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Experimental Study On Characteristic of Slurry Flow Regime In Pipeline

Ratna Bachrun[#1], Muhammad Saleh Pallu[#2], Muhammad Arsyad Thaha[#3] and Bambang Bakri[#4]

[#1]*Doctoral Course, Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Jalan Poros Malino, KM-6 Gowa, South Sulawesi, Indonesia.*

[#2]*Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Jalan Poros Malino, KM-6 Gowa, South Sulawesi, Indonesia.*

[#3]*Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Jalan Poros Malino, KM-6 Gowa, South Sulawesi, Indonesia.*

[#4]*, Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Jalan Poros Malino, KM-6 Gowa, South Sulawesi, Indonesia.*

[1]ratnabachrun06@gmail.com, [2]salehpallu@gmail.com, [3]arsyad999@gmail.com, [4]bambangbakri@gmail.com

Abstract - *Flow mixed with solid particles or sediment is a problem that often occurs in open and closed channels. The properties of flow and sediment in pipelines and the interactions that occur are very influential factors in sediment transport. Due to this interaction, the sediment flow will experience a loss of energy along with the flow, which can reduce the channel's performance in reduced flow velocity and the appearance of deposits in the pipeline. This study aims to analyze the changes in velocity and sediment transport in pipelines. Energy loss depends on pipe diameter, sediment velocity, pipe length, coefficient of friction, and force of gravity. The research was conducted using experimental laboratory methods using a pipeline network with 4 flow variations (0.005 m^3/s, 0.004 m^3/s, 0.003 m^3/s, 0.002 m^3/s) and 3 variations sediment sizes (0.15mm, 0.25mm and 0.42mm) .In sediment size 0.15mm, the flow velocity value is 1.88m / s - 0, 63m / s, size 0.25mm is 1.77m / s - 0.63m / s and 0.42mm is 1.40m / s - 0.44m / s. Due to the velocity changes and flow at four flow variations and three sediment variations, three sediment flow regimes are produced: the heterogeneous regime, the moving bed flow regime, and the moving bed. Stationary flow regime. The result shows that the larger the sediment size (ds), the more the flow velocity (v) decreases, and the sedimentation velocity becomes greater (vL).*

Keywords — *Flow, sediment size, velocity, energy loss, flow regime*

I. INTRODUCTION

Flow regimes are associated with different boundary conditions. Three flow regimes are usually identified: steady-state, pseudo-steady-state, and transient state. The flow regime depends on the boundary condition, and it can be determined by the rate of change in pressure with time. The steady-state flow regime corresponds to a system where the mass flow rate is constant everywhere, and pressure is constant to time. The flow regime is closely correlating to urban piping.

Urban pipe systems are one of the topics that show the need for surface flows and pressurized flows in steady and transient situations [5]. A hydraulic engineer confronted many problems in the planning, design, and operation of piped water supply systems. The issues can be divided into analysis and design types, both for steady flow and unsteady flow. Sediment deposits in the canal will reduce the channel's performance as a means of transporting water flow. To improve pipeline performance, it is necessary to meet the velocity requirements for discharges containing sediment, especially in large sediments. The limit deposit velocity (vL) is the minimum velocity is required to suspend a solid particle in a pipe. It corresponds to the momentum for the transition from the moving-bed regime to the heterogeneous regime [9]. The characteristics of the sediment and its movement in the pipeline are fundamental to know. Theoretically, streams containing sediment will first deposit coarse-grained sediments (bedload) compared to suspended sediments.

There will be shear stress against the pipe along with the flow, resulting in decreased speed or loss of energy. Changes in sediment flow velocity will result in changes in sediment transport in the pipeline. Depending on the mean rate of the flow and the terminal velocity of the solid particles in suspension, the mixture may be in one of the following states or regime Pseudohomogeneous, heterogeneous, moving bed flow, and stationary bed flow [9]

Hydraulic gradient and slurry flow velocity compared the transport of water-sand mixtures in circular pipes and square pipes, and the experimental results show that the hydraulic gradient of water in a round tube is larger than that of a square tube hydraulic particle size of the water-sand mixture in the pipe. Square is more significant than a round pipe[8]

Miedema [12] divided slurry transport into five flow regimes and integrated five independent models into the DHLLDV framework. This framework also classifies sediment transport into five basic flow regimes. The complex sediment transport parameters are made dimensionless, achieving comprehensive consideration of the type of energy loss and the role of interphase forces and a better description of the transition from the heterogeneous flow to the homogeneous flow. Therefore, this calculation framework has wide adaptability and can calculate the pipe resistance characteristics of dredged materials under different dredging conditions

A proper pipeline of trunk/limb mains and focusing most on specific pipelines effectively ensures cost-effectiveness and water pressure in the network. One of the methods available is the HGA method. The application of this method may be appropriate for a water authority in planning rehabilitation and expansion of a WDN. It can quickly clarify the optimal pipeline, diameter, and the combination of material and diameter pipe in the network for minimizing total LCC [2]. A multi-step genetic algorithm was developed to obtain the objective of selecting an optimal solution design for pipeline selection and trunk/limb mains diameters [2, 3].

