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Investigation of Effect Garbage Level in Filtration System to Headloss and Water Discharge by Computational Method

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ABSTRACT

Floating garbage in a filtration system is one of the main factors causing many problems in engineering structures because the accumulation of garbage can block the flow rate. The bar screen installed in a water channel is used to catch the garbage, but the main threat when installing a bar screen in a water channel (intakes) is that system can lead to headloss and disturb (block) fluid flow occurrence. However, there is no concern about the effect of garbage level on the bar screen to head losses and water discharge; for the filtration system, the main concern is discharge. Therefore, this study aims to investigate the effect of garbage level on bar screens to head losses and water discharge by the computational fluid dynamics (CFD) method. Based on the results, the CFD method is capable of predicting the headloss and discharge for the filtration system in the channel. However, the headloss that occurred was insignificant (as still normal) and can reduce the water discharge from the inlet by more than 45%. Then, water energy dissipation due to the narrowing of the flow field consequence of the blockade of garbage. Then, estimating discharge in a filtration system connected to the high seas requires tidal analysis because tides affect the headloss and the water discharge. Further, the headloss is directly proportional to the flow speed and the channel's width.

1. Introduction

Floating garbage in a river or water channel is considered one of the main factors causing many problems in engineering structures. The accumulation of garbage at the entrance of a waterway (bridge) can block the flowrate, adversely affect buildings (structures) [1, 2], damage the boats [3], cause problems with navigation systems, increase the bed scour due to the amount of floating garbage [4], and worsen flooding [5]. The hazard of floating garbage is more significant in the opening structure because of the difficulties in removing it.

The bar screen installed in a water channel is used to catch the garbage that can disturb (block) fluid flow in that channel [6]. The goal of installing bar screens at the entrances of water intakes,

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culverts, bridges, turbines [3], hydroelectric facilities [7], and pumping stations is to protect those buildings (systems) against damage and operational problems.

The main threat when installing a bar screen in a water channel (intakes) is that system can lead to headloss occurrence [8]. It has the same impact as narrowing the channel: the flow rate will increase, and the water might flow above its maximum level [6]. In other words, the headloss gets worse, increase the water level, and increase the potential for flooding to occur [6, 9]; and indicates a failure of irrigation engineer due to rising water levels. Furthermore, the clogging caused by that garbage will decrease the flow rate, disabling hydroelectric systems, thermal power plants, and turbines [8, 10]. It also can cause many harmful consequences for hydraulic systems, the environment, and the economy.

Head loss caused by the bar screen is one of the crucial aspects of the performance. It is an important factor in designing the bar screen [11]. The increase in headloss has a significant effect, including the emergence of many problems. They examine the hydraulic impact of vertical and inclined trash screens from the bed; the main focus is the head loss due to the bar screen installation.

Kirschmer [12] developed a headloss equation for inclined trash screen from the channel bed with inclination angled (β) ranging from 60° to 90° (vertical). Then, similar empirical equations by Fellenius and Lindquist [13], Spangler [14], and Osborn [15].The first sentence should start here [1].

Clark studied head losses through a submerged trash screen with different bar shapes. The results show that the head losses decrease with a bar shape other than a rectangular cross-section. Furthermore, increasing approach velocity and blockage ratio indicates a higher headloss.

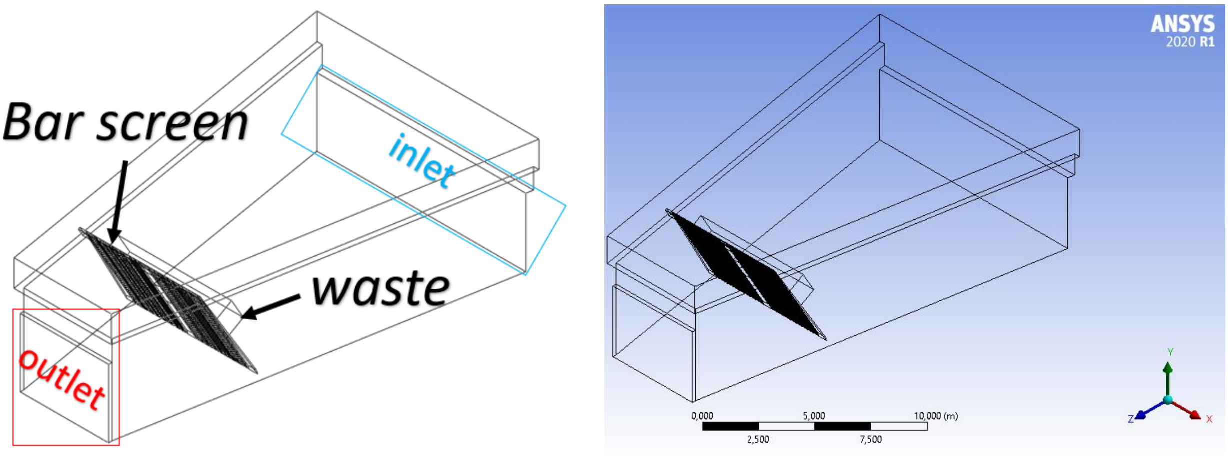
Raynal highlighted the effect of different inclination angles (β) for the bar screen. The minimum angle was β of 15°, and the maximum was β of 90°. From the result, the bar screen should be sharply inclined (β less than 25°). In the illustration of garbage behavior by Blanc [9], the garbage can rotate to align parallel with the flow direction through a higher flow rate.

