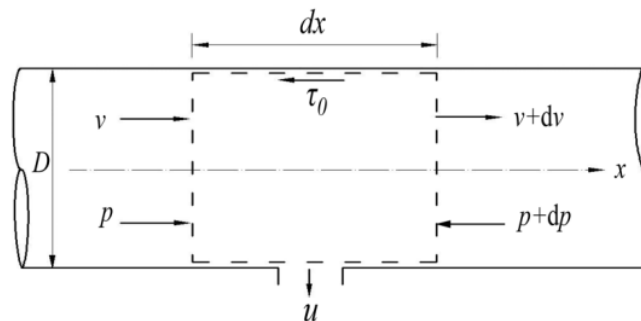
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 to the continuity and momentum equation from a pair of quasi-linear hyperbolic partial differential equation in terms, namely discharge Q and hydraulic-grade-line elevation H that usually called the piezometric head [14, 15].

$$\frac{\partial H}{\partial t} + \frac{Q}{A} \frac{\partial H}{\partial x} - \frac{Q}{A} \sin(\theta) + \frac{a^2}{gA} \frac{\partial Q}{\partial x} = 0 \quad (6)$$

The use of momentum equation is analyze changes in flow energy around perforation pipe holes by establishing assumptions as the basis of the analysis i.e. (i) the flow is one dimensional; (ii) the fluid is incompressible; (iii) the velocity is 0 at the closed end; (iv) pressure is constant; (v) hole are vertical to the axis; (vi) size of the cross-section is constant, slope uniform along the flow [15]. The assumption that describe by following figure.



20
Figure 1. schematic of pipeline with multiple outlets.



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Figure 2. control volume of varying mass flow.

3
 Based on the assumptions and schemes above, the discharge in the hole depends on pressure, which means that the distribution of the discharge in the porous pipe depends on the pressure distribution. This means that all pipe holes have a uniform flow velocity.

$$\frac{1}{\rho} \frac{dp}{dx} + \frac{\lambda}{2D} V^2 + 2kV \frac{dV}{dx} = gI \quad (7)$$

Drag and lift coefficient are important factors in determining particle movement especially movement in a pipe. The given drag force equation generally considers the particle inertia defined.

$$C_D = \frac{F_D}{\frac{1}{2}\rho \cdot U^2 \cdot A} \quad (8)$$

For the drag coefficient C_D associated with the Reynold number it has a correlation with the shape of the particle so that with the assumption of spherical particles the drag coefficient in is given the equation of the model wen and yu as follows

$$C_D = k^{-1.65} \max \left[\frac{24}{N_{Rep}} \left(1 + 0.15 N_{Rep}^{0.687} \right), 0.44 \right] \quad (9)$$

Resulting in drag force for the distribution of solid particles For the solid volume fraction given k_s value < 0.2, this model is a modification used in flow calculation using ANSYS-CFX to ensure the limit of particle inertia behavior

$$M_d = \frac{3C_D}{4d_s} k_s \rho_l |U_s - U_l| (U_s - U_l) \quad (10)$$

Whereas for large scale solid particles with volume fraction $k_s > 0.2$ the gidaspow drag force model can be considered with the equation

$$M_d = \frac{150(1-k_l)^2 \mu_l}{k_l d_s^2} + \frac{7(1-k_l) \rho_l |U_l - U_s|}{4 d_s} \quad (11)$$