Fulfilling the need for flow velocity in flowing water containing sediment is expected to overcome deposition in the pipe. This research is an experimental study conducted in the laboratory to determine the behavior of sediment in the pipe due to changes in flow velocity along the pipe (head loss). Therefore it is necessary to test to compare changes in sediment behavior and their interactions with variations in sediment size and variations in flow velocity.

II. LITERATURE STUDY

The flow regime is one of the means that addresses the complexity of streamflow response by systematically organizing streams, rivers, or catchments into groups that are most similar to their flow characteristics. When a liquid is forced to flow together inside a pipe, there are at least 7 different geometrical configurations, or flow regimes, that occur. The regime depends on the fluid properties, the size of the conduit, and the flow rates of each of the phases.

Longitudinal dispersion of sediment particles in a horizontal pipe is employed in the dispersion analysis of the neutral matter. It is assumed that the concentration of particles is diluted and that there is no deposition of particles onto the pipe bottom [6]. The flow of sediment or slurry is a mixture of solid and liquid substances.

A manure/sludge deposit is a concentrated slurry or slurry having a very fine amount of material, giving a high viscosity. A typical example of slurry is a mixture of solid-liquid substances found in the mineral processing of plants and the extraction of materials from rivers and weirs [9].

The slurry is a mixture of solid particles and water to form a slurry. When the sludge is transported using pipes, and if the flow rate is not high enough, the sludge will not survive to form a slurry so that it occurs.

The flow of sediment particles carried by a liquid in a pipe is called a slurry pipeline. The ability of fluid in a horizontal motion to be able to suspend solid particle depends on the counterbalance of two actions, namely [9]:

1. Gravity, which causes the particles to fall or settle in the fluid ;
2. Upward scattering of particles, caused by a concentration gradient of particles (more particles at lower elevations), is created by gravity.

A. *Basic properties of fluids*

Fluid is a flowing substance containing particles that can easily move and change shape without separating the substance. According to Triatmodjo [14], in general, fluids have essential characteristics or properties that are important for flow, including density, which indicates the mass of the liquid per unit volume, the specific weight of the volume, and the volume is unique.

The flow behavior of concentrated slurry depends on particle size distribution, shape, density, and concentration. The slurry flow behavior can change from Newtonian to non-Newtonian depending on the concentration, slurry composition, and content of fine and especially colloidal particles, which evoke a complex rheological behavior of the slurry [4].

B. *Flow characteristics in a pipe*

The critical parameter in explaining the flow characteristics in the pipe is based on the flow rate (Q); the amount of liquid flowing through the cross-section of the flow rate per unit time is called the flow rate. Flow calculations can use the equation [14]

$$Q=\frac{v}{t} \quad (1)$$

Q is the flow (m^3 / sec), v is the volume (m^3), t is the time (seconds), Fluid flow velocity (v), i.e., the flow velocity measurement using a Pitot tube. The L-shaped pitot (Pitot tube) is in a flowing liquid with one end facing the flow direction, while the other end is upward and in direct contact with the outside air (pressure atmospheric). The equation calculates the equation for flow velocity is:

$$v=\sqrt{2gh} \quad (2)$$

The Reynold number (Re) describes the flow pattern in a variable channel based on individual observations and the conditions of the circulating fluid for a particular flow situation. In Reynolds 1884, three factors influence the state of the flow, namely the viscosity of the liquid μ (mu), the density ρ (rho), and the diameter of the pipe (D). the relation between μ, ρ, and D has the same dimensions as the speed [15]:

$$Re=\frac{\rho dv}{\mu} \quad (3)$$

Where Re is the Reynold number, v is the flow velocity (m / sec), d is the pipe diameter (m), μ is the kinematic viscosity of water (m^2 / s). Based on in-pipe flow experiments, Reynolds determined that for Reynold numbers less than 2000, the flow under these conditions was laminar. The flow will be turbulent if the Reynolds number is between 2000 <Re <4000. The flow is a transition. Reynold number in the two values above (Re> 2000 and Re <4000)

