



# Contribution of Perforated Pipe Roughness to Improve Sediment Transport in Hybrid Fluidization Method as an Alternative Dredging Technique

R. Azis\*<sup>a</sup>, M. Arsyad Thaha<sup>b</sup>

<sup>a</sup> Civil Engineering Department, Engineering Faculty, Lakidende University, Indonesia

<sup>b</sup> Civil Engineering Department, Engineering Faculty, Hasanuddin University, Indonesia

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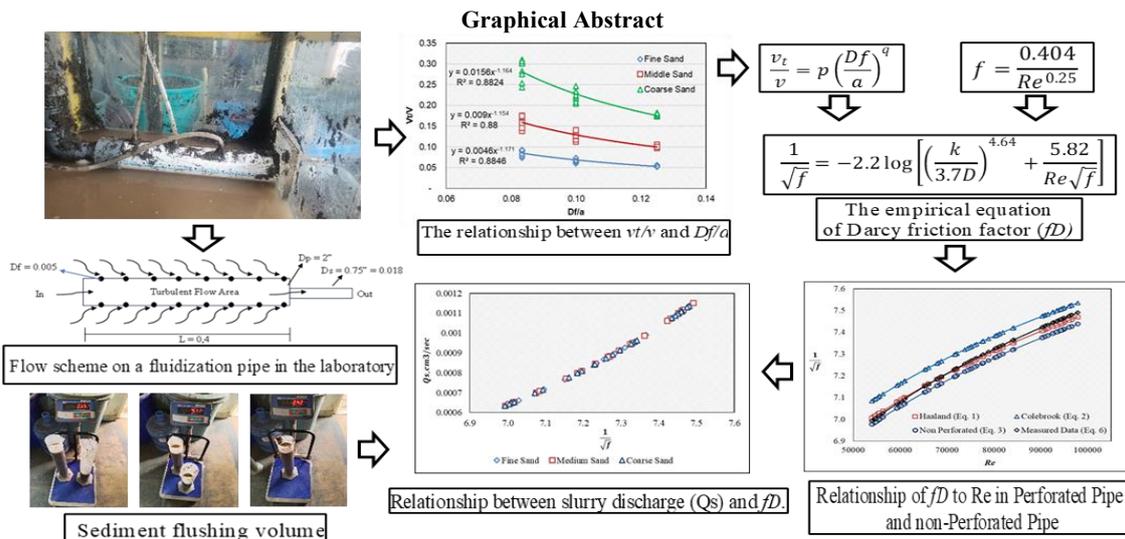
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ABSTRACT

The slurry discharge ( $Q_s$ ) through the pump is made possible by the roughness of the perforation pipe during the dredging technique with the hybrid fluidization method. This study purposes to find the relationship between pipe roughness formed based on the physical parameters of the hole ( $Df/a$ ) expressed through the equation of Darcy friction factor ( $fD$ ) to the value of Reynold ( $Re$ ) and  $Q_s$ . Physical simulations in the laboratory with sediment variations in characteristics ( $\rho$ ,  $d_{50}$ ), sediment thickness over the fluidization pipe ( $db$ ), and variations in perforation hole spacing ( $a$ ), and constant hole diameter ( $Df$ ) were the experimental sets used. The dimensionless analysis method was used to analyze the correlation between flow parameters ( $v_t/v$ ) and the physical parameters of the pipe ( $Df/a$ ). The  $fD$  equation was utilized by Colebrooke and Haaland to analyse the pipe's roughness in relation to the flow condition, which resulted in the formation of the friction relationship ( $f$ ),  $k/D$ , and  $Re$ . The results of the analysis found the relationship between the ratio of  $v_t/v$  and  $Df/a$  had a positive impact on the sediment transport process around the perforation pipe which resulted in a friction that was expressed as  $fD$  equation. The  $fD$  equation has been developed in an experimental and gives an empirical equation ( $1/\sqrt{f} = -2.2 \log[(k/3.7D)^{4.64} + 5.82/Re\sqrt{f}]$ ) is a theoretical contribution to the developed simple dredging technology. The empirical equation  $fD$  finding the relationship of the slurry discharge and the darcy friction factor by meeting the criteria of the physical parameters of the perforation hole ( $Df/a$ ).

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\*Corresponding Author Email: [ruidiazis.civil@gmail.com](mailto:ruidiazis.civil@gmail.com) (R. Azis)

## 1. INTRODUCTION

The Hybrid fluidization represents a promising alternative dredging technique for trench maintenance, integrating the principles of fluidization with sediment management to enhance efficiency and reduce environmental impacts. This technique combines fluidization and sediment flushing within a single system, utilizing a perforated pipe that facilitates both processes simultaneously. Azis highlights the effectiveness of this hybrid system, demonstrating through experimental modeling that it simplifies dredging operations while maintaining performance standards (1). The study emphasizes the potential for hybrid fluidization to streamline maintenance dredging, particularly in challenging environments where traditional methods may be less effective.

The dynamics of fluidized beds, particularly in hybrid configurations, are crucial for optimizing dredging operations. Research by Ali et al. (2) indicated that the behavior of fluidized beds, including pulsed fluidization, can significantly influence sediment separation and management techniques. This is particularly relevant in dredging applications where the physical properties of sediments, such as bulk density and particle size distribution, affect the efficiency of sediment removal and transport. The integration of pulsed fluidization techniques can enhance the fluidization behavior, thereby improving the overall dredging process (3).

Moreover, the environmental implications of dredging practices cannot be overlooked. Dredging operations often lead to sediment resuspension, which can adversely affect water quality and aquatic ecosystems. Luo et al. (4) discussed the role of dredging in ecological restoration, noting that while it is essential for maintaining navigable waterways, it also poses risks of nutrient release from disturbed sediments. Therefore, hybrid fluidization techniques that minimize sediment disturbance and enhance sediment management are particularly valuable in mitigating these environmental impacts.

