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LATTICE-BOLTZMANN STUDY OF CASCADE AERATOR SYSTEM

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ABSTRACT: *This paper investigates the three-dimensional (3D) simulation of Cascade aerator system using Lattice Boltzmann simulation. Cascade aerator system can be applied in the riverbank and water treatment systems. The cascade aerator plays an important role in this case due to the aeration phenomena that can help to filter the water by increasing the amount of oxygen in the water. This study focused on the water flow pattern and the velocity from the Cascade aerator system. CAD models of cascade aerator are prepared for simulation-using LBM based solver. Based on the findings, it was shown that LBM simulation could effectively simulate the velocity distribution. Additionally, it was also found that velocity of the water plays a significant influence on the aeration efficiency. The Grain size of the obtained NPs is found to be increased with laser fluence and decreased with number of laser pulses.*

Keywords: Three-dimensional (3D), cascade aerator, Lattice Boltzmann (LBM), riverbank, pattern, velocity and aeration efficiency.

1. INTRODUCTION

River bank can be defined as the land alongside the edge of the river. Unstable riverbank is frequently susceptible to rapid erosion. Many techniques are developed and applied to the river bank such as stepped spillways, stacked rock rolls, stacked soil cells and others in order to stabilize the river bank and improve the flow in river bank.

Stepped spillway has been used for more than 3500 years. Stepped spillway is the modification on the configuration for the spillway. The steps are constructed on the spillways. The stepped spillway is a hydraulic structure that increases the rate of energy dissipation in the stepped spillway. Thus, it can greatly reduce the need for an energy dissipater at the toe of the spillway. Stepped spillway can be applied to river training, overtopping protection of embankments, dam spillways, town supply channel and others due the low maintenance cost of the spillways and the development in hydraulic jump stilling basins. Figure 1 shows the diagram of spillway and Figure 2 shows the diagram of stepped spillway.

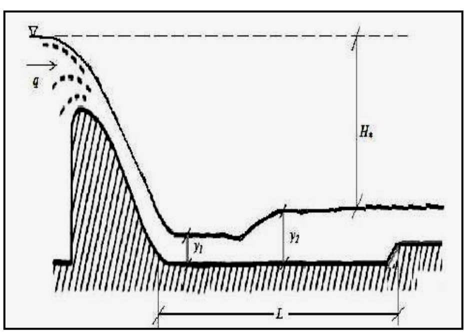


Fig (1) Spillway [1]

The skimming flow is emphasized in this project. There is two flow region in the skimming flow: non-aerated flow region and aerated flow region. The inception point is the position where the flow bulking first occurred. The upstream of the inception point is known as non-aerated flow region. Non- aerated flow region is the flow region that contains water only with a free surface. The downstream of the inception point is known as aerated flow region. The flow in this region consists the water and air bubble. Figure 3 shows

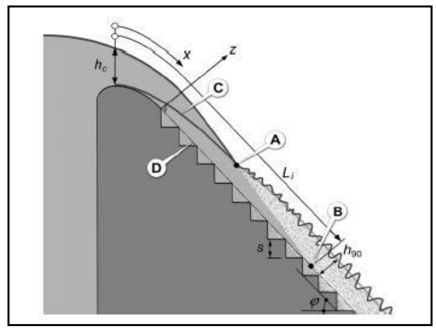


Fig (2) Stepped Spillway [2]

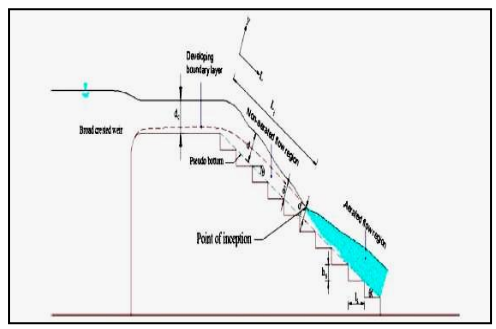


Fig (3) Non-aerated and aerated flow region in skimming flow. [3]

the non-aerated and aerated flow region in skimming flow.

Aeration is the process that is often used by many factories and treatment plant in order to remove the constituents in water such as dissolved gas and oxidised dissolved metals and important to provide DO for aerobics organisms in BOD removal and nitrification [10]. According to [10], aeration is defined as using atmospheric air as the oxygen sources and oxygenation happened, this method are important process in water and wastewater treatment to tranfers oxygen from gases to the liquid [11,12] The turbulence of aeration process will cause the scrubbing process that will help to remove the dissolved gases from the water. Subsequently, the dissolved gas will escape into the surrounding air. The efficiency of the aeration is influenced by the amount of the surface contact between air and water. The size of the water drop will also affect the efficiency of the aeration.

Iron and manganese minerals can be usually founded in the soil and they will be dissolved into the groundwater. The water will turn to dark brown colour due to the presence of iron and manganese. For this reason, the water is not suitable to be consumed by human. The aeration process can help to filter this water thereby increasing the quality of the water until it is safe for consumption. In this project, the function of the stepped spillway is same as the cascade aerator. Given the similarity between both problems, the stepped spillway is used to generally investigate the aeration process in this project. Figure 4 shows the process of stepped spillway setup.

