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Empirical models for predicting longitudinal contaminated into One-Dimensional (1-D) steady flow of pipe network system

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Abstract

Experiment were undertaken to modelling the longitudinal contaminated behavior in pipe network system. In this study, the venturi tube is investigated to understand the effect of viscosity, pressure drop and condition of pipe on the characteristic of 1-D steady flow as contaminant disturbance. The scope of this study cover fluid flow from the industrial effluent treatment system (IETS) at the source to the final discharge point before release to the environment. Water and heavy oil is used separately as a fluid flow in this experiment to obtain different Reynold numbers in wide range since the Reynold numbers has relative significant to the viscous effect. The result presented, at fluid with low Reynold numbers which is laminar, the length required for fully develop zone is increase proportionally. In this experiment, considering with an assumption the system in steady state, pipe flow in horizontal where there is no change in elevation, incompressible flow and negligible frictional loss. The Bernoulli principle is applied to understand the flow rate changes with pressure and velocity thus obtain different observation with experimental values. Empirical model was developed based on the flow rate of the fluid passing through the venturi. The result indicated the characteristic of the fluid in flow system for model prediction at constant area, variable change in pressure in venturi showed satisfactory with theoretical values and the understanding of this behavior can be used in monitoring and predicting the fluid flow characteristics of heavy metal discharge in pipe network system.

Keywords: Venturi, IETS, Reynold numbers, Bernoulli principles, empirical models.

1. Introduction

In general, Heavy metal is define as a metals at certain level in concentration in water that may pose detrimental health effect. Basically, it will considered to be those when density exceeds 5 g per cubic centimeter [1]. It is include lead, cadmium, zinc, copper, nickel, chromium, zinc, cadmium and tin. Industrial wastewater are emitted by sources such as industrial wastes from mining sites domestic waste water, run off from roads, and manufacturing and metal finishing plants. In Malaysia, industrial effluent for heavy metal discharge that release into any soil, or into inland water should be applied the law regulation of Malaysian Environmental Quality Act, [2] called Environmental Quality (Industrial Effluent) Regulations 2009. The proper technique, sampling personnel and equipment is compulsory in achieving accurate and representative data for heavy metal discharge from treatment system before release to the aqueous environment. However, heavy metal discharge cannot rely only on those because the travelling of heavy metal in the pipe network system has a tendency to give inaccurate data at final discharge point.

In this paper, one of the phenomenon which can cause longitudinal contamination form inside the pipe network is investigated. The contamination disturbance can lead to changes in pressure, velocity and flow rate of the heavy metal discharge. There is several factors that contributing to the contamination of waste water in pipe network such as infiltration of contaminants into the pipe network, corrosion or crack, unprotected wastewater reservoir, water age and biofilm formation. Infiltration of contaminants into the pipe network is a major problem where the contaminated water outside the pipe network enter the system and cause the contamination in pipe network [3]. In this case, a low pressure zone will created in the system.

The pressure drop is the main issued to consider in this research. According to the previous research [4], the change in pressure directly proportional to the flow rate. The previous researcher state [5], the flow rate is essential parameter to be consider that affecting the release of heavy metal across pipe such as the change in concentration, physical disturbance (pH and DO), and oxidation rate of organic compound. For monitoring heavy metal discharge, the flow rate is essential part to measure and recorded at final discharge point. This data represents the true batch that enters the treatment system was treated and discharged. Furthermore, the changes in flow can stress the pipe and enhance weakening of pipe and joints especially for intermittent joints pipe. Hence, the weakening pipe joints lead to occur leakage and promote to the corrosion and crack.

2. Physical model for longitudinal contaminant form in pipe network system

To demonstrate the contaminants, the principle of venturi is used to develop mathematic model. A venturi is commonly used in industrial application for fluid measurement based on Bernoulli principles. Others application for venturi are carburetor in automotive part, spray tank, and steam injector. It is divided to 5 parts whereas main inlet, convergent cone, cylindrical throat, diverging section and exit section. This principles, inside the pipe, pressure is drop by reducing the cross-sectional area of the pipe flow. The velocity of the fluid at the throat increase since the main inlet area is bigger than throat and the pressure is decrease. Thus, there has a pressure difference in main inlet and the throat. To understand the changing of the fluid flow, the difference pressure is calculate using Bernoulli equation and discharge formula. Refer to the figure 1.