Propose the empirical formula to calculate head losses through various conditions by Mosonyi [16], Zimmermann [17], Molinas [18], and Tsikata [19]. However, based on a previous study, there is no concern about the effect of garbage level on the bar screen to head losses and water discharge; for the filtration system, the main concern is discharge. Therefore, this study aims to investigate the effect of garbage level on bar screens to head losses and water discharge by the computational fluid dynamics (CFD) method. Then, it recommends a method to predict the garbage level for a filtration.

2. Method

2.1 Geometry Model 3D

The mouth intake geometry has a width of the inlet is 12 m, and the outlet is 5 m. The slope of the screen bar against the channel is 60°. Figure 1 shows the schematic of simulated mouth intakes.



(a) (b)

Fig. 1. Simulation setup (a) Determination of boundary condition (b) Visualization of boundary conditions

2.2 Setup CFD

Geometry is imported into computational fluid dynamics (CFD) software for simulation after geometry is built at SOLIDWORKS. Figure 1(b) is the result of the importation of geometry to Ansys 18.1.

$$\frac{\partial(\rho)}{\partial t}+\frac{\partial(\rho u_j)}{\partial x_j}=0 \quad (1)$$

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial(\rho u_i u_j)}{\partial x_j}=-\frac{\partial p}{\partial x_i}+\frac{\partial(\tau_{ij}-\rho u_i' u_j')}{\partial x_j}+\rho g_i \quad (2)$$

where $-\rho u_i' u_j'$ is Reynolds stress:

$$-\rho u_i' u_j'=\mu_t\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\frac{2}{3}\left(\rho k+\mu_t\frac{\partial u_i}{\partial x_i}\right)\delta_{ij} \quad (3)$$

Then, the simulation is carried out with a volume fraction approach because two fluids are employed, namely water and air. Calculations for the mixture of density (ρ) and viscosity (μ) of the two fluids [20]:

$$\rho=\alpha_w\rho_w+\alpha_a\rho_a \quad (4)$$

$$\mu=\alpha_w\mu_w+\alpha_a\mu_a \quad (5)$$

Turbulent flow approach k- ε Reynolds Average Navier-Stokes (RANS) based standard is applied to improve the accuracy of numerical calculations [20]. To k:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_j}=\frac{\partial}{\partial x_i}\left(\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right)+G_k+G_b+\rho\varepsilon+Y_M+S_k \quad (6)$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon u_i)}{\partial x_j}=\frac{\partial}{\partial x_i}\left(\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right)+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \tag{7}$$

2.3 Mesh Independent Test Analysis

Mesh tests using a grid convergency index (GCI) [21, 22]. GCI calculations use the concept of extrapolation to predict exact values, then calculate the mesh size error by an exact value. GCI requires three variations of mesh. Examples of GCI analysis are [23]:

$$\mathrm{GCI_{mf}}=S_F\left(\frac{1}{u_f}\frac{u_m-u_f}{r_{12}{}^{p_n}-1}\right)\cdot 100\% \tag{8}$$

S_F is a safety factor with a value 1.25, p_n is convergence observed order, r is grid ratio ($r=(M_M/M_F)^{0.5}$). The variable used for GCI analysis is the flow velocity at one point. Then, the calculation of p_n is:

$$p_{\mathrm{n+1}}=ln\left[\left(\frac{u_c-u_m}{u_m-u_f}(r_{12}{}^{p_n}-1)\right)+r_{12}{}^{p_n}\right]/\,ln(r_{12}\cdot r_{23}) \tag{9}$$

Next, predict the exact value (u_∞):

$$u_\infty=u_f-\left(\frac{u_m-u_f}{r_{12}{}^{p_n+1}-1}\right) \tag{10}$$

2.4 Mathematical Calculation of Δh

The mathematical calculation of Δh uses the proposal by Sayed *et al.,* [24]. The parameters required in the analysis are the width of the material bar screen (d), the distance between the screen bars (s), the depth of water (h0), the number of screen bars (z), the width of the water route (w), the water velocity (U), and gravity (g).