In addition to environmental considerations, the economic aspects of dredging operations are critical. Pellegrini et al. (5) presented a techno-economic assessment of innovative dredging methods, including jet pump systems, which are designed to reduce costs while minimizing environmental footprints. The hybrid fluidization approach can similarly contribute to cost-effective dredging solutions by enhancing operational efficiency and reducing the need for extensive sediment handling.

Furthermore, the application of advanced modelling techniques, such as hybrid 1D/2D hydrodynamic models, can provide insights into the impacts of dredging on sediment transport and flood mitigation (6).

This modelling approach allows for a more nuanced understanding of how hybrid fluidization can be optimized for specific trench maintenance scenarios, ensuring that dredging operations are both effective and environmentally responsible.

The hybrid fluidization technique provides a viable alternative to the dredging approach, which is characterized by significant operational costs and requires the use of a dredge machine. The experimentation of hybrid fluidization technology in 2D is currently underway, but there's another fascinating aspect of the operating system. The combination of the fluidization method and the flushing method operated in a hybrid manner requires the design of the fluidization hole in the form of a perforation hole that must be optimal in terms of size in both methods. The perforation hole was found to have an impact on sediment transport due to friction in the hybrid fluidization experiment. In the numerical simulation of fluid flow through the perforated pipe, it was found that the suction flow in the perforation hole is radial inflow that moves perpendicular to the flow in the pipe (main inflow), so that the collision of the flow in both creates a lubrication effect that can reduce friction resistance (7). The hybrid fluidization experiment suggests that the lubrication effect will increase the flow in the perforation hole, thus improving its suction power.

Lubrication within perforation holes can reduce frictional resistance, which is critical in enhancing flow rates. For instance, Kravchuk et al. (8) conducted experiments on a steel pipeline with perforated sections, measuring fluid flow and pressure loss. Similarly, Abdullah et al. (9) highlighted that increasing the diameter of perforation holes and optimizing slope conditions can enhance exfiltration rates, further implying that lubrication could facilitate smoother flow through larger orifices.

The pressure drop across perforation holes is a significant factor in flow dynamics. The pressure drop generated in perforation holes is often negligible compared to the overall flow pressure difference, particularly in high-permeability reservoirs (10). This suggests that while lubrication may not drastically alter pressure drops, it can still contribute to maintaining optimal flow conditions by minimizing friction losses (11, 12). Furthermore, Mustafa et al. (13) discussed the components of total pressure drop in a horizontal wellbore, emphasizing that effective lubrication can mitigate friction and enhance fluid mixing, thereby improving flow efficiency.

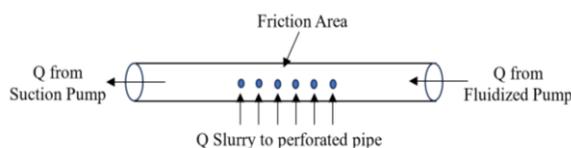
In hybrid fluidization experiments, a factor that influences successful sediment discharge is the roughness effect of perforation holes on the fluidization pipe. The roughness caused by perforation holes has a direct impact on fluid dynamics within the pipe (14, 15). The ratio of hole diameter to hole spacing ( $D_f/a$ ) is a

parameter that forms the surface roughness effect of the fluidization pipe designed as a hole that agitates and sucks sediment in the hybrid fluidization method (1). The studies by Kravchuk et al. (8) indicate that the diameter variation of perforation holes can create measurable differences in pressure loss across the perforated section, suggesting that larger perforations may exacerbate disruptions in fluid flow and lead to greater overall resistance in hydraulic systems. This disruption of fluid flow benefits the pouring process, as sediment that enters through the perforation hole does not experience sedimentation around the perforation hole.

The suction flow must reduce the pressure along the pipe during discharge to prevent pressure changes. Research by Kravchuk et al. (8) showed that the diameter of the perforation hole significantly affects the pressure loss and flow speed of the fluid inside the pipe. In this case, the pressure drop due to the perforation hole does not have an impact on the loss of power to pour because in a hybrid fluidization experiment the role of the suction pump and the fluidization pump working simultaneously can create a balance in the flow. The fluidization pump still supplies the suction flow along the fluidization pipe with the perforation hole in this case.

The turbulent effect on the flow after the perforation hole is due to the surface roughness created by the slurry flowing through it. Various studies have provided a comprehensive explanation of this condition. For instance, Gong et al. (16) noted that a reduction in effective diameter due to increased roughness corresponds with higher friction factors, which consequently elevates losses in the system. This finding highlights the necessity of carefully considering perforation sizes and their resultant roughness to optimize fluid flow efficiency. However, in a hybrid fluidization system, the role of perforation holes both in terms of hole diameter and hole distance ( $Df/a$ ), only serves to optimize the fluidization function and the sediment suction function in a hybrid manner (Figure 1). In order for the mixture flow to maintain turbulent conditions, it is necessary to meet the pressure factor that results in energy loss around the perforation hole.

The magnitude of fluid friction in the perforation hole is determined by calculating the friction factor provided by perforation roughness through a formula.



**Figure 1.** Perforation hole scheme in a hybrid fluidization system

This experiment uses the Darcy friction formula ( $fD$ ) to measure the degree of roughness of the duct walls. The Darcy friction formula is a fundamental equation used to analyze the friction factor in various types of pipes, including perforated pipes. The friction factor is crucial for understanding pressure drops and flow characteristics in fluid systems. In perforated pipes, the flow dynamics are influenced by the presence of holes, which can alter the effective roughness and flow regime, thus affecting the friction factor.

The friction factor in perforated pipes can be significantly influenced by the geometry and arrangement of the perforations. For instance, studies have shown that the pressure drop in perforated pipes is affected by multiple factors, including wall friction, perforation roughness, inflow acceleration, and mixing effects (17). The friction factor can be decomposed into contributions from turbulent stress and other flow characteristics, which are modified by the presence of secondary currents in partially filled pipes (18). This highlights the complexity of flow in perforated systems, where traditional models may need adjustments to account for these unique flow patterns.