Energy losses due to collisions and interactions between liquids and particles that correlate with particle size based on kinetic energy factors α_k and deposition velocity v_t are given for particle size in general. For small particles the relationship of energy loss to kinetic energy factors and sediment velocity is interpreted through the equation

$$\Delta E_{s,kin,p} = \frac{1}{2} m_p \cdot (\alpha_k \cdot v_t)^2 \quad (12)$$

$$V_{sl} = \frac{\frac{1}{2} m_p (\alpha_k \cdot v_t)^2}{m_p \cdot v_{ls}} = \frac{\alpha_k^2}{2} \cdot \frac{v_t^2}{v_{ls}} \quad (13)$$

for large particle :

$$\Delta E_{s,kin,p} = m_p \cdot (\alpha_t \cdot v_t) \quad (14)$$

$$V_{sl} = \frac{a_m \cdot m_p \cdot v_t}{m_p \cdot v_{ls}} = a_m \cdot \frac{v_t}{v_{ls}} \quad (15)$$

for middle particle :

$$\Delta E_{s,kin,p} = m_p \cdot (\alpha_t \cdot v_t)^{3/2} \quad (16)$$

$$V_{sl} = \frac{a_t^{3/2} \cdot m_p \cdot v_t^{3/2}}{m_p \cdot v_{ls}} = a_t^{3/2} \cdot \frac{v_t^{3/2}}{v_{ls}} \quad (17)$$

The mean velocity dan pressure drop are important parameters in the design of slurry pipes, it is necessary to predict the analysis of these parameters to choose the pipe size and type of slurry pump suitable for the slurry drainage system. (Seitsit al., 2014) designed slurry pipe needs with multi-sized solids. The pipeline design is based on a flow velocity based on Durand correlation design that substituting from evaluating the practical transport velocity [6]

$$V_{cl} = 1.34 \sqrt{2 \cdot g \cdot D \cdot (\delta_s - 1)} \quad (18)$$

the practical transport velocity could be evaluated by

$$V_m = 1.2 \cdot V_{cl} \quad (19)$$

Substituting equation (18) into (19), it yields the practical flow velocity of slurry

$$V_m = 1.2 \times 1.34 \sqrt{2 \cdot g \cdot D \cdot (\delta_s - 1)} = 1.608 \sqrt{2 \cdot g \cdot D \cdot (\delta_s - 1)} \quad (20)$$

2

Design pipe diameter of settling slurry should be restricted by the maximum size of solid that commonly write by following equation [7].

$$D > 3 \cdot d_{max} \quad (21)$$

Diameter design D also created by Durand correlation that flowing at mean velocity V_m can given by

$$Q = \frac{\pi}{4} \cdot D^2 \cdot V_m \quad (22)$$

If the diameter design based on Durand correlation substituting into flow velocity equation, it could be

$$Q = \frac{\pi}{4} \cdot D^2 \cdot 1.608 \sqrt{2 \cdot g \cdot D \cdot (\delta_s - 1)} \approx Q = 5.593 \cdot D^{5/2} \sqrt{(\delta_s - 1)} \quad (23)$$

And converted to the slurry flow rate equation which is the transport rate of solid G_a (in kg / second) to the delivered concentration of particle C ($3,154 \times 10^4 \cdot \eta \cdot \gamma_s \cdot C$), so that the slurry pipe diameter design given by

$$D = 5.028 \times 10^{-4} \cdot \left(\frac{G_a}{\eta \cdot \gamma_s \cdot C \cdot \sqrt{(\delta_s - 1)}} \right)^{0.4} \quad (24)$$

4. Previously published experimental

The following experimental studies are based on the results of research by researchers who outline the analysis of the pipeline parameters, liquid parameters, solid particle parameters and system parameters

4.1. Affecting pipe material, temperature, density on the head loss and velocity

Fluid flowing in the pipe is influenced predominantly by the viscosity (thickness) of the liquid. Therefore the relationship of fluid to its viscosity value divides fluid flow in both Newtonian and Non-Newtonian fluid. Especially for jetting in pipes that are not resistant to shear stress, velocity gradient and temperature, the viscosity of the fluid changes with time, which means that viscosity is a function of time such as slurry, paper pulp, lubricating oil and others [6]. Experiments on non-Newtonian flow flowing in 1-inch pipes with fluid concentration varied by 45%, 35% and 25%. From these experiments produce a coefficient of mud friction value higher than the coefficient of water friction at a solid concentration above 35%. This is shown in the relationship between apparent viscosity and shear rate which shows that the instantaneous viscosity of fluids with larger solids reduces the velocity gradient, and vice versa the velocity gradient increases with the decrease of the solid which affects the instantaneous viscosity which conditions flow the fluid is close to Newtonian nature. The relationship between instantaneous thickness and velocity gradient for the varying solids conditions is shown in Figure 3 and 4.