The calculation of water elevation starts from blocked ratio (B):

$$B=\frac{A_b+A_s}{A_t} \tag{11}$$

where A_b is a large area of garbage, A_s is the area of the screen submerged in water ($A_b=h_0\cdot d\cdot z$), and A_t Is the area through which the water passes ($A_t=h_0\cdot w$). The waste area is a function of a high percentage of waste and the width of the route ($A_b=(h_0-h_1)\cdot w$). Figure 2 shows the schematic height of garbage and piles.

Next, the calculation q (unit flow discharge):

$$q=\mathrm{Q/d} \tag{12}$$

Q is the water discharge, and d is the width of the inlet. Once known q, then calculate Δh* using:

$$\frac{\Delta h}{U^2/2g}=7.88\cdot\left(\frac{q\cdot g}{U^2}\right)^{0.37}\cdot(B)^{1.68}\cdot(sin\,\alpha)^{3.5} \tag{13}$$

To find out Δh_a use:

$$\Delta h *= \frac{\Delta h_a}{U^2/2g} \tag{14}$$

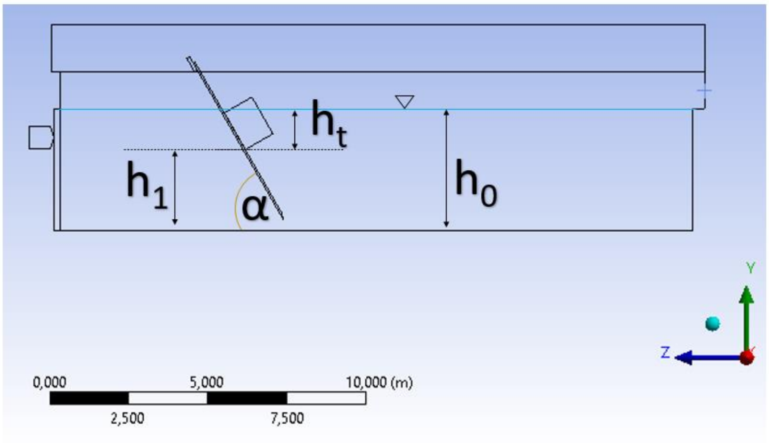


Fig. 2. Schematic high piles and garbage

The Verifier of Sayed *et al.,* [23] mathematical calculations was verified using the proposed equation by Sayed *et al.,* [25]. Calculation analysis Δh_b [25]:

$$\Delta h_b = \xi \cdot \frac{U^2}{2 \cdot g} \tag{15}$$

where ξ:

$$\xi = 8.13 \cdot B^{1.84} \cdot F_0{}^{-0.49} \tag{16}$$

F_0 Is a number Froude:

$$F_0 = \frac{U}{\sqrt{g \cdot h_0}} \tag{17}$$

3. Results and Discussion
3.1 Mesh Test Results

The mesh test uses three variations of the mesh number: 600k, 950k, and 1450k. The flow velocity at the point of 1,1,1 has values of 1.61 m/s, 1.3889 m/s, and 1,377 m/s, respectively. Before calculating the GCI value, it is necessary to calculate the p_n value first using Eq. (9). The extrapolation calculation of u_∞ after obtaining the P_n using Eq. 10. Furthermore, the calculation of GCI is through Eq. (8). Table 1 shows the results of the mesh count test using GCI. From the test results, a mesh with an amount of 950k is sufficient for the intake mouth CFD simulation because it has an error below 10%. Figure 3 shows a mesh visualization with a quantity of 950k.

Table 1
Mesh count test results using GCI

Number of mesh	Velocity (m/s)(1,1,1)	p_n	GCI (%)
600k	1.61	12.65	-
950k	**1.3889**		**1.15**
1450k	1.377		0.08
x→∞	1.376		-