The relationship between the Reynolds number and the friction factor is well established. As the Reynolds number increases, the friction factor typically decreases, which is attributed to the inversely proportional relationship between the friction factor and average flow velocity (19, 20). This relationship is critical when applying the Darcy-Weisbach equation, which is often used in conjunction with empirical correlations like the Colebrook-White equation to estimate the friction factor in turbulent flow conditions (21). The Darcy-Weisbach equation is particularly relevant in practical applications, as it provides a more reasonable basis for calculating head loss compared to other formulas like Hazen-Williams, especially in critical flow scenarios (22).

In the context of perforated pipes, specific studies have focused on the hydraulic friction factor, revealing that the hydraulic characteristics can vary significantly based on the design of the perforations and the flow regime (8). For example, experimental investigations have shown that the hydraulic friction factor in perforated pipelines is crucial for developing reliable hydraulic calculations, which are essential for effective engineering design (23). Additionally, numerical studies have demonstrated that the friction factor can be accurately estimated using computational fluid dynamics (CFD) models, which allow for detailed analysis of flow characteristics in complex geometries (24).

Estimating the Darcy friction factor ( $fD$ ) in the hybrid fluidization method is like estimating the energy loss that could occur because of the roughness effect in the perforation hole. The author strongly believes that estimating the magnitude of energy loss in the hybrid

fluidization method will be the same as estimating energy loss in other hydraulic case studies as in hydraulic jumping (25). Therefore, in research that is still 2-Dimensional, hydraulic behavior is produced, especially at the magnitude that will determine the success of the application of dredging technology that only uses simple equipment, namely fluidization pipes (perforation pipes) and fluidization pumps and suction pumps.

### 1. 1. The Hybrid Fluidization in Dredging Technique

The Hybrid fluidization emphasizes the combination process of fluidization and flushing techniques in solving sedimentation problems in estuarine grooves, especially in grooves that are predominantly influenced by sea waves, resulting in sediment movement that cannot be forwarded to the sea (1). Despite the limited implementation of hybrid fluidization research in 2-dimensional testing, several hydraulic phenomena can be considered for field scale applications in the future. One of the hydraulic behaviors that tends to affect the volume of sediment that can be sucked through the fluidization hole is the occurrence of friction forces due to the interaction of the perforation hole with the fluidization flow throughout the flushing process after the sediment is fluidized.

In the physical experiments of hybrid fluidization, various phenomena were found that can be attributed to several interdisciplinary research approaches. Hybrid fluidization research is the development of a fluidization system used in handling sediment problems in river mouths and channels in general (1, 26). One of the distinctive features of the hybrid fluidization experiment is the use of hydraulic science to analyze sediment movement in closed channels. This is a separate study where for several years previous fluidization research emphasized the hydraulic mechanism used to produce jet bursts in the sediment layer (27-29).

The results of the hybrid fluidization experiment found a relationship between the ratio of the perforation hole ( $Df/a$ ) to the ratio of sediment flow velocity ( $vt/v$ ) where the perforation hole exerts a roughness effect on the perforation pipe (1). The perforation hole area's roughness causes disturbance in the flow due to its lubricating effect. These conditions have a beneficial impact on the hybrid fluidization system, particularly on the relationship between flow velocity and sediment particle precipitation rate ( $vt/v$ ).

### 1. 2. Surface Roughness in Fluidization Pipes

The perforation hole's design is established using data from previous research. From the initial experiment, the number of holes represents the best quantification result. Lubrication has an effect on the fluid flow through the perforation hole, which causes the pipe wall to be rough. As a result of the pressure difference between the fluid

flow through the pipe and the sediment layer above, the sediment layer will flow into the fluidization pipe.

The flow velocity of a channel is determined by friction, whether it's closed or open (30). The sediment suction process is affected by flow disturbances, which cause friction between the fluid and the pipe wall in the basic conceptual model of flow through perforated pipes. In perforation pipes, flow disturbances cause changes in flow velocity along the pipeline formed through contact between the radial inflow near the perforation hole and the main inflow at the center of the flow of the pipe (7).

**1. 3. Darcy Friction Factor ( $fD$ )** The Reynold value ( $Re$ ) describes the flow conditions produced at the level of roughness of the perforated pipe wall where the shear stress (wall shear stress) in the perforated pipe causes the flow velocity to change. The friction factor is a function of the number  $Re$  and the relative roughness of the pipe  $k/D$  where  $K$  is the equivalent of the roughness of the pipe and  $D$  is the diameter of the pipe. The equation developed from the von Karman formula for turbulent flow with a comparison of the Colebrook-White formula was developed by Haaland who used the Darcy friction factor ( $f$ ) to describe the flow conditions in perforation pipes.

$$\frac{1}{\sqrt{f}} = -1.8 \log \left[ \left( \frac{\varepsilon/D}{3.7} \right)^{1.11} + \frac{6.9}{Re} \right] \quad (1)$$

The Colebrook-White formula is essential for calculating the Darcy friction factor ( $f$ ) in turbulent flow conditions (31).

$$\frac{1}{\sqrt{f}} = -2 \log \left[ \frac{k}{3.7D} + \frac{2.51}{Re\sqrt{f}} \right] \quad (2)$$

The application of this formula in practical scenarios can be complicated because it requires numerical methods for its solution, which is implicit. However, Haaland proposed an explicit approximation of the Colebrook equation that simplifies the calculation of the friction factor, making it more accessible for engineers and practitioners in fluid dynamics (32, 33).