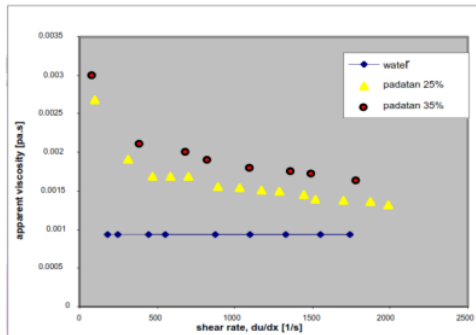


Figure 3. Apparent viscosity and shear rate curves.

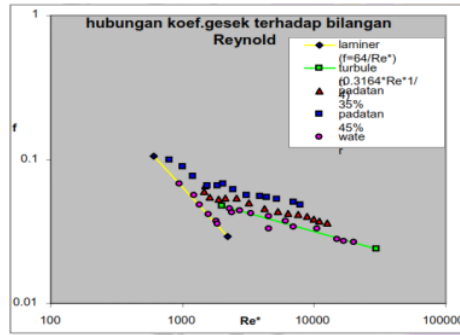


Figure 4. The relationship curve between friction and Reynold's numbers.

The relationship of the thickness of the fluid is expressed also by the dimensionless number Reynold Re to the friction factor f where the friction factor (friction) decreases with increasing value of the Reynold number as in the graph of the coefficient of friction relation to the Reynold number for the solid conditions varying in the figure 4. The curve shows that the viscosity of a fluid is very dependent on several factors including the concentration of solids CW that can be found in the slurry flow in the form of mud. In experiments using two types of pipes with different materials namely metallic and plastic pipes with input parameters such as water temperature, density, dynamic viscosity, variations in the diameter of the pipe and variations in discharge Q . by comparing the head loss (coefficient of friction) between the Darcy-Weisbach and Hazen - William equations produces a dimensionless relationship between discharge Q to the coefficient of friction at temperatures of 20°C to 60°C where the increase in discharge Q increases the head loss as in the following curve

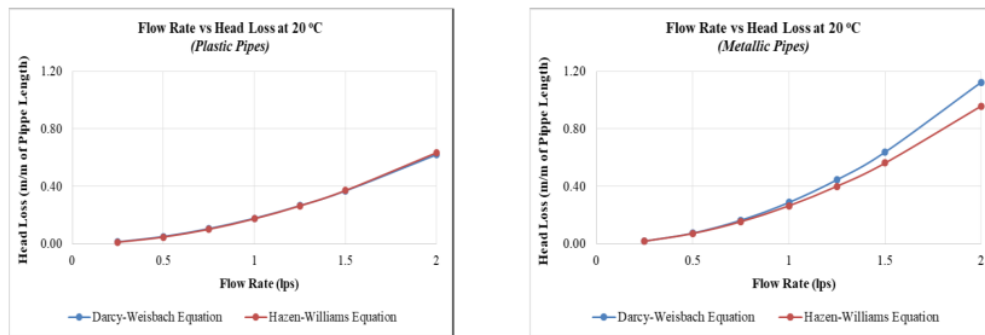


Figure 5. Relationship curve discharge to head loss at water temperature for 20°C