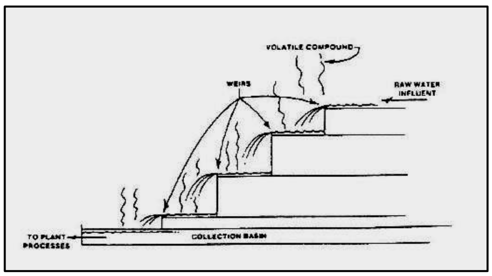


Fig (4) Process of stepped spillway/cascade aerator [4]

In the laboratory experiment, different configurations of stepped spillway are built. The 3mm thickness of Perspex is selected in this project. The Perspex is cut to certain dimension based on the configuration of the stepped spillway. Then, the Perspex plates are connected in order to build the stepped spillway. The model of the stepped spillway is shown in the Figure 5. After the stepped spillway is built, the experiment will be carried out. Firstly, the water is poured into the water tank. Then, the water will flow down the stepped spillway. The velocity and pressure on the barrier of the step edges located in the non-aerated and aerated flow region are determined in order to investigate the aeration. Besides, the flow of the stepped spillway is also observed.

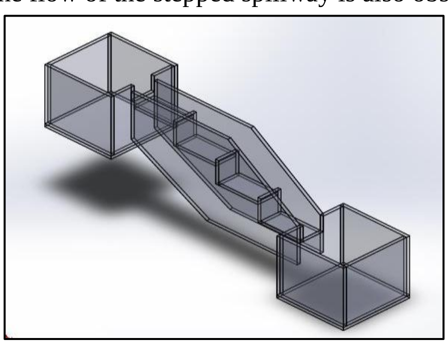


Fig (5) Schematic diagram of stepped spillway

The Lattice Boltzmann Method (LBM) based solver is selected to simulate the flow in the stepped spillway. The LBM solver has been found effective for simulation of fluid with high accuracy on the computed solution [5,6]. Afterwards, the Paraview software is used to post-process the results and then analyzed.

2. GOVERNING EQUATIONS

2.1 Lattice-Boltzmann Formulation

The D3Q19 model is selected in this simulation. There are 19 velocity vectors in this model.

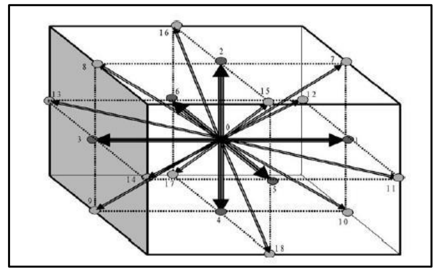


Fig (6) Lattice arrangement for D3Q19. [7]

Lattice Boltzmann Method, LBM is a computational simulation method used for simulation of fluid flow [5]. LBM also is a simulation technique, which use the distribution function to replace tagging each particle as in molecular dynamic simulations. The Boltzmann transport equation is applied in this simulation. Firstly, the statistical description is represented by the distribution function, $f\ (r, c, t)$. This distribution function can determine the number of the molecules with particular velocity between c and $c + dc$ within a particular range between r and $r + dr$ at a given instant of time (t). If the collision, Ω is applied to the system, the distribution equation become:

$$f(r + cdt, c + Fdt, t + dt) - f\ (r, c, t) = \Omega[f\ (r, c, t)] \qquad (5)$$

If there is no any external force is applied to the system, the Boltzmann transport equation can be rewritten as:

$$\frac{\partial y}{\partial x} + c.\nabla f = \Omega \qquad (6)$$

2.2 The BGKW Approximation

However, the collision term is very complicated thus it is difficult to solve the Boltzmann transport equation. The outcome of two body collisions is not likely to influence significantly. Therefore, Bhatnagar, Gross and Krook (BGK) introduce a simplified model for collision operator in 1954 in order to solve it.

$$\Omega = \omega(f^{eq} - f) = \frac{1}{\tau}(f^{eq} - f) \qquad (7)$$

The coefficient ω is called the collision frequency, a Maxwell-Boltzmann distribution function and τ is called relaxation factor. Besides, f^{eq} is the local equilibrium distribution function.

The discretized Boltzmann equation along specific can be written as:

$$\frac{\partial f_i}{\partial t} + c_i.\nabla f_i = \frac{1}{\tau}(f_i^{eq} - f_i \qquad (8)$$

The right-hand side of the equation is the advection (streaming) whereas the left-hand side term is the collision process. The above equation is the working horse of the lattice Boltzmann method. Besides, it can replace the Navier–Stokes equation in CFD simulations. Thus, it is possible to derive Navier–Stokes equation from Boltzmann equation.