As a validation of the equation for perforated pipes, it is necessary to consider  $f$  (darcy friction factor) for the Reynolds value in porous pipes which ranges from 3.545 to 105.000, where the flow occurs at the roughness of the finest pipe under turbulence conditions (34). The exact formula for turbulent flow in pipes without perforations is:

$$\frac{1}{\sqrt{f}} = -2 \log \frac{5.28}{Re^{0.89}} \quad (3)$$

The Darcy-Weisbach equation is characterized by its use of the Darcy friction factor, which is crucial in determining pressure losses in pipe systems. The relationship of friction factor and flow characteristics, like Reynolds number and relative roughness, is crucial

in hydraulic engineering. The Haaland equation provides a reliable means to estimate the friction factor for turbulent flow, particularly when the Reynolds number exceeds 2000 (35, 36). This approximation has been validated against various empirical data, demonstrating its effectiveness in predicting friction losses in different pipe configurations (13, 37).

The Haaland approximation has been studied extensively to improve the accuracy of friction factor calculations, in addition to its practical applications. For instance, researchers have explored the limitations of traditional methods, such as the Moody diagram, and have proposed alternative approaches that leverage computational fluid dynamics (CFD) to refine the estimation of the Darcy friction factor (38, 39). The explicit nature of Haaland's correlation allows for quicker computations, which is particularly beneficial in large-scale simulations where iterative methods would be computationally expensive (33, 40).

In addition, the Colebrook-White formula and its approximations are important beyond simply calculating pipe flow. They are also applicable in complex systems involving multiphase flows and varying fluid properties, where accurate friction factor estimation is crucial for system design and optimization (41, 42). The ongoing research in this area continues to enhance our understanding of fluid dynamics and improve the tools available for engineers (43, 44).

## 2. MATERIAL AND METHOD

**2.1. Material and Equipment** In this study, the material used consists of sedimentary material in the form of sand ( $\rho = 2.598 - 2.673$ ) and perforation pipes 40 cm long with the diameter determined based on the results of the fluidization research with a hole distance consisting of 4, 5 and 6 cm (1, 45).

**2.2. Experimental Test Method** The research methodology involves conducting experiments with two

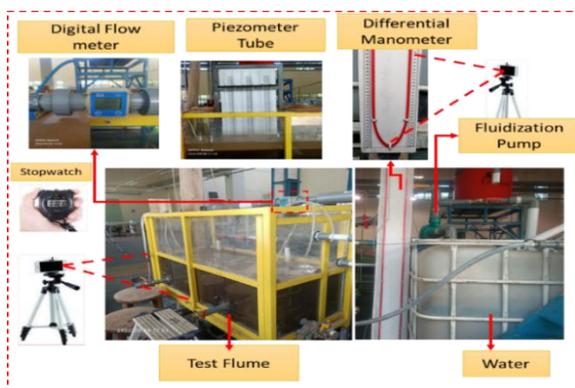


Figure 2. Research materials in the Laboratory

techniques that have been extensively researched, which are fluidization and flushing techniques. The two techniques were combined in this study, starting with the process of injecting water through a fluidization pump to generate fluid pressure in the sediment layer and agitate the sediment. The discharge given continues to increase in the range of  $450 \text{ cm}^3/\text{s} - 1099.03 \text{ cm}^3/\text{s}$  in the sediment layer 40 cm above the fluidization/perforation pipe, until a condition where the sediment layer is at a critical vortex which means that the fluidization pressure has been maximized, the flushing process can continue (29). The pressure is modified due to the flow of fluid in the pipe when the suction pump is turned on and the valve at the end is opened. At this stage, both the fluidization pump and the suction pump work in a hybrid manner to produce an optimal flow rate in the fluidization pipeline so that pressure changes occur. Sediment particles that had originally turned into post-fluidized slurry were sucked into the pipe through the perforation hole. Flow velocity measurements during the flushing stage are carried out to obtain flow conditions (Figure 2).

The volume of sediment that can be flowed through the porous fluidization pipe (perforation) was quantified by several experimental variations where the variables of suction pump height ( $H_s$ ), perforation hole spacing ( $a$ ), and variation in sediment type and thickness ( $db$ ). The dimensionless analysis method was used to analyze the correlation between flow parameters ( $vt/v$ ) and the physical parameters of the perforation hole ( $Df/a$ ).

The results of the experiment were analyzed by analytical method with the friction factor formula developed by Darcy ( $fD$ ) which was quantified from dimensionless parameters, namely the fluidization pipe parameters expressed in the perforation hole ratio ( $Df/a$ ) expressed in the pipe roughness ratio ( $\epsilon/D$ ,  $k/D$ ) and the mixed flow parameter ( $vt/v$ ) expressed in Reynolds ( $Re$ ).

## 3. ANALISYS RESULT

The velocity required in a hybrid fluidization system is the flow rate that can transport sediment through the fluidization pipeline where there are perforation holes as a factor that affects the flow conditions along the fluidization pipeline (Figure 3). The  $vt/v$  ratio is used to visualize the relationship between  $Df/a$  and  $vt/v$ , which has a certain velocity effect on the fluidization pipe

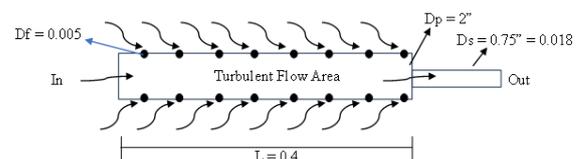


Figure 3. Flow scheme on a fluidization pipe in the laboratory

through the  $vt/v$  ratio. The graph's curves that show in Figure 4, medium, and coarse sediment types can be represented by equations.

$$\frac{vt}{v} = p \left( \frac{Df}{a} \right)^q \tag{4}$$

The sediment velocity ratio ( $vt/v$ ) ranges from 0.05 to 0.06 when the  $Df/a$  ratio is 0.13. The value of  $vt/v$  rises as the  $Df/a$  ratio decreases. The  $vt/v$  ratio decreases when the  $Df/a$  ratio is 0.10 and 0.08, respectively. In the graph, it is evident that the  $vt/v$  ratio depends on the settling velocity ( $vt$ ) of sedimentary particles. When the settling velocity is large, it leads to a high  $vt/v$  ratio. Fine sediments have a  $vt/v$  ratio of 0.05 to 0.09, medium sediments have a  $vt/v$  ratio of 0.10 to 0.17, and coarse sediments have a  $vt/v$  ratio of 0.17 to 0.31.