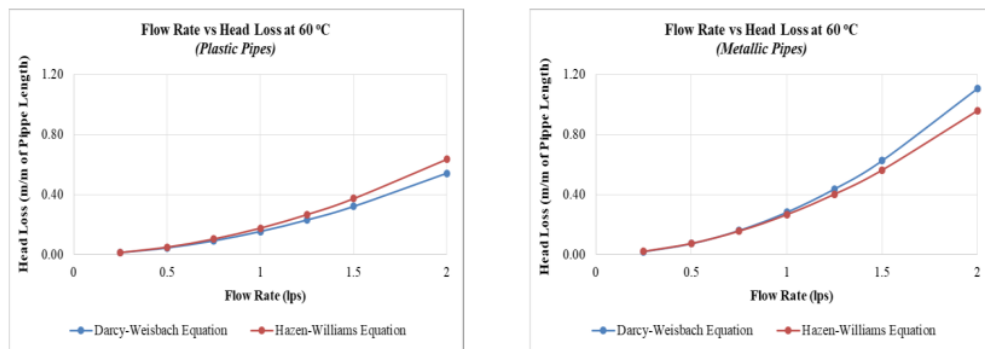


Figure 6. Relationship curve discharge to head loss at water temperature for 60°C

4.2. Relationship particle size, and velocity slurry in pipe

On friction pressure loss the effect of particle size significantly shows that a constant increase in particle size at one place for each particle volume fraction can reduce friction pressure flow loss in the pipe for fine particle size ($d_p = 90 \mu\text{m}$) which means kinematic viscosity increases under suspension conditions and decrease the value of Reynold Re . for coarse particles ($d_p > 90 \mu\text{m}$) will settle to the bottom or bottom of the pipe which eventually blocks the flow in the effective flow area [10]. The particle volume fraction gives an effect on the solid or solid phase where both are linearly related that if the particle volume fraction is high it will produce a high friction pressure loss.

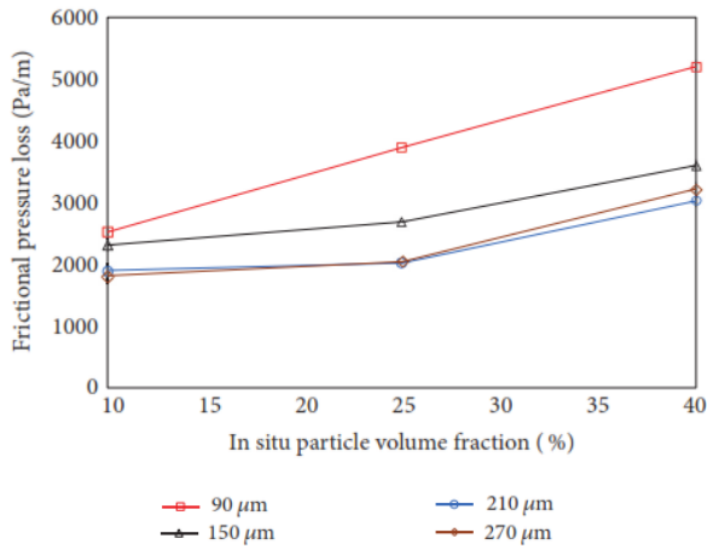


Figure 7. Effect of particle volume fraction in situ on friction pressure loss for constant particle size.

Friction pressure loss also increases in fine particle slurry and decreases in coarse particle slurry. For this reason the results of this experiment correlate with the concentration gradient of particles over r/R dimensionless numbers.

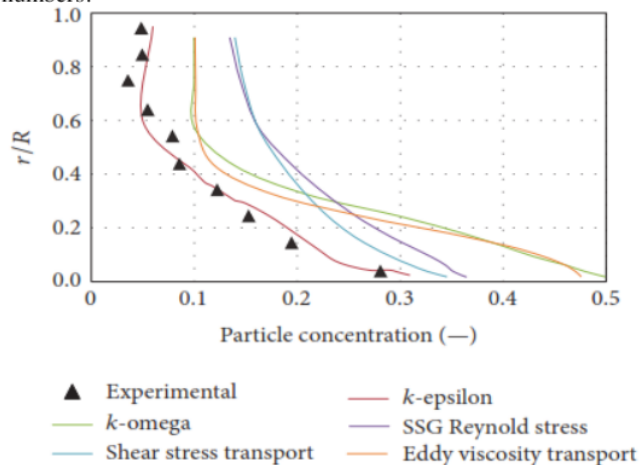


Figure 8. Comparison of particle concentration profiles of experimental and predictive results.