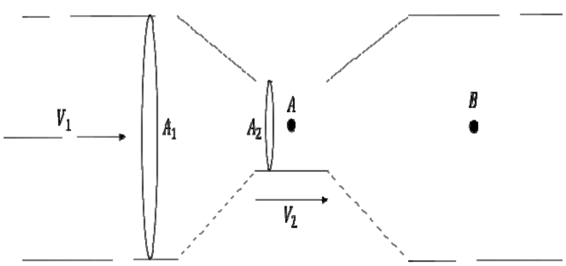

Figure 1 Systematic Diagram for Venturi

By continuity equation,

$$A_1V_1 = A_2V_2 \quad (1)$$

Using Bernoulli equation,

$$\frac{1}{2}\rho V_2^2 - p_A = \frac{1}{2}\rho V_1^2 - p_B \quad (2)$$

2.1 The venturi tube model and flow rate discharge

There has a vary dimension of tube diameter for venturi tube as figure 2. These variation tends to occurs changing of pressure inside the pipe network. Venturi with converge angle is selected in order to prevent the corrupted result that introduce steps in pipe network experiment [6]. To measure the flow rate by pressure variation, two pressure taps is create at throat area and inlet area thus the measuring pressure is substitute to the Bernoulli equation. Therefore, D_1 and D_2 are the hydraulic diameter for pipe network, C_d is the discharge coefficient whereby equal to 1 by assuming no friction loss.

Flow rate on discharge by pressure drop (for incompressible fluid),

$$Q = \frac{\pi D_2^2}{4}\frac{C_d}{\sqrt{(1-(D_2/D_1)^4}}\sqrt{\frac{2(p_1-p_2)}{\rho}} \quad (3)$$

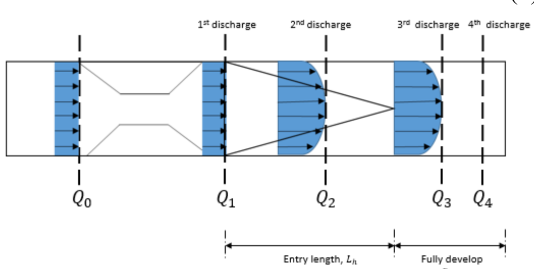

Figure 2 Theoretical of modelling longitudinal contamination form by venturi effect

2.2 The physical model

The physical model is developed in the laboratory as figure 2 to represent the study flows, and the contamination phenomenon. The change in pressure as existing contamination has been represented with a venturi tube in order to depress the fluid flow inside the pipe network. By venturi effect, we can observe and model the principal flow with the reading of manometer tube on the venturi tube.

In this pipe network system interest, viscous effect and velocity changes are significant as the flow rate will change and effect the concentration of heavy metal discharge. The region of fluid flow where the fluid velocity is effected by viscous effect called velocity boundary layer.

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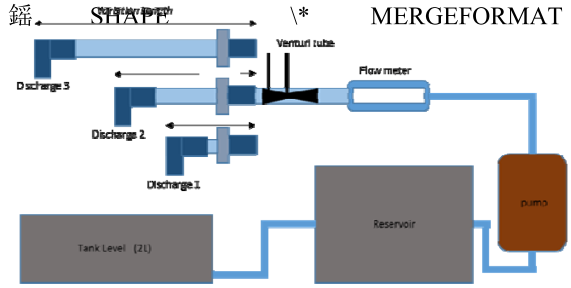

Figure 3 Experimental model for analysis the contaminant and fluid flow

2.3 Numerical Method

A numerical analysis of the pipe flow as modelling longitudinal contamination form has been carried out based on Computational Fluid Dynamic (CFD). The model was simulate with the aid of software "ANSYS Fluent 16.0" [7][8][9]. In this paper, finite element method has been used to determine the fully develop zone after the fluid velocity has changed cause of contamination. However, the geometric for the pipe is selected as simple form and two dimensional. The reason is because we extend the study to the entrance region through venturi tube and determine pipe length for experimental work.

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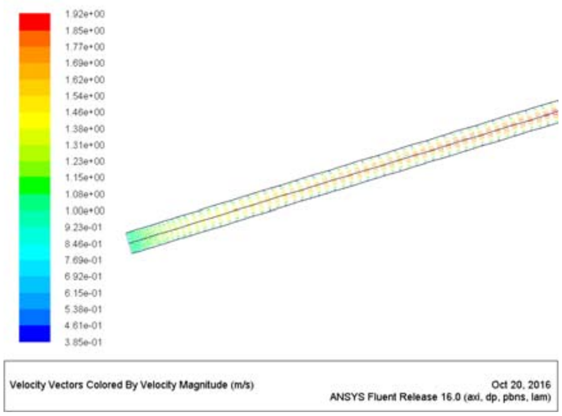
Boundary condition for the fluid flow is presented as figure 4.

a)



b)

