The Use of Computation Fluids Dynamics to Select Outlet System Configuration in Biosand Filters

A. C. Berbert*, R. A. de Almeida*, R. V. de P. Rezende*and S. R. Lautenschlager*

* Department of Civil Engineering – Graduate Program of Urban Engineer State University of Maringa - Brazil – (E-mail: allanberbert@gmail.com; regiani_al@hotmail.com; rezendervp@gmail.com; srlager@uem.br)

Abstract
The biosand filter is considered the one of the most sustainable type of point-of-use (POU) water treatment technology. This work aimed, through computational fluid dynamics, simulate different configuration of inlet collection system. This paper presents a comparison of four different outlets for the filtrate water in Biosand Filter with the follow design, PEU/UEM, CAWST version 10 and HydrAid. Based on the results, we can conclude that the ring water outlet is the better choice between both design.
Keywords
Biosand filter; computational fluid dynamics; outlet system

INTRODUCTION
The point-of use technologies of water treatment are used to reduce the number of people without access to safe drinking water in rural and urban areas (Kennedy *et al*, 2012). Sobsey *et al* (2008) showed a comparison between five water treatment methods. The method considered more sustainable was the BioSand filter (BSF), it consists of a slow sand filter with a biological layer formed in the top of process (Elliot *et al*, 2006).

The BioSand filter is a residential adaptation of slow sand filter in small-scale, and frequently operates intermittently. It is estimated that more than 300,000 bio-sand filters, with different designs, have been installed in over 69 countries by June 2011 (CAWST, 2012). Three layers are used to fill out: filter layer (sand with a height between 40 and 60 cm) separation layer (gravel with height of 5cm) and drainage layer (gravel with height of 5cm). Over the granular filter layers there is a permanent water layer of five centimeters to ensure aerobic conditions (Young-Rojanschi and Madramootoo, 2014).

Although, there are some research about BSF hydrodynamics there aren’t nothing about dealing with outlet system. Therefore, this research aimed to simulate the hydrodynamics of outlet.

MATHEMATICAL MODEL
For all models of this work was adopted the following hypotheses: monophasic and 3D flow; Newtonian fluid; steady state and isothermal.

Conservation of Mass
This principle indicates that in a given volume control the mass that enters must be the same mass exiting coupled with mass accumulated in the system. That is,

$$\frac{\partial\left(\rho v_1\right)}{x}+\frac{\partial\left(\rho v_2\right)}{y}+\frac{\partial\left(\rho v_3\right)}{z}=0$$

where v_i are the velocity components of the fluid, x, y, z are the spacial components and ρ is the fluid density

Conservation of Linear Momentum
Applying the Newton’s Second Law in a control volume (CV), it is has the difference between the momentum in and out of the CV more the resultant of the forces acting on the system, resulting in the accumulated momentum in it.

$$v_1\frac{\partial(\rho v_1)}{\partial x}+v_2\frac{\partial(\rho v_1)}{\partial y}+v_3\frac{\partial(\rho v_1)}{\partial z}=-\frac{\partial P}{\partial x}+\rho g_x+\mu\left(\frac{\partial^2 v_1}{\partial x^2}+\frac{\partial^2 v_1}{\partial y^2}+\frac{\partial^2 v_1}{\partial z^2}\right)$$

$$v_1\frac{\partial(\rho v_2)}{\partial x}+v_2\frac{\partial(\rho v_2)}{\partial y}+v_3\frac{\partial(\rho v_2)}{\partial z}=-\frac{\partial P}{\partial x}+\rho g_y+\mu\left(\frac{\partial^2 v_2}{\partial x^2}+\frac{\partial^2 v_2}{\partial y^2}+\frac{\partial^2 v_2}{\partial z^2}\right)$$

$$v_1\frac{\partial(\rho v_3)}{\partial x}+v_2\frac{\partial(\rho v_3)}{\partial y}+v_3\frac{\partial(\rho v_3)}{\partial z}=-\frac{\partial P}{\partial x}+\rho g_z+\mu\left(\frac{\partial^2 v_3}{\partial x^2}+\frac{\partial^2 v_3}{\partial y^2}+\frac{\partial^2 v_3}{\partial z^2}\right)$$

where ∂x is the partial differential of control volume’s length, ∂P is the partial differential of pressure and ∂F is the partial differential of the shear force.