Comparing the magnitude of the friction coefficient ( $f$ ) generated along the sediment flow in the perforated pipe to the Reynolds flow parameter ( $Re$ ) allows for the expression of the  $vt/v$  ratio produced by the  $Df/a$  ratio. However, it has been confirmed that the Reynolds value ( $Re$ ) of the flow is turbulent where the viscosity is very small, but the value of  $Re$  can explain the relationship between the flow parameters of the sediment mixture ( $vt/v$ ) and the perforation hole parameters ( $Df/a$ ). The formula proposed by Blassius is followed for determining the friction coefficient ( $f$ ) during laboratory experiments. According to Blassius equation, the empirical equation for Fanning friction coefficient is:

$$f = \frac{0.404}{Re^{0.25}} \tag{5}$$

The friction factor ( $f$ ) tends to have little impact on any increase in the Reynold value, this can be shown in the relationship  $f$  to any change in the Reynold value (Figure 5).

The flow relationship between Reynold's number and the friction factor is showing a positive trend in  $f$ . The friction factor was reduced by  $0.404/Re^{0.25}$  (Equation 5) using an increased Reynold value of  $1 \times 10^5$ , which was applicable to all tested sediments. for sediments that are coarse, medium, or fine. The values of Reynold are categorized into fine sediments at 54,485– 96,600, medium sediments at 53,480 – 97,926, and coarse sediments at 53,962 – 96,635.

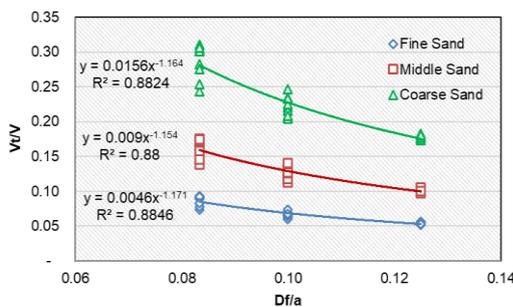


Figure 4. The relationship between  $vt/v$  and  $Df/a$

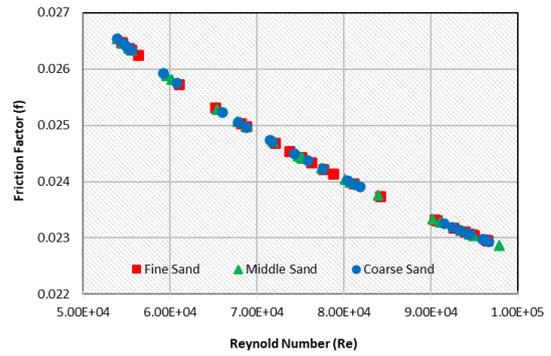


Figure 5. Reynold (Re) and Friction (f) Relationship

The friction value remained consistent within the range of 0.023–0.026 for every increase in sediment diameter, except for certain Reynolds numbers. This indicates that the range of friction numbers for increasing sediment diameter is limited to the flow of slurry around the perforation hole. This data indicates that the validation of non-perforated pipe slurry flow is different due to the increase in friction rate with increased sediment diameter (46). Furthermore, the friction coefficient ( $f$ ) can be seen with  $k/D$  to produce a constant that is suitable for the development of the Darcy friction equation ( $fD$ )

Figure 6 of the  $k/D$  relationship in hybrid fluidization with friction coefficient  $f$  shows that the roughness caused by the lubrication effect of the perforation hole is proportional to the  $k/D$  ratio where the smaller the hole spacing means that the number of holes is greater than the large hole spacing the  $k/D$  value increases. The  $k/D$  values for hole spacing were 0.0017 to 4 cm, 0.0019 to 5 cm, and 0.002 to 6 cm, respectively.

The relationship between the friction coefficient, the number of  $Re$ , and  $k/D$  in the fluidization pipe can be obtained by determining it through the Blassius formula. For each perforation hole spacing ( $a$ ), the  $k/D$  value is equal to 0.0017 for  $a = 4$  cm, 0.0019 for  $a = 5$  cm, and 0.002 for  $a = 6$  cm in the moody diagram (47). The magnitude of the  $k/D$  value in each hole space tends to

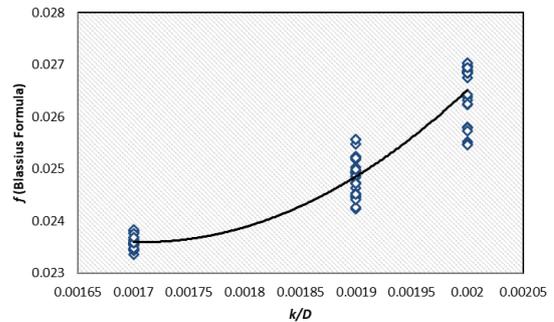


Figure 6. The interrelationship between  $f$  and  $k/D$

affect the magnitude of the friction coefficient so that by using the Blasius formula for the magnitude of the friction coefficient ( $f$ ) in the transition zone and the Colebrook equation for coarse hydraulic turbulent flow, the darcy friction factor ( $fD$ ) can be written with an empirical equation:

$$\frac{1}{\sqrt{f}} = -2.2 \log \left[ \left( \frac{k}{3.7D} \right)^{4.64} + \frac{5.82}{Re\sqrt{f}} \right] \quad (6)$$

Equation 6 is a development of Equation 1 proposed by Haaland and Equation 2 proposed by Colebrook, so empirically the equation of Darcy friction factor ( $fD$ ) obtained from the results of the experiment by considering the roughness of the fluid flow that contracts between the sediment and the water flow from the fluidization pump (Figures 7 and 8).