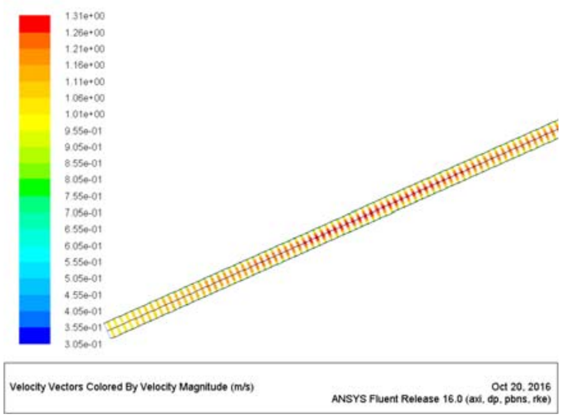


Figure 4 Boundary condition for a) laminar flow b) turbulent flow

To begin the numerical analysis, regarding to literature [10], axial velocity increases along x-direction pipe length and will becomes constant when achieve fully develop zone at certain distance. For the fluid flow at low Reynold numbers which is laminar flow as figure 5, changes from inlet profile the fully developed zone gradually, the length for fully develop zone is defined, the axial velocity for that zone is around 1.92m/s at 0.919m and the velocity become constant after that zone while from the analytically solution is 0.915m. Similarly, at high Reynold number which is turbulent flow, the value of axial velocity for fully developed zone is 1.24m/s at 0.67m while from the analytical solution is equal to 0.629m. All of those data is satisfies by finite summation. The percentage error for both fluid flow is acceptable in range of 6 – 9 % which in conformity to the results obtained for pipe length in extend experimental work. From the results also, it is observed that laminar flow represented longer hydrodynamically zone until fully developed zone when comparing with turbulent flow and satisfy as literature [11]. In contrast, laminar flow require more distance in x-direction to achieve fully developed zone. Hence, it can be conclude from the figure 6 and 7, the change of velocity for laminar flow is higher than turbulent flow.

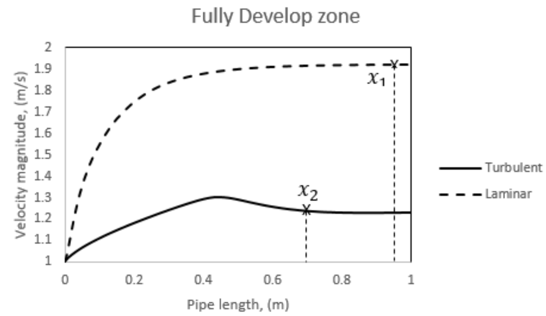


Figure 5 Axial velocity of fluid along x-direction of pipe

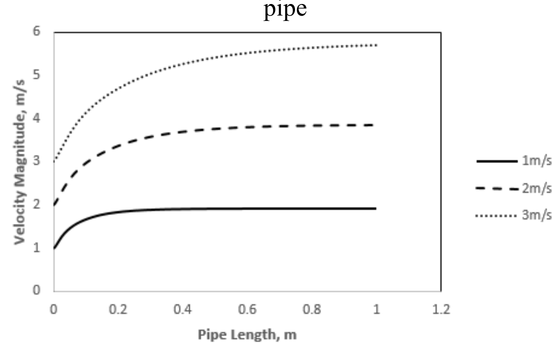


Figure 6 Velocity changing with different velocity for laminar flow

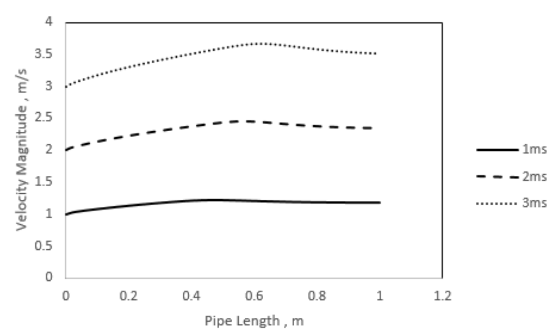


Figure 7 Velocity changing with different velocity for turbulent flow

In previous systematic overview for flow rate distribution, it can be observed four flow rate discharge at certain pipe network length. Hence, as refer to table 1, it can be observe that the fluid with low Reynold number has a more changes in velocities and require more pipe network length to achieve fully develop zone. From the numerical analysis also, it can be conclude that the flow measurement will be inaccurate and representative data at flow before achieve fully develop.

Table. 1 Numerical analysis for studies changes of flow rate.