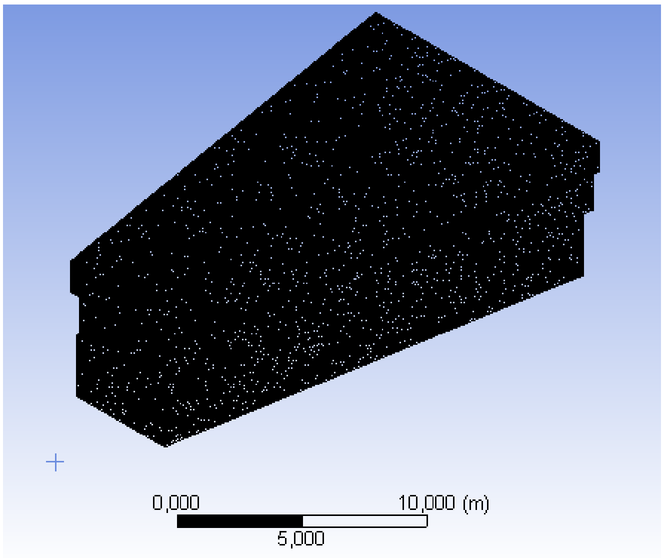


Fig. 3. Mesh visualization with 950k elements

3.2 Simulation Results

Table 2 is the data obtained from the results of the CFD simulation. Table 3 shows the discharge (Q) relationship and water velocity in front of the bar screen to the logarithmic garbage height (Figure 4). Thus, discharge to the blockade of garbage on the bar screen can be predicted. Percentage garbage (X) is the ratio between the height of the water in the inlet (h_0) and the garbage (h_t).

Table 2
CFD simulation results Δh, Q, and U

X	Discharge (Q) (kg/s)	Velocity (U) (m/s)	h_0 (m)	h_1 (m)	Δh (m)
0%	10621.6	0.65	3.935	3.93	0.005
10%	7343.95	0.603	4.1353	3.9553	0.18
30%	5044.24	0.597	4.174	3.975	0.199
50%	3974.95	0.596	4.205	3.905	0.3

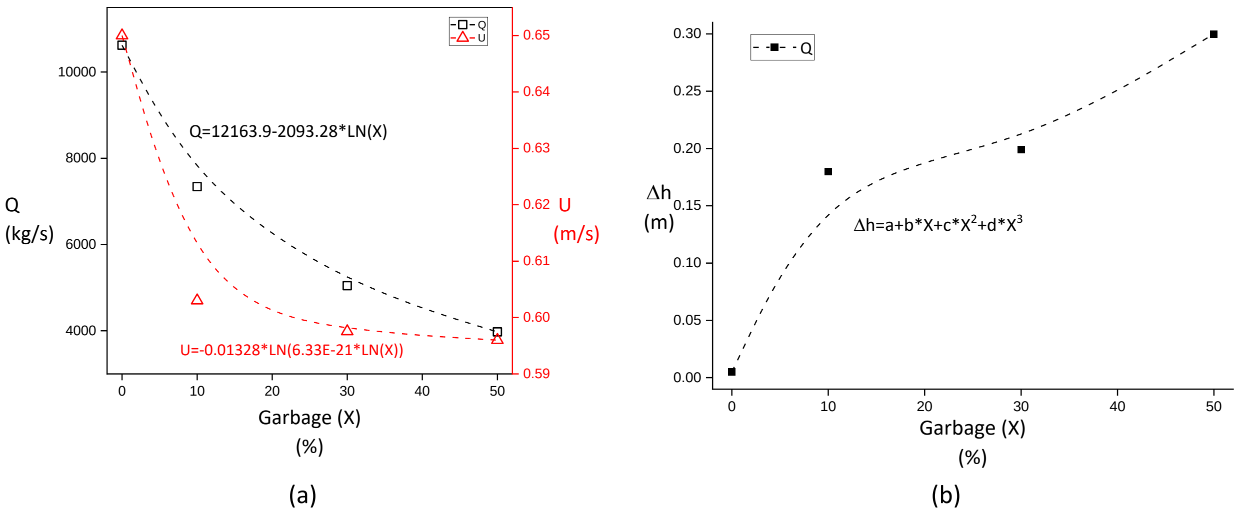


Fig. 4. CFD Results (a) The relation of Q and U to the percentage of garbage (b) Relation of Δh to the percentage of garbage

The relation constants of the Equation Figure 4-b are: a: 0.00495, b: 0.0267, c: -0011, and d: 0.000013. The relation of the equation Figure 4-b is reasonable because the result of the estimate of Δh is 4.57 m with 100% garbage. Figure 5 shows the water volume fraction of CFD intake mouth results.