The empirical equation  $fD$  can be compared to Equation 2 proposed by Haaland and Equation 1, which ranges from 7.1 to 7.5. According to the comparison in Figure 9, Equation 6's outcome is equivalent to the Colebrook equation, which represents the coarse hydraulics in the perforated pipe. By using the Haaland equation, the roughness value matches with the random distribution of the experiment's results.

A significant Darcy friction value exists in the small hole space, resulting in the main flow in the perforation pipe experiencing turbulence proportional to the  $k/D$

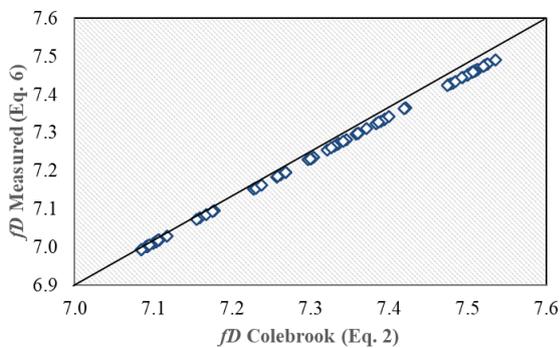


Figure 7.  $fD$  Equations 2 and 6

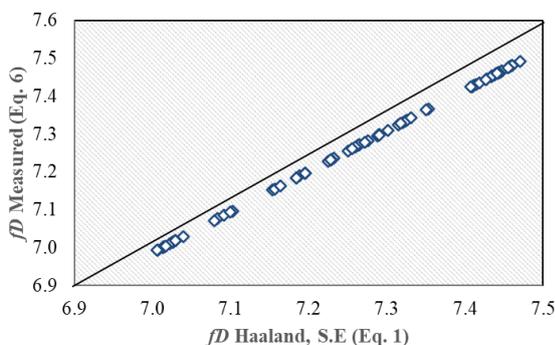


Figure 8.  $fD$  Equations 1 and 6

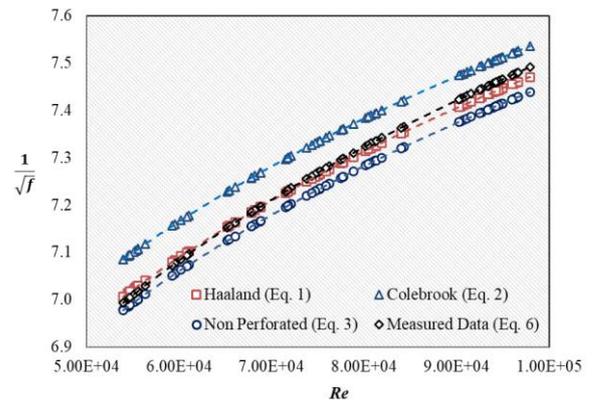


Figure 9. Relationship of  $fD$  to  $Re$  in Perforated Pipe and non-Perforated Pipe

value. Darcy's friction coefficient ( $fD$ ) at a hole distance of 4 cm ranges from 7.4 – 7.5, for a hole distance of 5 cm the  $fD$  value is between 7.4 – 7.2, and for a hole distance of 6 cm it ranges from 7.0 – 7.2. All types of sediments are subject to the same field value during flow experiments.

It is based on the effect of flowing sediment particles which is considered an important factor affecting the field value, that with a typical sediment flow that has a diameter size of  $\phi$  and a greater mass density  $\rho$  can minimize the effect of  $k/D$  or  $\epsilon/D$  values.

The field value for perforated pipes can be closely compared with that for non-perforated pipes in turbulent flow conditions. When the Reynold value is increased, the field value on the perforated pipe tends to be in close proximity to the Colebrook equation. The value of  $k/D$  or  $\epsilon/d$  is not taken into account in non-perforated pipes due to the smaller roughness of the pipe (smoothing). The transition zone in perforated pipes in the hybrid fluidization model is where the lubrication effect is restricted to the horizontal walls of the pipe. The equations proposed by Haaland and the results of laboratory observations (Equation 6) are both prone to moving at specific  $k/D$  values until they reach the turbulent zone. Nikuradse divided turbulent zone results in the zone of Darcy's friction coefficient in Equation 6 being in the transition zone (31).

The value of  $Re$  in Figure 4 depends on the height condition of the pump ( $H_s$ ) and the perforation hole ( $a$ ). When the pump ( $H_s$ ) increases, the  $Re$  value decreases. The same is true for the hole spacing ( $a$ ). The greater the hole spacing, the less the  $Re$  value decreases. In fine sediments the  $Re$  values at  $H_s$  40 cm range from 90.457 – 94.515 for  $a = 4$  cm, 68.791 – 94.515 for  $a = 5$  cm, and 54.446 – 61.045 for  $a = 6$  cm. During  $H_s$  30 cm, the range of values for  $a = 4$  cm, 72.136 – 78.835 for  $a = 5$  cm, and 54.548 – 65.225 for  $a = 6$  cm is all over the same scale. The  $Re$  value for 4 cm in  $H_s$  20 cm was 93,934 – 96,604, while for 5 cm in  $H_s$  20 cm, it was 73,790 –

84,267, and 55,342 – 68,212. Medium sediments and coarse sediments with the same trend line have the same tendency line, and the  $Re$  value tends to be influenced by  $H_s$  conditions.

#### 4. DISCUSSION

The  $Df/a$  ratio has an impact on the flow i.e. it gives a turbulence effect on the flow along the fluidization pipeline although the relationship is very small where turbulence can be seen at the Reynolds value ( $Re$ ) formed on the viscosity effect of the fluid. The perforation hole's smoothing effect on the flow is influenced by the roughness of the perforation pipe wall (fluidization hole). The fluid flow that was mixed with sediment caused a collision with the fluid flow produced by the fluidization pump, resulting in a retention of the main flow around the pipe wall. As a result, the flow velocity in the fluidization pipeline decreases, which follows the results of the experiment in the graph. The relationship of  $vt/v$  with  $Df/a$  is shown that the ratio of sediment flow velocity decreases with an increase in the ratio of  $Df/a$ .