The experimental results explain the effect of particle size on particle concentration, particle velocity, and friction pressure loss. Particle concentrations for fine grains neutrally float due to fluid turbulence which results in particle suspension. In other applications, the particle size is analyzed to

produce the Minimum Fluidization velocity (v_{mf}) of the channel fluidization work using the dynamic porosity (ϵ) and viscosity parameters (μ) that related to the hydraulic conductivity equation [4].

4.3. Relationship particle shape, and velocity slurry in pipe

The experiment of the effect of differences in particle shape the efficiency and characterization of slurry transport in pipe media by numerical analysis using computational fluid dynamics (CFD) and Discrete Element Method (DEM) techniques. The two phases of flow conditions are simulated by the CFD and DEM techniques, respectively for the flow of liquid (fluid) is simulated using the CFD method and for particle-shaped substances are simulated using the DEM method and both use also using the Eulerian-Eulerian method. For particle parameters [8] using three particle shapes namely spherical particle, square platens particle and line-shape particle. In this study, Sliding-bed flow occurs in the spherical particle flow transition when the velocity reaches 2 m / s and when the speed increases reaches 4.1 to 8 m/s the flow gradually reaches the transition phase to the shear flow.

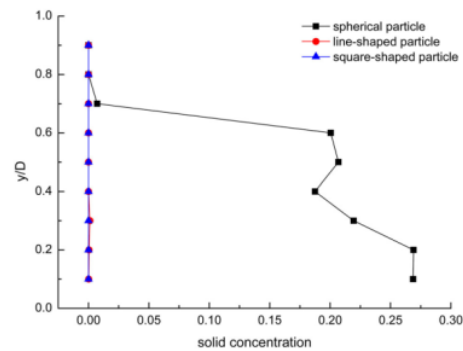


Figure 9. Concentration of solid particles at 2 m/s.

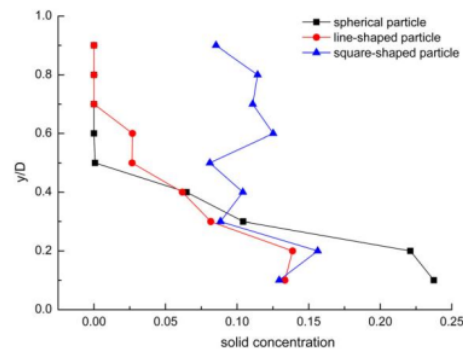


Figure 10. The concentration of particle solids at 4.1 m/s.

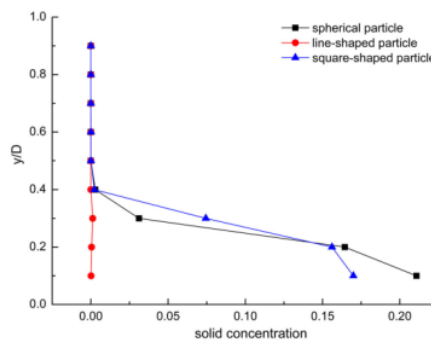


Figure 11. The concentration of particle solids at 8 m/s.