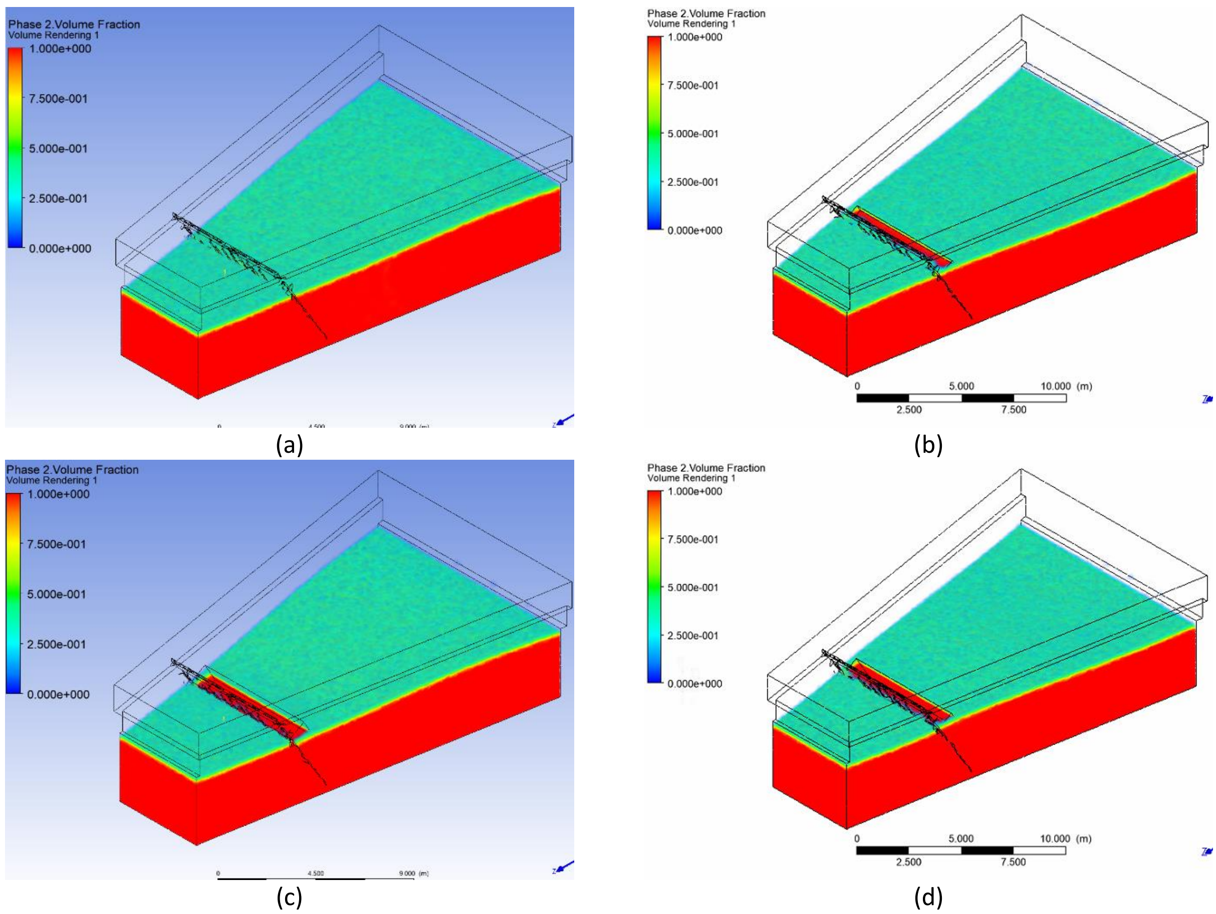


Fig. 5. Visualisation of volume fraction by CFD results (a) 0% (b) 10% (c) 30% (d)50%

3.3 Verification of Mathematical Analysis Δh

Based on Figure 1, d is 10 mm, the distance between screens is 62 mm, h_0 is 3.85 m, w is 3.2 m, and z is 35. All data used to determine B using Eq. 11. The measured flow velocity in the inlet is 0.15 m/s (A_t=46.2 m^2) and at the outlet it is 0.36 m/s (A_t=19.25 m^2). The location of the bar screen is at At=24.87 m^2. Then, based on the law of conservation of mass, the average U is 0.28 m/s. From the calculation results, Q is 6.93 m^3/s (Q=0.28·3.85·3.2). Thus, the q value of 1,155 is the same for all percentages of garbage.

Next, determine Δh* using Eq. 14. The α is 60° derived from geometry. Then, calculate Δh using concept Eq. 14. Table 3 shows a recapitulation of the Δh_a calculation. From the calculation results A_s is 1.35 m, U is 0.28 m/s, g is 9.81 m/s^2, A_t is 12.32 m^2, q is 1,078 m^2/s. In the bar screen used 2 units, the value of Q is 3.45 m^3/s. Then the calculation of F_0 and ξ is carried out before the analysis of Δh_b. using Eq. 15.