After the equation (4) is discretized,

$$f_i(x + e_i\Delta t, t) = f(x,t) + \frac{\Delta t}{\tau}(f_i^{eq}(x,t) - f_i(x,t)) \quad (9)$$

It also known as collision step where are fluid density and macroscopic velocity can be obtained from the moment of the distribution function as below:

$$\rho = \sum_i f_i^{eq} \quad (10)$$

$$u = \frac{1}{\rho}\sum_i f_i^{eq} c_i \quad (11)$$

3. EQUILIBRIUM DISTRIBUTION FUNCTION

The equilibrium distribution function can be written as:

$$f^{eq}(\rho, u) = \rho w\left[1 + \frac{1}{c_s^2}(c.u) + \frac{1}{2c_s^2}(c.u)^2 - \frac{1}{2c_s^2}(u.u)\right] \quad (12)$$

The weight functions for D3Q19 are:

i) $w_0 = \frac{1}{3}$

ii) $w_{1-6} = \frac{1}{18}$

iii) $w_{7-18} = \frac{1}{36}$

4. STREAMING STEP

The solution domain in the LBM needs to be divided into lattices. The factitious particles reside in each lattice node. Some of these particles will move along a specified direction to the neighbouring nodes in accordance with the velocity set.

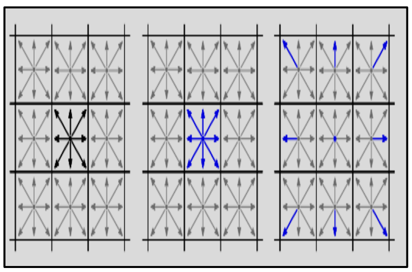


Fig (7) Collision-Propagate scheme for the D2Q9 model. [8]

*Black colour: Pre- collision values for populations

*Blue: Represent the post-collision status

5. BOUNDARY CONDITION

Figure 8 shows the boundary conditions of the cascade aerator system. Periodic boundary condition is set at the start and the end of the simulation to simulate continuous flow of water. Additionally, the bounce back boundary condition are set at the barrier of stepped spillway to simulate wall boundary.

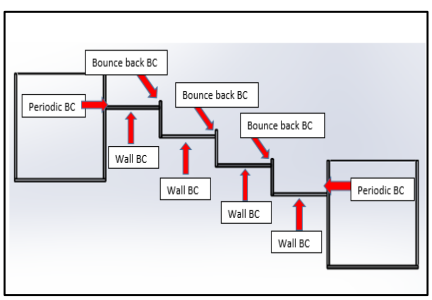


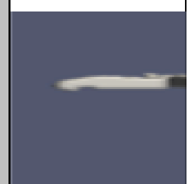
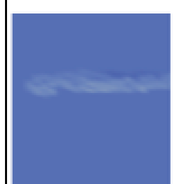
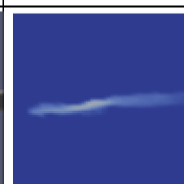
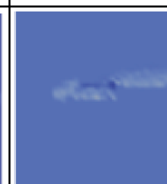
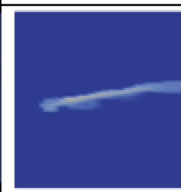
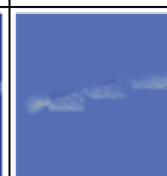
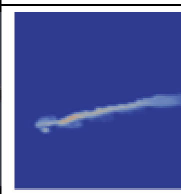
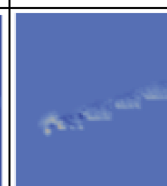
Fig (8) Periodic Boundary Condition Diagram

6. RESULTS AND DISCUSSIONS

Water Flow Pattern, Velocity And Pressure Profile

Based on the Table 1, the water flow pattern, velocity and pressure profile for four difference steps of the cascade aerator are computed. It was shown that the velocity of the main flow of the water over the stepped spillway and the velocity of the water that is located at the steps are increased over stepped spillways. The velocity from the inlet of the Cascade aerator is larger than the velocity of the water that is located at the steps. This is due to the water that is located at the steps has a greater flow resistance than mainstream flow. The maximum velocity of the mainstream water flow was found to be 3.51 m/s. It was also founds that the air is trapped in the 4th proving that the aeration phenomena are mainly formed in the 4th step. The aeration is concluded to happen at the 4th step of the stepped spillway.

Table (1) Water flow pattern, velocity and pressure profile.

Step	Flow Pattern	Velocity	Pressure
1.			
2.			
3.			
4.			

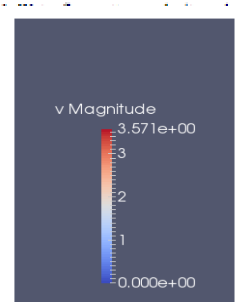


Fig (9) Water flow pattern of velocity

7. CONCLUSIONS

In this project, a stepped spillway system is simulated to investigate the water flow pattern, velocity and pressure profile of the cascade aerator system using LBM based code. The main flow velocity was found to be larger than the velocity at the steps. Moreover, the findings also show that the air is trapped at the 4th step and aeration is mainly formed in this 4th step. In this project, it was shown that the velocity of the water would influence the energy dissipitation rate per unit width and the aeration efficiency for the stepped spillway. This is the main reason the higher accumulation of aeration efficiency at the 4th step of the stepped spillway. In theory, the dissolved oxygen (air trapped) is an indicator of the degree of contamination of water because the lower the dissolved oxygen, the more polluted the water [9].

8. ACKNOWLEDGMENT

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9. REFERANCE

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