Parameter	Value, m^3/s	
	Turbulent	Laminar
Flow rate (inlet), Q_0	0.5067e-3	0.5067e-3
Flow rate (discharge 1), Q_1	0.5067e-3	0.5067e-3
Flow rate (discharge 2), Q_2	0.6303e-3	0.9346e-3
Flow rate (discharge 3), Q_3	0.6380e-3	0.9692e-3
Flow rate (discharge 4), Q_4	0.62360e-3	0.9737e-3

3. Analytical solution

In this analytical overview, the wide Reynold number is used to obtain laminar and turbulence flow by different kinematic viscosity of water and heavy oil. The correlation Reynold numbers for both fluid is given by,

For water (turbulent flow ≥ 4000),

$$Re = \frac{Ud_h}{v} = \frac{1(25.4)}{(0.801x10^{-3})} = 31710$$

For heavy oil (laminar flow ≤ 2300),

$$Re = \frac{Ud_h}{v} = \frac{1(25.4)}{(40x10^{-3})} = 635$$

Where U is the instantaneous velocity at x-direction, d_h is the hydraulic diameter of pipe, v is the kinematic viscosity of fluid.

To determine the fully develop zone, we must know the entrance region, L_h . Since the Reynold numbers (Re) and hydraulic diameter (d_h) is known [12][13],

$$L_{h,turbulent} = 4.4DRe_D^{1/6}$$
$$L_{h,turbulent} = 620mm$$
$$L_{h,laminar} = [(0.619)^{1.6} + (0.0567Re)^{1.6}]^{\frac{1}{1.6}} x D$$
$$L_{h,laminar} = 915mm$$

In present analysis, the flow rate for outlet is directly calculated from equation (3). The pressure drop is based on tapping reading on venturi tube at the throat and inlet area. The valid procedure obtain the difference behavior of data with considering Bernoulli principle. As a mention above, for the calculation, the viscous and wall friction effect is negligible so return to difference values of measurement. However, almost venturi meter has discharge coefficient close to 1. Discharge coefficient is equal to 1 in absence friction losses, but in this case, it is design the discharge coefficient for 0.98 [14][15]. This analytical data made in comparison with the values that indicate from experimental work without pipe discharge length. Since the percentage difference below 10%, it can be regarded as an acceptable data for next procedure. It is not convenient to use in instrumentation application especially for data acquisition system.

Table. 2 Analytical solution based on change in pressure.

Change in pressure	Value, m^3/s		Percentage difference, %
	Analytical	Experiment	
10	5.2070e-5	5.5791e-5	7.15
26	8.3970e-5	8.3822e-5	1.76
27	8.5570e-5	10.0241e-5	1.71
30	9.0100e-5	11.2208e-5	2.45
50	11.6400e-5	13.3333e-5	1.45
70	13.7770e-5	15.0512e-5	9.25
80	14.7300e-5	18.4162e-5	2.5
100	16.4670e-5	23.0203e-5	3.98

4. Result and discussion

It is significantly to begin by analyzing the flow streamline using numerical analysis. In fact, the hydrodynamically zone will be obviously resulted to represent the several of streamline changes. All of those method just describe the potential region that will be essentially affect the acquisition data by particular of instrument. After the pattern was plotted and linear dependence of parameter, the experiment was conducted to confirmed the behavior of fluid flow after experience the disturbance from longitudinal contamination form. This experimental work extend of previous study.

4.1 Effect of contamination based on venturi model for turbulent flow

Many researcher measure the pressure drop in venturi tube in order to understand the velocity effect as proportionally as flow rate. In analysis made by this researcher [16][17], the dissipation of energy and momentum principle should take into account when calculate the pressure drop. However it is involve to complexity theory behind and enhance the numerical work hence this research use continuity. By experimentally work, as refer to figure 8, the changes of flow rate gradually increase by increasing the velocity inlet. Here, the pattern also explained the increasing velocity at inlet proportionally to difference in pressure. It should be emphasized that fluid flow just before fully develop zone and backward, the tendency to obtain more differences result as the fluid flow in pipe network system bigger and will disturb the concentration of fluid.

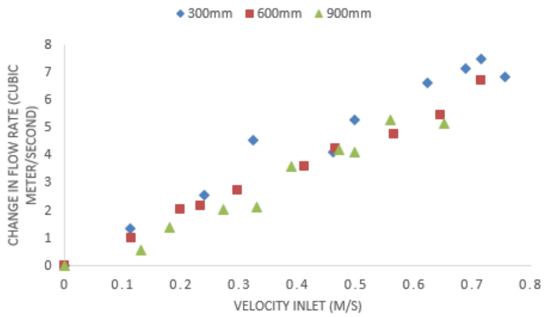


Figure 8 Changes of flow rate discharge in turbulent flow

4.2 Effect of contamination based on venturi model for laminar flow

Subsequently, the form of laminar flow plotted the pattern as a resulted in figure 9. The result demonstrate the change of flow rate is almost similar for difference velocity inlet. Increasing the velocity inlet not necessary increasing the flow rate changes. It is clearly adverse pattern if comparing to turbulent flow. Essentially, both of fluid flow showed the change of flow rate when undergo the venturi tube.