Slurry flow velocity is influenced by the concentration of particle solids where the smaller dimensionless number y/D indicates that the concentration of solids is very high and tends to reduce the flow velocity. From the flow velocity of 2 m/s, 4.1 and 8 m/s, the concentration of solids > 0.10 - 0.20 with $y/D = 0.1$ can be seen. these flow conditions form sedimentation and aggregation at the

bottom of the pipe. Solid concentrations also differ in each type of particle shape, where spherical particles tend to experience a decrease in the concentration of solids respectively at $y/D = 0.1 - 0.7$ for accuracy of 2 m/s, at $y/D = 0.1 - 0.5$ for speeds of 4.1 m/s and at $y/D = 0.1 - 0.4$ for a speed of 8 m/s. whereas the elongated shape particles tend to be constant with solid concentrations close to 0 for all y/D at speeds of 2 m/s and 8 m/s. solid conditions can indicate the occurrence of blockage before a steady flow where a number of particles are generally concentrated at the top of the pipe. This is also represented by square-shaped particles whose irregular density concentrations at $y/D = 0.3 - 0.9$ for speeds of 4.1 m/s [8].

The solid concentration gradient affects the slurry velocity in the pipe where the vertical solid gradient decrease occurs when the solid particle consists of several layers [9] particles that move together. Homogeneous particles tend to maintain flow speed. The shear flow state is an ideal condition in all particle forms and when the flow is in the shear layer or in a transition state the number of particles at the outlet continues to fluctuate which can cause clogging [13].

4.4. Design diameter of slurry pipe

Flow characteristics in the pipe can also be expressed in terms of the relationship between discharge flow and velocity which focuses on the bottom flow of the pipe for the condition of pure liquid as well as two-phase flow [13]. So, the diameter design of pipe is require to flow the liquid in a smooth condition. Design of the slurry pipe diameter by considering the head loss per unit distance over the hydraulic gradient where practically the flow velocity should be set over the critical velocity. Therefore a hydraulic gradient i and critical velocity V_{cd} relationship based on a curve $i-V_m$ with two sediment transport conditions, namely single size settling slurry and Mixed-sized slurry [13].

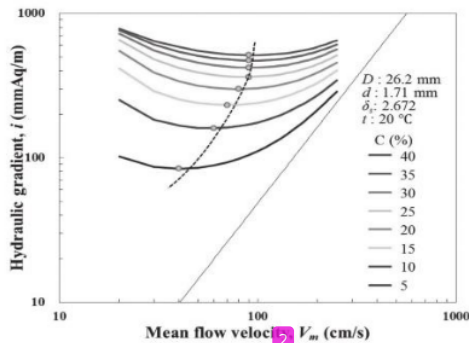


Figure 12. $i-V_m$ relationship of single size slurries based on the laboratory data of fine solids.

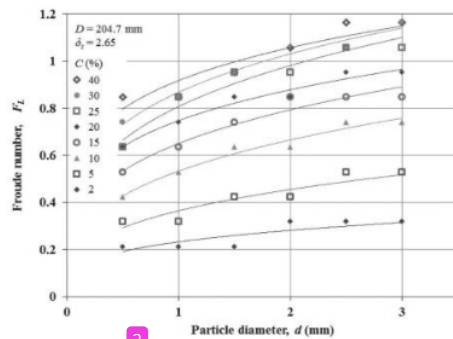


Figure 13. Predicted Froude number against particle diameter based on analytical models.

The $i-V_m$ relationship in figure 12 means that the V_m relationship is determined by the critical velocity relation to the gradient $\partial i / \partial V_m$. Froude number value is a function of critical velocity V_{cd} and pipe diameter D which is described in the Durand Froude number equation. The relationship is depicted in figure 13.

$$F_L = f(V_{cd}, D) \approx F_L = \frac{V_{cd}}{\sqrt{2gD(\delta_s - 1)}} \quad (26)$$

The velocity critical V_{cd} also decrease if the portion of fine solids in slurry increase, it can occur in a mixed-sized slurry. The equation 26 can be developed and used created models for recommended evaluation of hydraulic gradient coarse-fine and coarse-coarse slurry models.