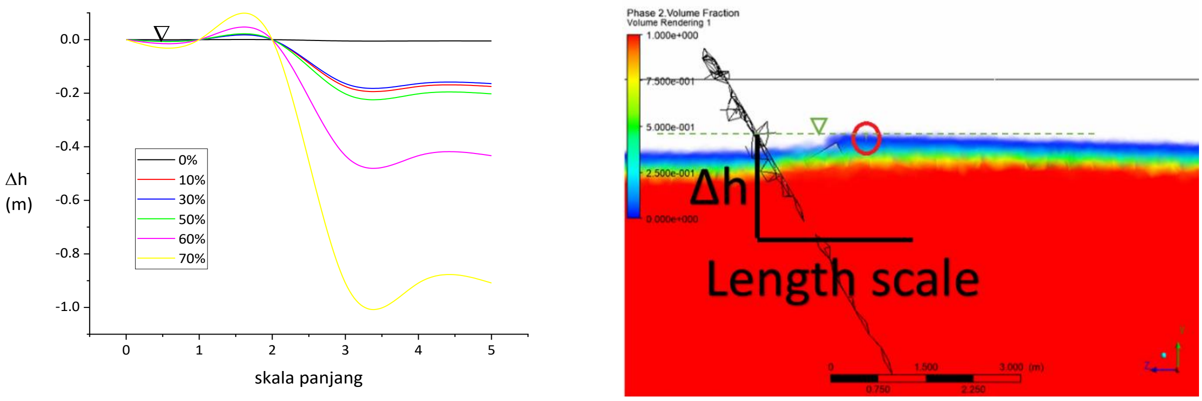
Table 3
Calculation of Δh

X	Ab (m^2)	B	Δh*	Δh_a (m)	Δh_b (m)
0	0	0.11	0.71	0.00284	0.00246
10%	1.232	0.21	2.11	0.00845	0.0082
20%	2.464	0.31	4.07	0.0163	0.0168
30%	3.696	0.41	6.52	0.0261	0.0283
40%	4.928	0.51	9.41	0.0376	0.0424
50%	6.16	0.61	12.72	0.051	0.059

From Table 3, the calculation deviation Ref. [24] against Ref. [25] is 0.003 m (≈ 0.3 cm). Thus, the equation of the analysis approach Δh_a is verified. Therefore, the Δh_a calculation method is able for the CFD data.

3.4 Discussion

Figure 6 is a visualization of Δh that occurs with a condition of system 0 to 70% of waste. Figure 6-a get by the empirical equation Figure 4-b. From Figure 6, per50% garbage has a Δh of 0.3 m; this certainly does not significantly affect the water level in downstream conditions. Based on Table 3, the maximum recommended threshold of garbage for this system is 30% of the water level upstream since the available water discharge in the intake mouth after filtration is 5.04 m^3/s (Figure 4-a).



(a) (b)

Fig. 6. Estimation of Δh for garbage 0 – 70%: (a) Δh prediction of CFD results; and (b) Visualization of Δh on the condition of the percentage of garbage 50%

Then, using the data from Table 2, Δh_a was calculated to predict the conditions of the high tide (h_0 = 4.5 m), normal (h_0 = 4 m), and ebb (h_0 = 3 m). The pattern of Q and U adapts the CFD results in Figure 4-a. Q of 10.622 m^3/s, h_0 of 4 m, w of 12 m, then it is known that the instantaneous water velocity after inlet is 0.22 m/s, and the velocity immediately after inlet is assumed to be the same in tidal, normal, and receding conditions. Hence Q_{ups} and$_{downs}$ Q is known. Then, it is assumed that the water velocity (U) in front of the screen bar *is* the same for all conditions (tides, ebbs, and normals). Table 4 shows the Δh estimate's resulting [4] calculations with CFD result data.