The Head Loss is the loss of energy due to the friction between the flow and the pipe's inner wall. In general, energy losses can be classified as significant energy losses due to friction with pipe walls and minor energy losses due to joints, elbows, valves, and other fittings [9]. The energy loss (hf) due to friction with the wall of the uniform flow pipe can be calculated with the Darcy-Weisbach equation [15]

$$hf = f\frac{L}{D}\frac{v2}{2g} \quad (4)$$

Gradient Hydraulic (hf/L) can be calculated with the Darcy-Weisbach equation [15]

$$hf/L = f\frac{v2}{D2g} \quad (5)$$

Where the height hf is lost due to friction (m), f is the friction factor, L is pipe length (m), v is the average velocity (m / s), D is pipe diameter (m), g is gravity (m /s^2), hf / L is the slope of the energy line or hydraulic gradient (m /m). Orianto & Pratikto [10] gave a value for the friction factor, namely:

$$f(Re\,laminar) = \frac{64}{Re}, Re<2100. \quad (6)$$

Blasius f (Re turbulen)

$$0{,}316/Re^{0{,}25}, 4000 < Re < 10^5 \quad (7)$$

C. Slurry flow regime

Sediment transport is the amount of sediment measured for a moment. If the flow does not change quickly, then a one-time measurement of the sediment transport rate is sufficient to determine the average rate in one day. But if the flow changes rapidly and the sediment rate is high, several measurements are needed to determine the average daily rate [7] accurately. Liu [9] introduced one of the methods used to classify the religions of sediment flow. Liu identified four types of sediment flow conditions based on flow velocity and sediment size. Pseudohomogeneous occurs when the particle size is relatively small, and the pipe flow rate is relatively high, rather fine particles in a strongly turbulent flow. Heterogeneous occurs when particles are fully suspended but not uniformly distributed (nonhomogeneous). This condition happens when the velocity is somewhat smaller, or the particle size is slightly larger than in the previous case. Moving Bed flow – particles settle out of the flow and form a bed. The particles in the bed move in the flow direction by sliding, rolling, or saltation. This condition happens when either the flow velocity is less or the particle size is langer than in the previous case. Saltation refers to the phenomenon that some particles on the surface of the bed layer move intermittently in frog leaps. Stationary Bed flow, particles settle out n the bed, and they do not move in the bed. This condition happens with very coarse particles or relatively low velocity in pipes

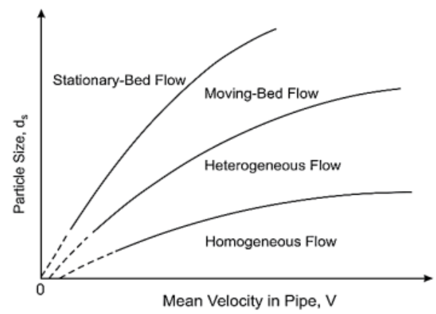


Figure 1. Four regimes for transport (Liu,2003)

The four states or regimes described above are illustrated in figure 1. Although only two parameters, mixture velocity in pipe and particle size, are used in classifying these four regimes, it should be realized that the density of the solid particles has the same effect as the particle size. Namely, a higher density causes the particle to settle more [9]

Along with river utilization, problems have been found regarding intake capacity and sediment entering the intake beyond the expectation. As a result, it puts an excessive burden on the water treatment plant. The research aims to get the most effective intake placement elevation in terms of the capacity and sediment entering the intake. As a result of this study, it can cope with the high sedimentation rates in the free intake building. The amount of sediment that comes out through the intake will be directly proportional to the fluid flow in the channel with the same slope and elevation. However, the amount of sediment that comes out through the intake will inversely proportional to the intake elevation, discharge, and the same slope [4]

III. METHODOLOGY

A. Type of The Research

The research used is an experimental study carried out in the laboratory to obtain research data; the data sources used come from primary data, namely data obtained directly from physical models simulated in the laboratory and secondary data from the literature. Moreover, the research results obtained have been done in the laboratory or other places related to research on speed distribution.