Boundary Conditions

The boundary conditions used in this work are presented in Table 1.

MATERIAL AND METHODS

The software ANSYS-CFX was used to simulate the flow in BioSand. It use the Finite Volume Method based on elements for solution of the conservation equations. The solution was performed in series with four processors. The criteria of stopping simulation was residual mean square (RMS) value less than 10^{-4} and conservation flow with maximum difference of 5%.

Outlet design models

Four outlet models were considered for the PEU/UEM filter: center (figure 1-A), side (figure 1-B), bottom (figure 1-C) and ring with interface down (figure 1-D). The option that shown better results was simulate with the other two type of BSF. Six regions were defined in the model domain: water (WA), sand (SA), corser sand (CS), gravel (GR), internal pipe (INP) and external pipe to the filter (OUP) and the last two domain had the mesh refinement due to be smaller than the others, as illustrated in figure 2. For the four cases the domain was discretized with a mesh of about 500,000 hexahedral and non-uniform elements.

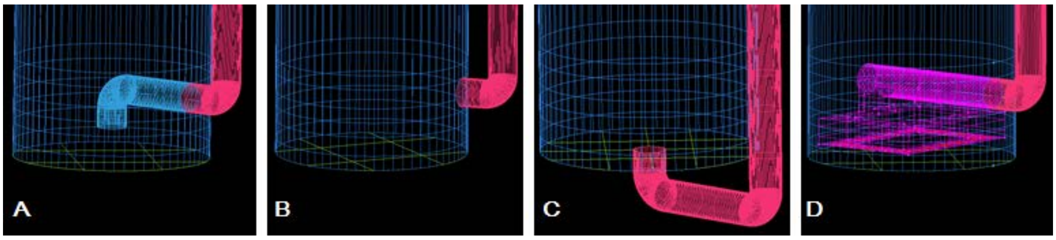

Figure 1. Outlet configuration (a) center, (b) side, (c) bottom, (d) ring.

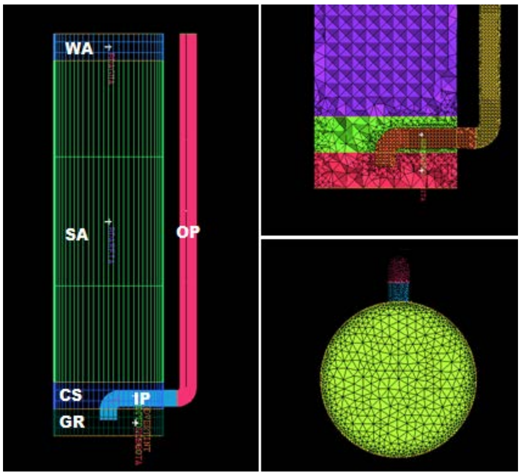

Figure 2. Mesh of filter PEU/UEM with outlet model central

Table 1. Parameters utilized to set up the models on software

PARAMETERS	PEU/UEM	CAWST	HYDRAID
Reference Pressure	1 [atm]	1 [atm]	1 [atm]
Static Relative Pressure	0 [Pa]	0 [Pa]	0 [Pa]
Fluid's velocity inlet	3.68e-6 [$m\ s^{-1}$]	3.49e-6 [$m\ s^{-1}$]	2.59e-6 [$m\ s^{-1}$]
Inlet Area	0,031 [m^2]	0,060 [m^2]	0,113 [m^2]
Outlet Pressure	0 [Pa]	0 [Pa]	0 [Pa]
Condition of Wall	No slip	No slip	No slip
Height of constant head	5 [cm]	5 [cm]	5 [cm]
Height of sand	60 [cm]	54.5 [cm]	43 [cm]
Porosity of sand	0.40	0.40	0.40
Permeability of sand	9.0e-5[mm^2]	9.0e-5[mm^2]	9.0e-5[mm^2]
Height of corser sand	5 [cm]	5 [cm]	5 [cm]
Porosity of corser sand	0.60	0.60	0.60
Perm. of corser sand	1.0e-2[mm^2]	1.0e-2[mm^2]	1.0e-2[mm^2]
Height of gravel	5 [cm]	5 [cm]	6 [cm]
Porosity of gravel	0.70	0.70	0.70
Permeability of gravel	0.1[mm^2]	0.1[mm^2]	0.1[mm^2]

CAWST and HydrAid models

The CAWST was modelled as described in the "BioSand Filter Construction Manual" (CAWST, 2012). The discretized model for usual outlet is shown in figure 3-A, and for the new proposed design outlet in figure 3-B. Both were discretized in a mesh of 550,000 hexahedral and non-uniform elements.