The  $Re$  value is greater than the  $k/D$  ratio at the small perforation hole distance. This value is proportional to the magnitude of Darcy friction ( $fD$ ) as shown in the figure of the  $k/D$  relationship with the value of  $Re$ . Turbulent flow conditions increase as  $fD$  increases, but they are not proportional to the  $k/D$  ratio. This is very suitable for the relationship between  $Df/a$  and  $vt/v$  where when the  $Df/a$  ratio is large, sediment particles in the perforation pipe are disturbed due to the lubrication effect.

Ouyang et al. (48) stated that turbulence in perforated pipes is a product of mass displacement of flow which causes the average velocity profile of the time for turbulent pipe flow to change due to the interaction of axial flow and inflow or outflow of the wall. The inflow lifts and expands the turbulent boundary layer thereby increasing the axial velocity of the flow. However, the process decreases the speed within the layers to follow the law of mass eternity. As a result, the axial velocity gradient near the pipe wall decreases, and so does the frictional tension of the wall ( $fD$ ).

Turbulent flow in hybrid fluidization is a product of the cooperation of the fluidization pump and the suction pump in the flow fluidization pipe will experience a disturbance right at the perforation hole where the flow will experience different friction on the pipe wall that is not perforated. As a result, the flow of fluid in the fluidization pipe will experience turbulence conditions. The turbulent flow in the fluidization pipeline will be enough to help the sediment transportation process so that sedimentation does not occur during the discharge process. Darcy Friction Factor ( $fD$ ) is used to obtain the

relationship between the friction coefficient with the Reynold number ( $Re$ ) and the equivalent friction coefficient ( $k/D$ ) which describes the flow conditions along the pipe affected by the perforation hole factor. The large  $k/D$  ratio is directly proportional to the hole spacing ( $a$ ) where the large hole spacing has a large  $k/D$  ratio.

The height of the Suction Pump ( $H_s$ ) contributes positively to the change in flow conditions during the flushing process. Although this study focuses more on the hydraulic behavior of the flow based on  $Re$  and  $k/D$ , it is operationally quite influential, but in this analysis, the change is quite small so the  $H_s$  ratio can be ignored. Based on the relationship between the perforation hole parameter and the pump position, the  $k/D$  value to the  $Rep$  provides a correlation pattern that tends to correspond to the changing conditions of the hole spacing parameters ( $a$ ) and the pump position ( $H_s$ ). Figure 4 proves that  $k/D$  depends on the hole spacing ( $a$ ) which forms a pattern of roughness in the pipe due to the lubrication effect.

As an expression of the potential disturbance of sediment deposits during the discharge process, the relationship between darcy friction ( $fD$ ) and the value of  $Re$  can provide proof of the volume of sediment discharged just by comparing the level of roughness of the perforation holes in the fluidization pipe.

The relationship between slurry discharge and darcy coefficient ( $fD$ ) coefficients in each type of sediment proves that the fluidization pipe density around the perforation hole has an effect on the volume of sediment that can be transported from the perforation hole (Figure 10). The lubrication effects of sediments with a moderate fraction of the  $d_{50}$  value of 0.321 are still greater than those of fine and coarse sediments. Each type of sediment fraction has its own tendency for increased slurry discharge ( $Q_s$ ) with each increase in lubrication effect. The slurry discharge in the hybrid fluidization model still depends on the  $Df/a$  ratio as in Equation 4, that the amount of sediment volume that can be sucked

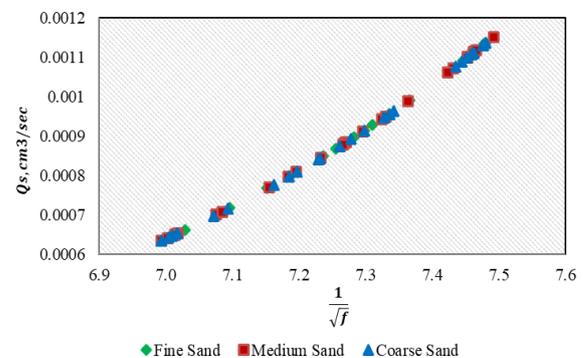


Figure 10. Relationship between slurry discharge ( $Q_s$ ) and  $fD$

is of course influenced by the diameter of the perforation hole ( $a$ ) and the hole space ( $Df$ ). The non-dimensional parameter,  $Df/a$  ratio, can be utilized to modify the physical parameters of the hybrid fluidization design. Changing the physical parameters of the perforation hole can lead to the possibility of adjusting the value of darcy friction ( $fD$ ) around the perforation hole.

#### 4. 1. Theoretical Contribution

The Darcy equation of friction ( $fD$ ) can be utilized to gain a clear understanding of how mixed flow or slurry flow behaves during the passage through the perforation hole. The amount of friction around the perforation hole is expressed in Equation 6 which is a combination of the flow of slurry entering through the perforation hole (radial inflow) and the fluidization flow moving along the pipe where the speed of the radial inflow depends on the speed of the main flow (main inflow). The flow expression described in Equation 6 occurs when the perforation hole parameter ( $Df/a$ ) is met, resulting in the slurry flow around the perforation hole not settled. The relationship of dimensionless numbers in Equation 4 represents this. Equation 6 also quantifies the magnitude of headloss due to friction in the perforation hole, but some studies state that the magnitude of headloss can be reduced by the magnitude of the speed in the main flow [7].