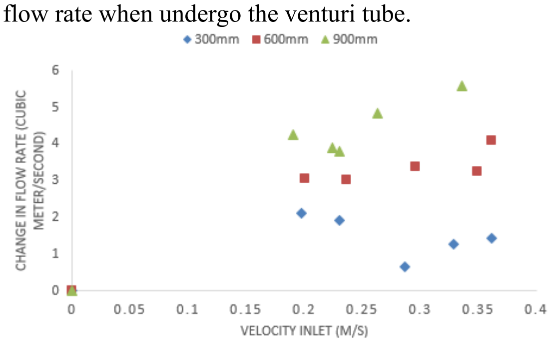


Figure 9 Changes of flow rate discharge in laminar flow

4.3 Effect of viscosity on pipe length network

The solution from governing equation that perform by finite element method shows the flow rate of discharge difference with pipe discharge length according to viscous effect. Reynold number has play a main role to configure the viscous effect. From wide range of difference Reynold number in figure 10 and 11, at the high Reynold numbers change in flow rate does not effected by the pipe length. The reason is, at 670mm (obtain from numerical analysis) the fluid flow is predicted to achieve fully developed zone where all the node along the pipe at x-direction more consistently. In addition, the flow pattern for pipe length 300mm shows a small difference because the fluid flow is not stable and achieve fully develop. On the other hand, the low Reynold number (laminar flow) depict the obviously difference for 3 type of length. The reason can be clearly explain because all of the pipe length not achieve fully develop zone. However, at the pipe length with 900mm, the discharge of flow rate become more consistent because as a prediction from numerical analysis, the length require for fully developed zone for this fluid flow is 919mm.

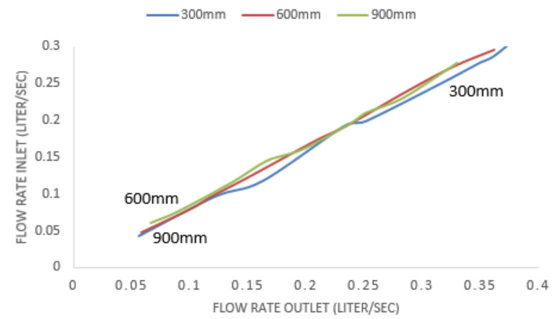


Figure 10 Changes of flow rate discharge in turbulent flow

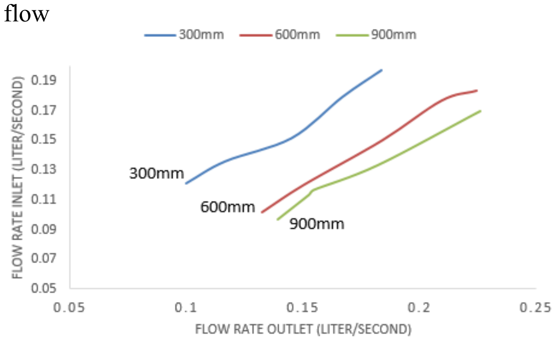


Figure 11 Changes of flow rate discharge in laminar flow

5. Conclusion

Heavy metal discharge often used pipe network system in many industrial until final discharge point before release to the aqueous environment. This study examined the longitudinal contamination form which were tested under different Reynold numbers condition which promote to laminar and turbulent flow. It was convenient to use venturi tube to predict the effect of disturbance and fluid flow in pipe network system [18].

It would be interesting to perform analytical, numerical and experimental works to check the validity of analysis. The results shows satisfactory for all conditions. Mathematical modelling using venturi tube has been proved to be greatest in understanding the effect of longitudinal contamination form in pipe network system. The results showed the flow rate changes after experience the disturbance. Furthermore, the change of flow rate after disturbance of contamination has create a different behavior depends on Reynold number and fully develop zone.

The following drawn conclusion from this concern. The change of flow rate at outlet have nearly constant for low Reynold number application, but high Reynold number results presented that the difference between flow rate inlet and outlet increases with velocity inlet so it will seeking the significant to control the flow rate from IETS. Lastly, it drawn a very specific issues during monitoring the heavy metal discharge. A proper pipe network system should be consider for develop instrument for monitoring heavy metal discharge.

6. Acknowledgement

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