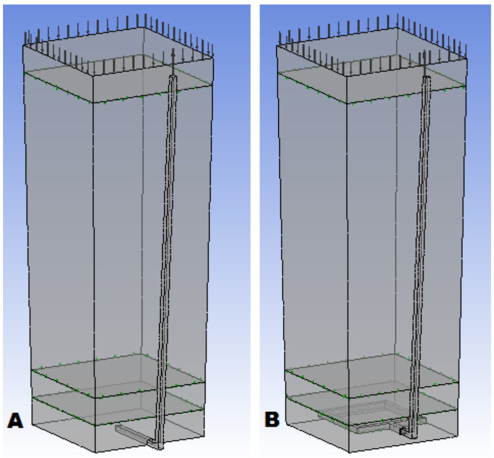

Figure 3. The discretized CAWST filter (A) usual (B) new design of outlet in ring shape.

The model HydrAid was done according to the work of Kikkawa (2008) and was discretized as showed in figure 4-A usual and figure 4-B for the new design.. Both were discretized in a mesh of 600,000 hexahedral and non-uniform elements.

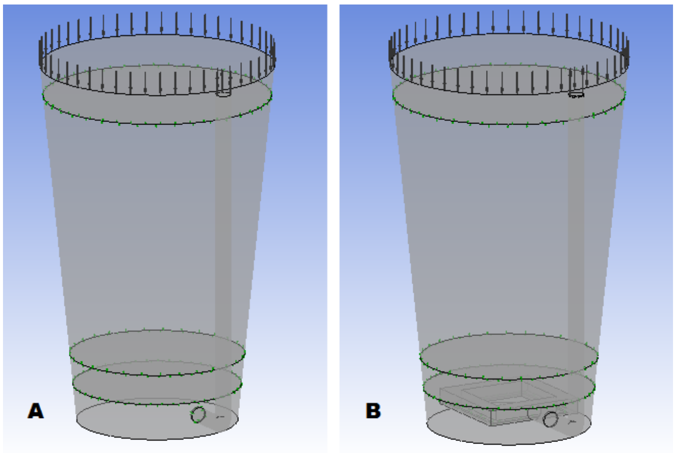

Figure 4. The discretized HydrAid filter (A) usual (B) new design of outlet in ring shape.

RESULTS

Design PEU/UEM filter

The four types of outlet were simulated with the BSF called PEU/UEM. The streamlines are shown in the figure 5-A to center outlet. The streamline shows symmetry with respect to a central axis. The streamline also approximate considerably the entire filter bottom area, which reduces dead zone. The same occurs in figure 5-D ring outlet. For side outlet, (figure 2b), there is not the same symmetry of the previous model, and the lines do not approach the filter bottom, producing dead zone in the last centimeters of the filter. The bottom outlet, figure 2c, presents symmetry of the streamline as does the center outlet. Upon approaching the exit, the flow is concentrated on an inverted cone shape.