B. Research parameters and design

The research materials used are tested for their physical characteristics. The sediment samples used were a mixture of water and silt (ds1), fine sand (ds2), and medium sand (ds3). The mean concentration of sample volume overflow (Cv) is 10%

TABLE I
SUMMARY OF CHARACTERISTICS OF SEDIMENT SAMPLES

Test parameters	Units	Sample		
		1	2	3
Grain size	mm	0,150	0,250	0,420
Density (ρ)	kg/m^3	2.695	2.663	2.562
Sedimentation rate of single particles (vs)	m/s	0,087	0,111	0,137
Temperature	°C	29,8	29,5	29,5°

The design of the test equipment is a straight pipe network of 600 cm in length, 64 mm in diameter of acrylic pipes. The pitot tube velocity gauge is installed at four measuring points at every 200 cm distance and vertical and horizontal starch gauges along the pipe to determine changes in sediment movement. The setup of the test equipment is shown in Figure 2.

Data collection is carried out horizontally by measuring the velocity (v) at the predetermined measurement point (Figure 2).

Inspection points are marked by a 200 cm distance based on four discharge variations, namely 0.005 m^3/s, 0.004 m^3/s, 0.003 and 0.002 m^3/s and three variations of each sediment (uniform sediment), sediments of 0.15 mm, 0.25 mm, and 0.42 mm in size.

After the measurement for the velocity is obtained, changes in sediment movement are observed along the flow to obtain high-velocity regimes for each sample.

a)

b)

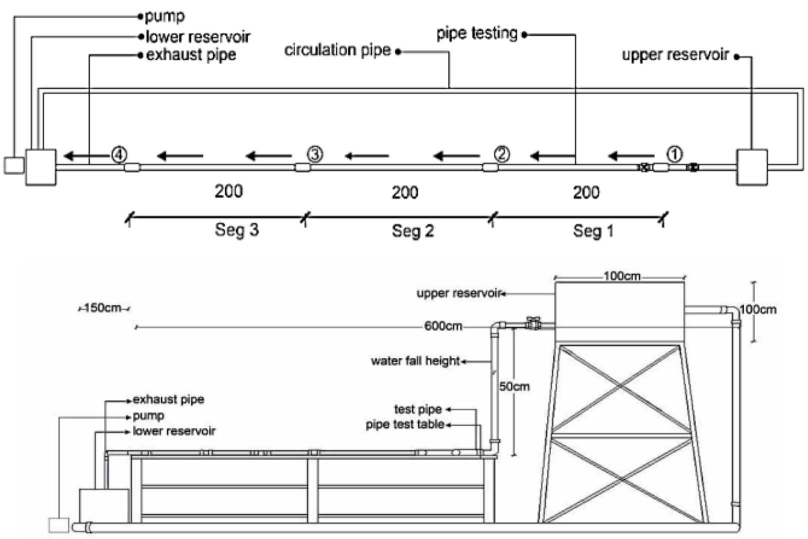


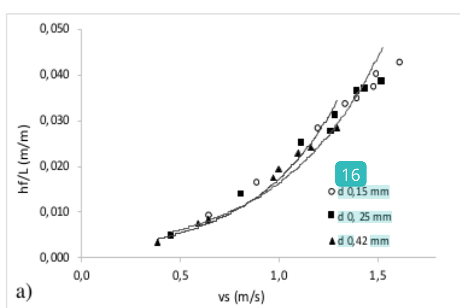
Figure 2. Setup model (a) top (b) side

IV. RESULTS AND DISCUSSION

Parameters to express sediment flow characteristics are flow velocity (v), sediment characteristics used, pipe diameter (D), pipe length (L), single particle sedimentation velocity (vs), head loss (hf), hydraulic gradient(hf/ L), Reynold number (Re), friction coefficient (f) and sediment flow regime at 0.15 mm, 0.25 mm and 0.42 mm sediment sizes.

A. Analysis of slurry flow velocity, head loss, and hydraulic gradient

The initial step that needs to be done is to determine the flow rate (Q) and sediment sample (ds) as fixed variables, resulting in high flow velocity in each sediment and four measurement points (Tp1, Tp2, Tp3, and Tp4). The increased flow velocity generated from the inner pitot tube velocity gauge is calculated using equation 2 to obtain the sediment flow velocity. Energy loss (hf) is influenced by flow velocity (v), friction coefficient (f), flow length (L), gravity (g), and pipe diameter (D). The relationship of flow velocity (v) to head loss (hf) and velocity (v) to hydraulic gradient (hf/L) is shown in Figure 3.