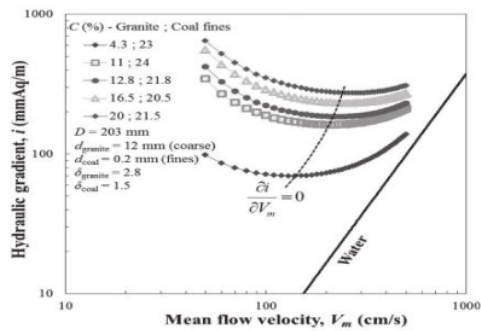


Figure 14. $i-V_m$ relationship of coarse-fine mixed size slurries based on the data of Boothroyde.

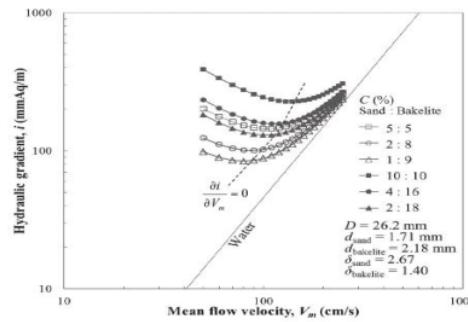


Figure 15. $i-V_m$ relationship of coarse-fine mixed size slurries based on the laboratory data.

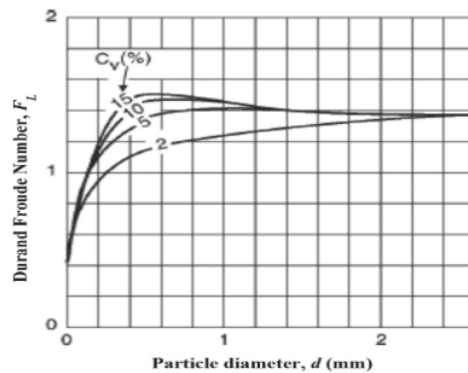


Figure 16. Variation of durand fronde number with particle diameter.

Figure 16 shown the effect of concentration on the hydraulic gradient of coarse-coarse slurry tend to differ from that coarse-fine slurry. Its correlation are fit to prediction of pipe diameter and flow velocity for transport condition. Research on the effect of pipe diameter on flow characteristics and heat transfer results in the conclusion that pipe diameter influences the saturated magnitude of Drag reduction effect. The values for the relationship of pipe diameter, j_s/f_s ratio (ratio of Colburn j factor and friction factor of the slurry) and Reynold number Re caused by the influence of Drag Reduction DR . The experimental results show that the pipe diameter of 8 and 13 mm results in an increase in the value of the ratio J_s/f_s and Re [13].

5. Conclusions

The main conclusions that can be drawn from the various studies above are as follows:

- Viscosity of a fluid is very dependent on several factors including the concentration of solids (CW) that can be found in the slurry flow in the form of mud.
- By comparing the head loss (coefficient of friction) between the Darcy-Weisbach and Hazen - William equations produces a dimensionless relationship between discharge (Q) to the coefficient of friction at temperatures of 20°C to 60°C where the increase in discharge (Q) increases the head loss.
- The Friction pressure loss the effect of particle size significantly shows that a constant increase in particle size at one place for each particle volume fraction can reduce friction pressure flow loss in

the pipe for fine particle size ($d_p = 90 \mu\text{m}$) which means kinematic viscosity increases under suspension conditions and decrease the value of reynold (Re). for coarse particles ($d_p > 90 \mu\text{m}$) will settle to the bottom or bottom of the pipe which eventually blocks the flow in the effective flow area.

- Slurry flow velocity is influenced by the concentration of particle solids where the smaller dimensionless number Y / D indicates that the concentration of solids is very high and tends to reduce the flow velocity.
- Froude Number is a function of critical speed and pipe diameter in the relationship of critical velocity and hydraulic gradient to determine the size of the slurry pipe.
- The pipe diameter influences the saturated magnitude of Drag reduction effect. Values for the relationship of pipe diameter, j_s/f_s ratio (ratio of Colburn j factor and friction factor of the slurry) and Reynold number (Re) caused by the influence of Drag Reduction.

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