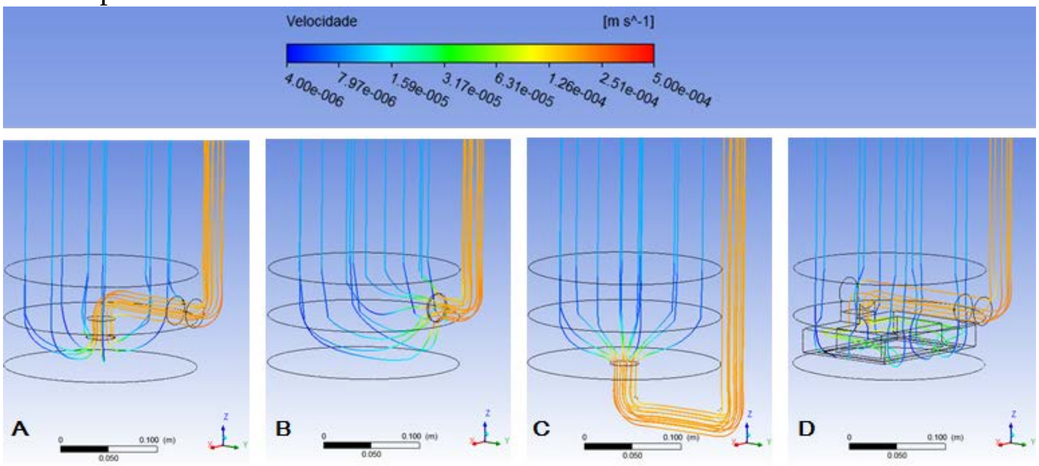

Figure 5. Streamlines to the four configuration (A) center, (B) side, (C) bottom and (D) ring

The velocity in the XZ and YZ planes are shown in figures 6 and 7, , respectively with reference to the Y axis = 0 and X = 0. The ring outlet is represented in figures 6-D and 7-D, , it is possible to see uniformity in both secctions, showing the best results. Both in center (figures 6-A and 7-A) and button outlet (figures 6-C and 7-C) has an increase in the velocity in the vicinity of the water intake. The side outlet shown in the figures 6-B and 7-B, is not uniform and also there is a side dead region. It is concluded then for the BSF PEU/UEM the best outlet design was the ring shape.

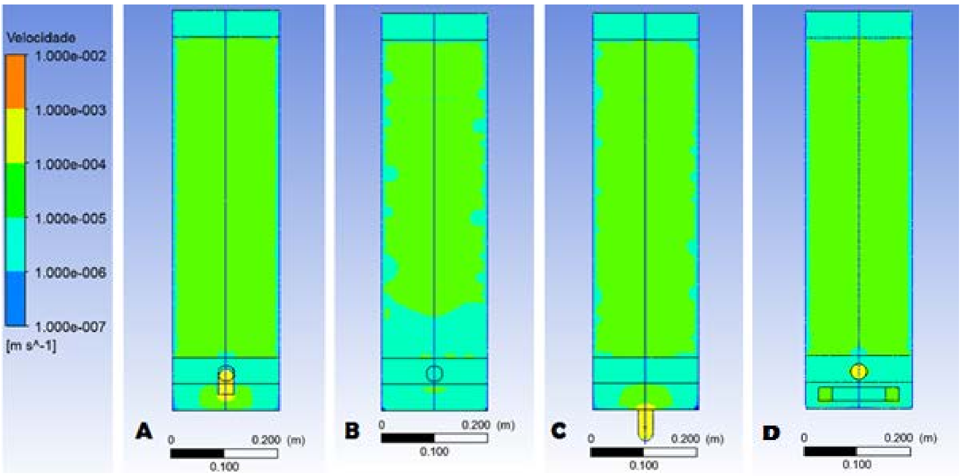

Figure 6. Velocity in plane XZ with reference to the Y axis = 0: (A) center, (B) side, (C) bottom and (D) ring shape

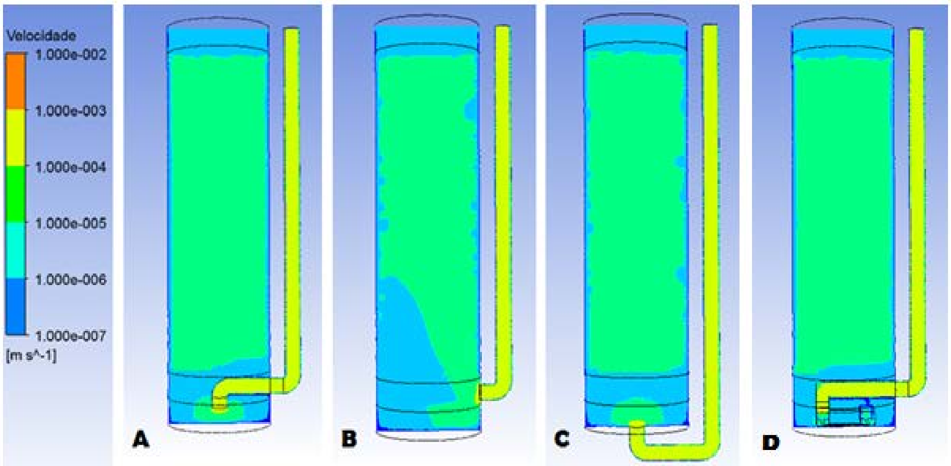

Figure 7. Velocity in plane YZ with reference to the X axis = 0: (A) center, (B) side, (C) bottom and (D) ring shape