Table 4
Estimated calculation of Δh tide, low tide, and normal conditions

Variable	h_0	Garbage (X) (%)					
	(m)	0	10	20	30	40	50
h_1 (m)	4.5	4.50	4.12	3.73	3.35	2.96	2.58
	4	4	3.615	3.23	2.845	2.46	2.075
	3	3	2.615	2.23	1.845	1.46	1.075
A_s (m^2)	4.5	1.575					
	4	1.4					
	3	1.05					
A_b (m^2)	4.5						
	4	0	1.232	2.464	3.696	4.928	6.16
	3						
A_t (m^2)	4.5	14.4					
	4	12.8					
	3	9.6					
B	4.5	0.1094	0.1949	0.2805	0.3660	0.4516	0.5372
	4	0.1094	0.2056	0.3019	0.3981	0.4944	0.5906
	3	0.1094	0.2377	0.3660	0.4944	0.6227	0.7510
Q (m^3/s)	4.5	11.949	8.260	6.379	5.471	4.890	4.470
	4	**10.622**	**7.344**	**5.893**	**5.044**	**4.442**	**3.975**
	3	7.966	5.507	4.252	3.647	3.260	2.980
U (m/s)	4.5						
	4	**0.650**	**0.603**	**0.599**	**0.598**	**0.596**	**0.596**
	3						
q (m^2/s)	4.5	3.734	2.581	1.993	1.710	1.528	1.397
	4	3.319	2.295	1.842	1.576	1.388	1.242
	3	2.489	1.721	1.329	1.140	1.019	0.931
Δh*	4.5	0.603	1.469	2.470	3.658	5.000	6.480
	4	0.577	1.538	2.714	4.087	5.618	7.277
	3	0.519	1.764	3.325	5.216	7.384	9.794
Δh	4.5	0.0130	0.0272	0.0452	0.0666	0.0907	0.1172
	4	0.0112	0.0327	0.0609	0.0949	0.1339	0.1771
	3	0.0124	0.0285	0.0497	0.0744	0.1019	0.1316

Figure 7 shows the estimation of the calculation of Δh and Q against the percentage of garbage. The estimated tolerance used is 25%, where this tolerance by a study [5]. The safe zone determines to review of the Q available in the channel after the water passes through the bar screen. From Figure 7, the tide condition ($4.5h_0$) of receiving waste is 20%, $4h_0$ is 15%, and $3h_0$ is 8%; all conditions have a discharge (Q) of 4.5 m^3/s. Figure 8 to predict the relationship h_0 to percentage garbage allowed for bar screen system. Figure 8 estimates the relation of percentage garbage to h_0 that is licensed. The relationship of X to h_0 is exponential. Figure 8 is formed from the drinking threshold (tolerance -25%) in Figure 7.

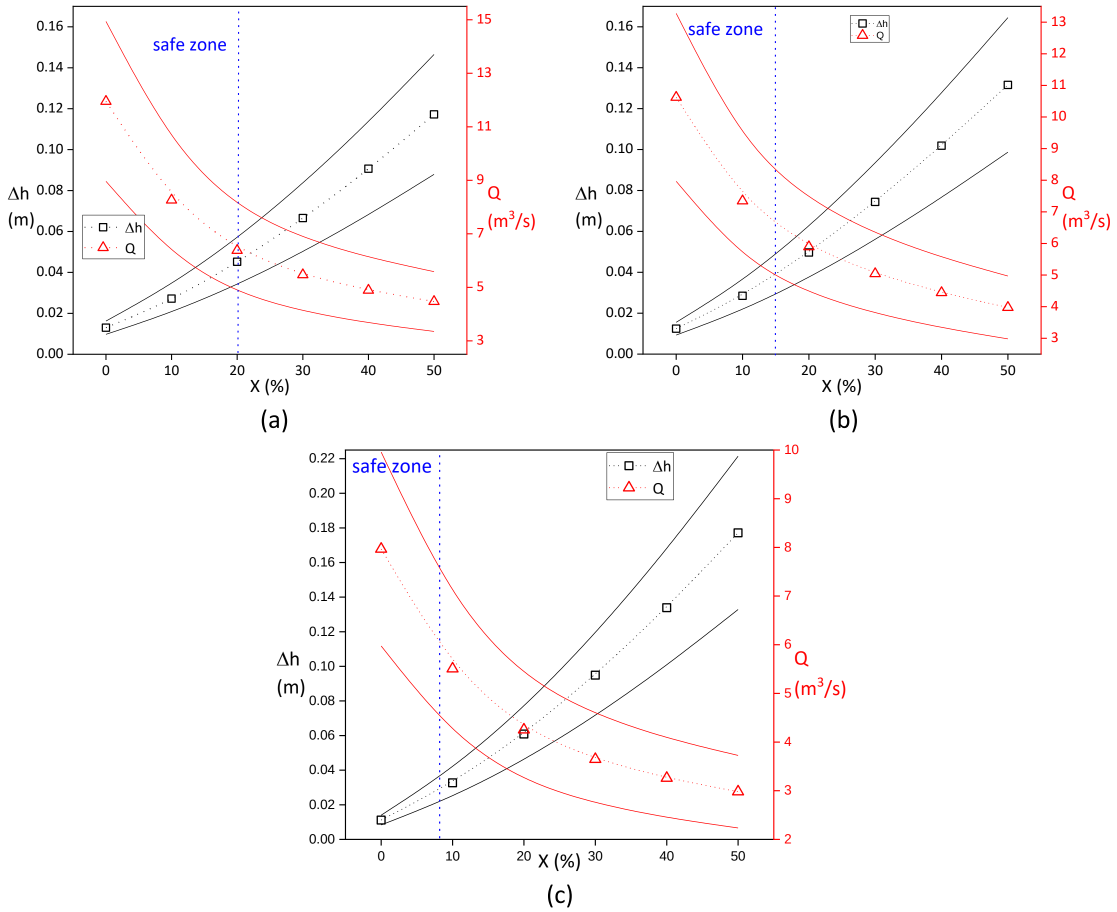


Fig. 7. Estimation of Δh and Q at garbage 0 – 70% with a tolerance of 25% (a) h_0: 4.5 m (b) h_0: 4 m (c) h_0: 3 m