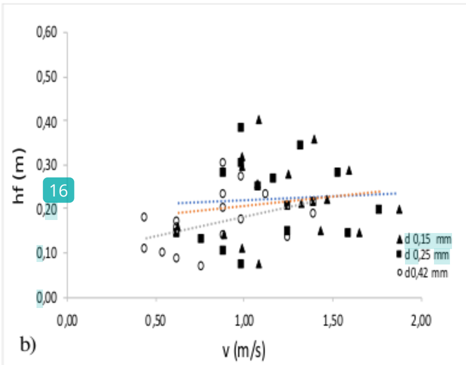


Figure 3. Relation of flow velocity to head loss (a) and hydraulic gradient (b)

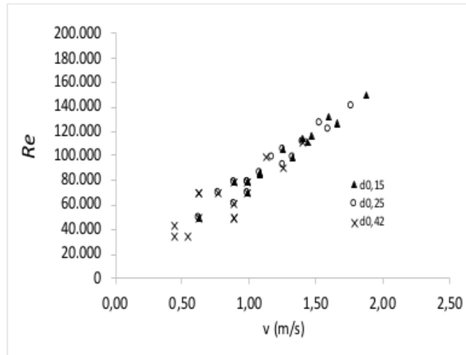


Figure 4. Relation between Re and V

Figure 3 shows the relationship between flow velocity and energy loss (hf) and hydraulic gradient (hf / L) at the four measurement points. Of the three sediment samples, the energy loss (hf) at a size of 0.42 mm is more significant than the size of 0.25 mm and 0.15 mm, and this indicates that in 0.42 mm sediment, the flow velocity (v) is smaller. Because of the influence of the sediment (ds) size and its significant sedimentation rate (vs). The smaller the sediment size (ds), the greater the flow velocity (v) and the greater the energy loss (hf). Figure 2 also shows the relationship of flow velocity (v) to the slope of the power line (hf / L), where the more prominent the sediment size (ds), the flow velocity (v), and the hydraulic gradient (hf / L) are getting smaller.

Sediment size 0.15 mm flow velocity is at 1.88 m / s - 0.63 m / s, hf is at 0.073 m - 0.402 m, hf / L is at 0.063 m / m - 0.016 m / m and size 0 , 25 mm flow velocity is at 1.77 m / s - 0.63 m / s, hf 0.071 m-0.300 m, hf / L is at 0.058 m / m - 0.016 m / m and, size 0.42 mm velocity flow (v) is at 1.40 m / s - 0.44 m / s, hf 0.067 m - 0.298 m, hf / L 0.034 m / m -0.007 m / m. at discharge (Q) the same flow

B. Analysis of Reynold number and coefficient of friction

The value of the Friction Coefficient (f) is determined based on the relative roughness (e / D) and the Reynolds number (Re), so that if the pipe has a specific size and flow velocity, then the energy loss due to friction calculated immediately [1].

The Reynold number (Re) is calculated based on the sediment flow velocity (v), sample density (ρ), and pipe dimensions (equation 5). At the same time, the friction coefficient (f) is calculated based on the Reynold number (equations 8 and 9). The relationship of flow velocity (v) to Reynol number (Re) and velocity (v) to the friction coefficient (f) is shown in Figure 4.

Figure 4 shows the relation of the Reynold number (Re) to the sediment flow velocity (v), where the greater the flow velocity (v), the greater the Reynold number (Re). The larger the sediment size (ds), the smaller the flow velocity (v) and the smaller Reynold number (Re) at the same flow variation (Q). In the sediment 0.15 mm the Re values are at 149,516 - 49,839, 0.25 mm Re 140,965 - 49,839, 0.42 mm Re 111,443 - 35,241.

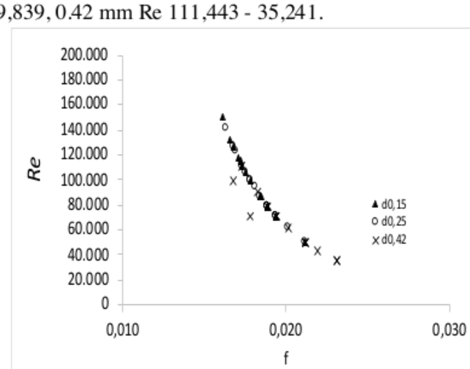


Figure 5. Relation between Re and f

Figure 5 shows that Reynold number(Re) and the friction coefficient (f) are inversely proportional, where the greater the Re, the smaller the f value. At the sediment size (ds) 0.15 mm f value 0.0161 - 0.021, 0.25 mm f value 0.016 -. 0.021, and 0.42 mm f values 0.017-0.023 at the same variation of flow rates.