CAWST and HydrAid models

The CAWST without ring shape outlet (figure 8-A) showed the same streamlines that looks like an inverted cone shape shown by bottom outlet for the filter PEU/UEM (Figure 5-C). The use of the ring shape outlet (figure 8-B) generated a greater symmetry than the bottom ones, and almost nothing of dead zone. The same analysis can be used to the HydrAid with ring outlet shape (figure 8-D), which performs is better than without the ring shape outlet (Figure 8-C)

Field velocity distribution at the plane located in outlet pipe is shown in figures 8-E and 8-G to CAWST and Hydraid without the ring respectively and the figures 8-F and 8-H to CAWST and Hydraid with the ring. This plane cut on the side section of the ring shape on the X axis equal to 6.5 centimeters. We can see a better distribution in the velocity in the collector.

It is possible to see that the outlet ring shape sections (figures 8-J and 8-L) are more homogeneous and uniform, without zones that have small speed and large distant from the outlet, as it happens in Figures 8-I e 8-K.

The same effect is observed to the vectors. In the figures 8-N and 8-P the vectors are next of the outlet ring shape, as in Figure 8-O, the slow section is on the opposite side of outlet.

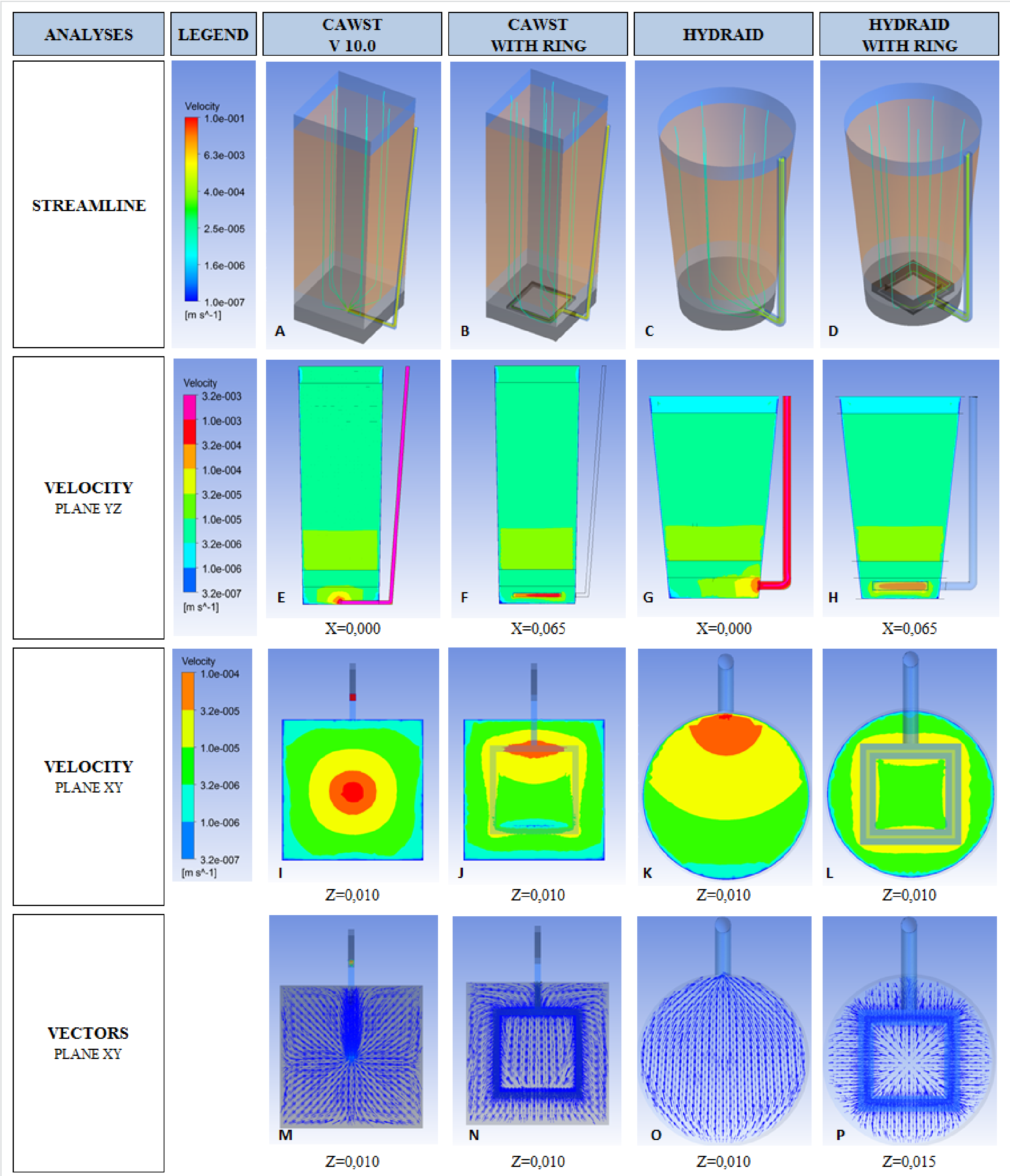

Figure 8. Results of the CAWST and HydrAid filters. Streamline of: (A) original CAWST filter; (B) CAWST filter with ring shape outlet; (C) original HydrAid filter; (D) HydrAid filter with ring shape outlet. Velocity in plane YZ of: (E) original CAWST filter; (F) CAWST filter with ring shape outlet; (G) original HydrAid filter; (H) HydrAid filter with ring shape outlet. Velocity in plane XY with Z=1 cm: (I) original CAWST filter; (J) CAWST filter with ring shape outlet; (K) original HydrAid filter; (L) HydrAid filter with ring shape outlet. Vector in plane XY with Z=1cm: (M) original CAWST filter; (N) CAWST filter with ring shape outlet; (O) original HydrAid filter; (P) HydrAid filter with ring shape outlet.