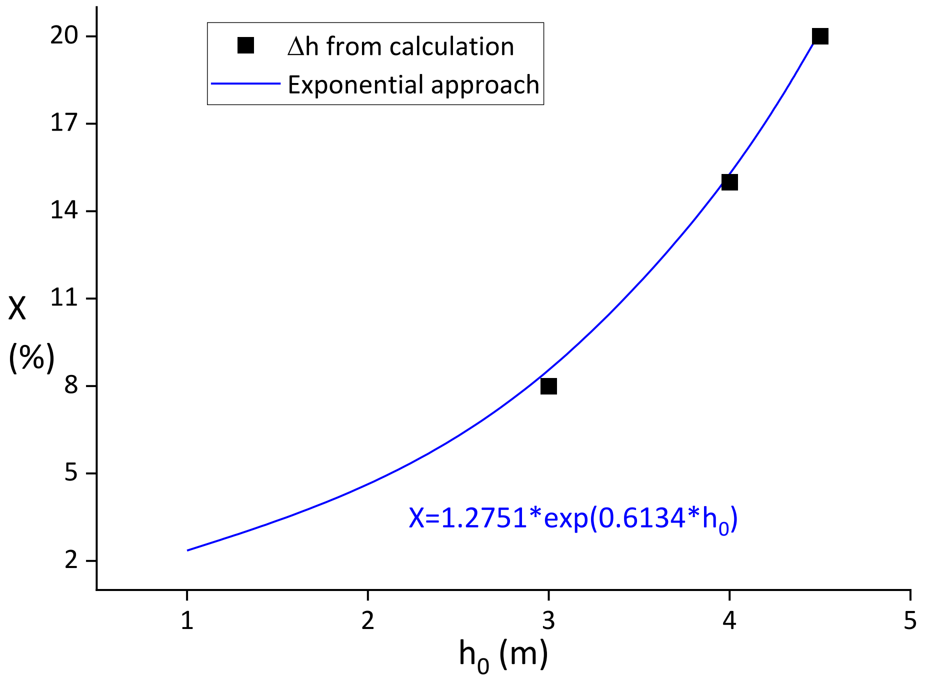


Fig. 8. Permissible garbage percentage relation to Δh

Thus, from the CFDs and mathematical analytics results, the bar screen is to be used as a rational Δh (head losses). Δh is directly proportional to the water velocity and the channel's width. So, the wider the channel and the lower the velocity, this is advantageous for Δh. In addition, the important flow dynamics phenomena besides Δh is Q. This is because, for the heat exchanger system, this new bar screen system aims to meet the needs of water discharge. From the CFD results, in the condition of 30% garbage (1.15 m waste blockade), the head elevation was insignificant, namely 0.199 m. However, this condition reduced the water discharge from the inlet side by up to 47.5%. This phenomenon shows that although Δh is still reasonable, water energy dissipation is due to the narrowing of the flow field due to the blockade of garbage.

4. Conclusions

The filtration system for heat exchanger systems, an important flow dynamics phenomenon other than Δh is Q. Based on results, CFD method is capable of predicting the Δh and Q for the filtration system in the channel (irrigation). Hence, at the condition of a waste percentage of 30% (waste blockade 1.15 m), the head elevation that occurred was insignificant, namely 0.199 m. However, this condition reduced the water discharge from the inlet to 47.5%. This phenomenon shows that although Δh is still reasonable, there is a significant dissipation of water energy due to the narrowing of the flow field due to the blockade of garbage.

Then, estimating Q in a filtration system connected to the high seas requires tidal analysis; this is because tides affect Δh and consequently affect Q. Further, Δh is directly proportional to the flow speed and the channel's width, which this similar to hypotheses of by previous studies [23, 25]. Hence, the bar screen will be used as a rational Δh (head losses). For this case, the availability of discharge after a bar screen is 4.5 m^3/s, so the filled operating conditions are 4.5h_0 with a percentage of waste of 20%, 4h_0 of 15%, and 3h_0 of 8%.

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