C. Sediment transport analysis

Sediment transport analysis aims to determine and identify the movement of sediment sizes 0.15 mm, 0.25 mm, and 0.42 mm in the pipe with the resulting difference in velocity (v) produced in this experiment. Energy loss (hf) that occurs along with the flow causes changes in flow velocity (v), and the flow ultimately affects sediment movement. From the observations in the measurement point segment and analysis of the relationship between flow velocity (v) and sediment size (ds), the classification of the sediment flow regime is 0.15 mm, 0.25 mm, and 0.42 mm.

The limit deposit velocity (vL) value from the Liu equation is influenced by the dosimetric froud number (FL) of the slurry flow and the size of the sediment (ds), gravity (g), pipe diameter (D), water, and sediment density (ρw and ρs) and solid volumetric concentration (Cv). Experimentally the boundary value of the flow regime is based on changes in the conditions where the sediments are located in the segment of the measurement point segment. The change in sediment location is then plotted in the graph to get the velocity (v) value for each regime.

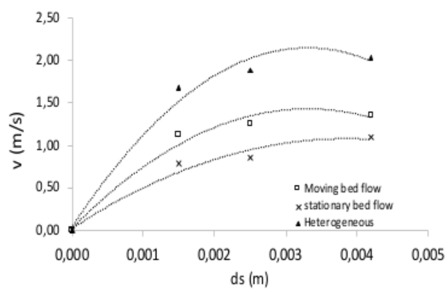


Figure 6. The relation of v and ds

Figure 6 shows the relation between sediment flow velocity (v) and sediment size (ds) where the larger the sediment size the smaller the flow velocity (v).Precipitation occurs when the sediment settling rate (vL) is greater than the existing flow rate (vL> v). From the three sediment samples (ds) and flow velocity (v) from the experimental results, several sediment flow regimes were produced where the sediment size of 0.15 mm is at 1.67 m / s -1.115 m / s heterogeneous regime, 1.15 m. / s - 0.793 m / s moving bed regime, 0.70 m / s - 0 m / s stationary bed regime and> 1.675 m / s homogeneous flow regime. Sediment size 0.25 mm is at 1.87 m / s - 1.25 m / s heterogeneous regime, 1.20 m / s - 0.85 m / s moving bed regime, 0.85 m / s - 0 m / s stationary bed regime and> 1,875 m / s homogeneous flow regime, sediment size 0.42 mm is at 1.83 m / s - 1.35 m / s heterogeneous regime, 1.35 m / s - 1.09 m / s moving bed regime, 1.09 m / s - 0 m / s, stationary bed regime. The three sediment samples show the same data trend in each regime, where the greater the sediment size (ds) the greater the settling speed (vL).

When the velocity is low (v), and the size of the sediment is large (ds), the sediment will settle at the bottom and begin to accumulate at the beginning of the flow. This condition occurs if the velocity cannot lift the sediment, or in other words, the sedimentation velocity is greater than the flow velocity (v <vl). The slurry flow velocity (v) that is expected in the slurry flow is the slurry flow velocity (v) which does not result in deposition, and this means that the slurry speed must be in the pseudo homogeneous or heterogeneous regime with the minimum speed limit being the moving bed flow regime. Regime moving bed flow is a slurry flow condition that can still suspend sediment particles until the end of the flow. Sediment transport in moving bed flow Regime is carried out by sliding or salting bed and does not produce stationary bed. From the results of observations, calculations and analyzes, there are 3 (three) regimes that occur in the sediment size of 0.15 mm, 0.25 mm, and 0.42 mm, namely the heterogeneous regime, the moving bed flow regime, and the stationary bed regime. The heterogeneous regime is in large velocity and minor sediment size conditions, and the moving bed flow regime is in low-velocity states. The sediment size is fine or medium velocity, and the large sediment size, stationary bed flow regime, is in a very low rate and large sediment size.

V. CONCLUSION

The sediment-containing flow exerts an influence on pipeline performance—the non-fulfillment of the flow rate results in the deposition in the pipe. Theoretically, a stream containing sediment will deposit coarse-grained sediment (bedload) first compared to suspended load at the same flow rate. This research was carried out experimentally by measuring the flow velocity as the main parameter for the sediments of 0.15 mm, 0, 25 mm, and 0.42 mm in size. The results showed that the larger the sediment size, the lower the flow rate and the greater the deposition rate—the greater the flow velocity, the greater the energy loss and hydraulic gradient. The three sediment samples show the same data trend in each regime, namely the heterogeneous regime, the homogeneous regime, the moving bed regime, and the stationary bed regime. The greater the sediment size (ds), the greater the settling speed

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