CONCLUSIONS

For the three designs PEU/UEM, CAWST and HydrAid, the best alternative to outlet was the use of ring shape with interface down, it aids in streamlines and create a better distribution of the velocity field in three directions. Besides, decreasing dead zones and increase the detention times, which will probability generates a better quality effluent. This study concludes that the outlet type ring shape generates hydrodynamic improvements in biosand filters and we recommended that the next biosand should consider this in design.

REFERENCES

CENTRE FOR AFFORDABLE WATER AND SANITATION – CAWST.2012. Biosand Filter Construction Manual. Calgary, Canada.

ELLIOTT M.A., STAUBER, C.E., KOKSAL, F., DIGIANO, F.A., SOBSEY, M.D. 2008. Reduction of E. coli, echovirus type 12 and bacteriophages in an intermittently operated householdscale slow sand filter. Water Res. Vol:42 2662p–2670p, .

KENNEDY, T. J., HERNANDEZ, E. A., MORSE, A. N., ANDERSON, T. A. 2012. Hydraulic Loading Rate Effect on Removal Rates in a BioSand Filter: A Pilot Study of Three Conditions. Water, Air, & Soil Pollution. Vol: 223, Issue 7, 4527-4537

KIKKAWA, I. 2008 Modification of a Biosand Filter in the Northern Region of Ghana. Master of Engineering in Civil and Enviromental Engineering at the Massachusetts Institute of Techonlogy.

SOBSEY, M. D., STAUBER, C.E., CASANOVA, L. M., BROWN, J. M. ELLIOT, M. A. 2008. Point of Use Household Drinking Water Filtration: A Practical, Effective Solution for Providing Sustained Access to Safe Drinking Water in the Developing World. Environmental Science & Technology. ,v. 42, n.12, 4261-4267.

YOUNG-ROJANSCHI, C., MADRAMOOTOO, C. Intermittent versus continuous operation of biosand filters. Water Res. Vol 49, 1p–10p, 2014.