The perforation hole ( $fD$ ), which has a Darcy friction value, can be represented by the expression ( $1/\sqrt{f}$ ) which means that the friction coefficient has a quadratic effect on the slurry flow. The magnitude of the friction coefficient ( $f$ ), in Equation 5 is expressed as a function of Reynolds ( $Re$ ) where for the viscosity value is given a condition limit at a temperature of 30°C i.e. dynamic viscosity ( $\mu$ ) of  $1.801 \times 10^{-3}$  N.d/m<sup>2</sup>. Equation 6 is the formula for Darcy friction factor that is used to calculate energy loss in perforation holes. From an analytical perspective, Equation 6 is closer to the results achieved in Equation 1 (Haaland formula), but the equation structure resembles that of Equation 2 (Colebrook formula) applied to experimental results as depicted in Figure 7. The Darcy friction factor ( $fD$ ) formula can be empirically applied to perforation pipes in the suction method by using Equation 6.

#### 4. 2. Practical Contribution

The results of the darcy friction factor ( $fD$ ) analysis in Equation 6 have provided a theoretical formulation that can be practically applied to quantify the magnitude of headloss in dredging techniques with the hybrid fluidization method. Although the hybrid fluidization method has not been applied in practical applications, the friction factor formula will be very useful in determining the ideal perforation hole ( $Df/a$ ) ratio. Related to the limitations that must be met by the perforation hole design, the perforation pipe design for the hybrid fluidization

method has been discussed in another paper where the author stipulates that the perforation hole ratio should follow Equation 4 where the constant magnitude for each type of transported slurry has been given according to Figure 3 about the relationship of the dimensionless parameter  $Df/a$  to  $vt/v$ .

However, the practical benefits of the results of this study still need to be tested in the 3D experiment to obtain the strength of the  $fD$  equation relationship strength to the volume of sediment that can be poured if the variation in the dimension of the perforation pipe is changed by a constant  $Df/a$  ratio as in Equation 4. In Figure 8 on the relationship between slurry volume and  $fD$  value, it has been obtained with a fairly good change and applies equally to all types of sediments, it shows that the limit of the  $Df/a$  ratio has been at the optimal point to be applied to both methods, namely hybrid fluidization and suction. The 3D experiment will be conducted to evaluate the geometric dimensions of grooves formed using the hybrid fluidization method.

## 5. CONCLUSION

From the results of the analysis and discussion, several conclusions can be written as follows:

1. The  $vt/v$  ratio and  $Df/a$  relationship have a beneficial effect on the sediment transport process surrounding the perforation pipe, producing a friction coefficient that is measured as Darcy friction factor ( $fD$ ). As the  $Df/a$  ratio increases, the  $vt/v$  ratio decreases, indicating a lubrication effect that disturbs the possibility of sediment depositing in the fluidization pipe.
2. Preventing sedimentation during the pouring process is made possible by the expected friction coefficient determined by the magnitude of  $k/D$  and  $Re$  values.
3. The Darcy Friction Equation ( $fD$ ) ( $1/\sqrt{f} = -2.2 \log[(k/3.7D)^{4.64} + 5.82/Re\sqrt{f}]$ ) is a theoretical contribution of the  $fD$  equation is an adaptation of Colebrook and Haaland's  $fD$  equation that has a significant fit for this experiment.
4. The empirical findings on the  $fD$  equation apply to the perforation pipe type expressed in the relationship of the slurry discharge ( $Q_s$ ) and  $fD$  where for each increases  $Q_s$  directly proportional to the increase in Darcy friction ( $fD$ ) by meeting the criteria of the physical parameters of the perforation hole ( $Df/a$ ) so that it can be used in estimating the magnitude of power loss during the operation of the hybrid fluidization method.
5. The scope of this research is limited to 2-D experiments that only measure hydraulic behavior. There is still a need for 3-D experiments that

directly obtains a geometric shape, groove, large volume of sediment that can be moved by changing (increasing) the diameter of the fluidization pipe and the power of the fluidization pump and suction pump

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**Persian Abstract**

چکیده

تخلیه دوغاب (Qs) از طریق پمپ به دلیل زبری لوله سوراخکاری در طول تکنیک لایروبی با روش سیال سازی ترکیبی امکان پذیر است. هدف این مطالعه یافتن رابطه بین زبری لوله تشکیل شده بر اساس پارامترهای فیزیکی سوراخ (Df/a) است که از طریق معادله Darcy Friction Factor (fD) به مقدار Reynold (Re) و Qs بیان می شود. شبیه سازی های فیزیکی در آزمایشگاه با تغییرات رسوب در مشخصات (ρ، d50)، ضخامت رسوب روی لوله سیال سازی (db) و تغییرات در فاصله سوراخ سوراخ (a) و قطر سوراخ ثابت (Df) مجموعه های آزمایشی مورد استفاده بودند. از روش تحلیل بدون بعد برای تجزیه و تحلیل همبستگی بین پارامترهای جریان (vt/v) و پارامترهای فیزیکی لوله (Df/a) استفاده شد. معادله fD توسط Colebrooke و Haaland برای تجزیه و تحلیل زبری لوله در رابطه با شرایط جریان استفاده شد که منجر به تشکیل رابطه اصطکاک (f)، k/D و Re شد. نتایج تجزیه و تحلیل نشان داد که رابطه بین نسبت vt/v و Df/a تأثیر مثبتی بر فرآیند انتقال رسوب در اطراف لوله سوراخ دار دارد که منجر به اصطکاکی می شود که به صورت معادله fD بیان می شود. معادله fD به صورت تجربی توسعه یافته و یک معادله تجربی (1/√f = -2.2 log[(k/3.7D)<sup>4.64</sup> + 5.82/Re√f]) ارائه می دهد که یک کمک نظری به فناوری لایروبی ساده توسعه یافته است. معادله تجربی fD با برآورده کردن معیارهای پارامترهای فیزیکی سوراخ دار (Df/a) رابطه تخلیه دوغاب و Darcy Friction Factor را پیدا می کند.