OPTIMAL CONFIGURATION OF SLUDGE HOPPER IN SWIRL FLOW HYDRAULIC CLARI-FLOCCULATORS BY CFD

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ABSTRACT

Hydraulic flocculation becomes a promising approach that commonly used for water and wastewater treatment works because of less energy and maintenance costs are needed when compared with mechanical flocculation. Swirl flow hydraulic clari-flocculators can be described as reactor clarifiers without mechanical mixing. The main objective of the present study is the determination of the optimal configuration of swirl flow hydraulic clari-flocculators in terms of tapering of velocity gradient, head loss in the flocculation zone, and sediments collection in the sludge hopper. For this, the best sizing of sludge hopper and the optimum diameter aspect ratio were then determined by computational fluid dynamics method (CFD). The obtained results reveal that the optimum diameter aspect ratio ranges between 0.2-0.4 for optimal configuration of swirl flow hydraulic clari-flocculators in terms of tapering of velocity gradient, head loss in the flocculation zone, and sediments collection in the sludge hopper.

Keywords: Computational fluid dynamics (CFD), Hydraulic clari-flocculator, Sludge hopper, Swirl flow.

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1 INTRODUCTION

Hydraulic flocculation becomes a promising approach that commonly used for water and wastewater treatment works. Hydraulic flocculators need to less energy and maintenance costs when compared with mechanical flocculation. In addition, no mechanical parts are required in hydraulic flocculators (Ghawi, 2009; Crittenden et al., 2005).

Swirl flow hydraulic clari-flocculators can be depicted as reactor clarifiers without mechanical mixing. These types of clarifiers were created and investigated in the field of water treatment through hydraulic mixing in a single basin (Davailles et al., 2012; Engelhardt, 2010; El-Bassuoni et al., 2005; Chaing, 2005). On the other hand, Ayoub et al. (2013) developed two models of hydraulic clari-flocculators for chemically enhanced primary treatment of sewage (CEPT). These models were produced as modifications of the conventional primary sedimentation tank, where flocculation and sedimentation processes can be merged. Moreover, the tangential inlet facilitates swirling flow and hydraulic mixing to generate tapered velocity gradient (G-values) from its level to end of the flocculation zone (Ayoub et al., 2013; Engelhardt, 2010).

Ayoub et al. (2013) demonstrated that tapering of velocity gradient is more regular in up flow than down flow hydraulic clari-flocculator due to impact of the gravitational acceleration. Thus, they suggested up flow hydraulic clari-flocculators for CEPT of sewage. However, position of the sludge hopper over the flocculation zone enables to some extent the small sediments to escape to the bottom of the tank. Therefore, up flow hydraulic clari-flocculators need to supplementary research work to configure the perfect sizing of the sludge hopper for best treatment efficiency.

Rashed et al. (2013) implemented an experimental model of up flow hydraulic clari-flocculator to investigate the feasibility of upgrading of sewage treatment plant using approach of CEPT to accommodate excess organic and hydraulic loads. The experimental model achieves removal efficiencies of 78% of total suspended solids (TSS), 60% of 5-day biochemical oxygen demand (BOD_5), 60% of chemical oxygen demand (COD), 76% of total phosphorus (T-P), and 12% of total nitrogen (T-N). All of these results were obtained with surface loading rate range between 60-90 $m^3/m^2/d$ for CEPT versus 30-50 $m^3/m^2/d$ for conventional primary sedimentation (Rashed et al., 2013; Metcalf & Eddy, 2003).

Computational fluid dynamics (CFD) has been effectively applied in water and wastewater treatment works to simulate the interaction of solids and water with surfaces characterized by boundary conditions (Lutfy et al., 2015; Ayoub et al., 2013; Ghawi, 2009; Anderson, 1995). CFD facilitates optimal design of the various treatment processes in addition to possibility to analyze full-scale systems where controlled experiments would be complicated if not impossible to perform (Zhang, 2014; Davailles et al., 2012; Brennan et al., 2009; Bridgeman et al., 2009).

This work aims to achieve the best sizing of sludge hopper and investigate the optimum diameter of sludge hopper to diameter of the clari-flocculator ratio (diameter aspect ratio) by CFD for optimal configuration of swirl flow hydraulic clari-flocculators in terms of tapering of velocity gradient, head loss in the flocculation zone, and sediments collection in the sludge hopper.

2 METHODOLOGY

2.1 Model development of swirl flow hydraulic clari-flocculator

Figure (1) represents the components and different zones of swirl flow hydraulic clari-flocculator developed by Ayoub et al. (2013) as modification of the conventional primary sedimentation tank with the same dimensions to accommodate excess hydraulic and organic loads of wastewater. A flow direction is up flow from the tangential inlet in the flocculation zone to end of the clarification zone. The tangential inlet facilitates swirling flow and hydraulic mixing to generate tapered velocity gradient from its level to end of the flocculation zone as shown in figure (2) (Ayoub et al., 2013; Engelhardt, 2010). According to design criteria of the clarifiers, the ranges of diameter between 10-40 m as well as diameter of sludge hopper to diameter of the clari-flocculator ratio (Φ_s/Φ_t) between 0.2-0.8 were selected to be investigated in the present study.

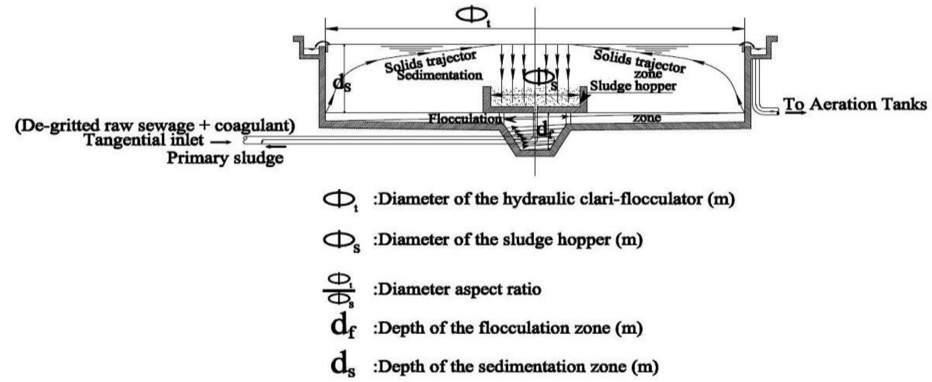


Figure 1.Swirl flow hydraulic clari-flocculator (Ayoub et al., 2013; Engelhardt, 2010)

Figure 2.Velocity vectors of swirl flow dominates in the flocculation zone

2.2 CFD software

Model development and boundary conditions were completed using meshing software Gambit 2.4 as appeared in figure (3). Numerical simulation and solving flow problems were depended on commercial CFD software Fluent 6.3 (Fluent® Inc., NH, USA). Fluent 6.3 is a finite volume code is utilized as a part of hydrodynamics and mass transfer computations.

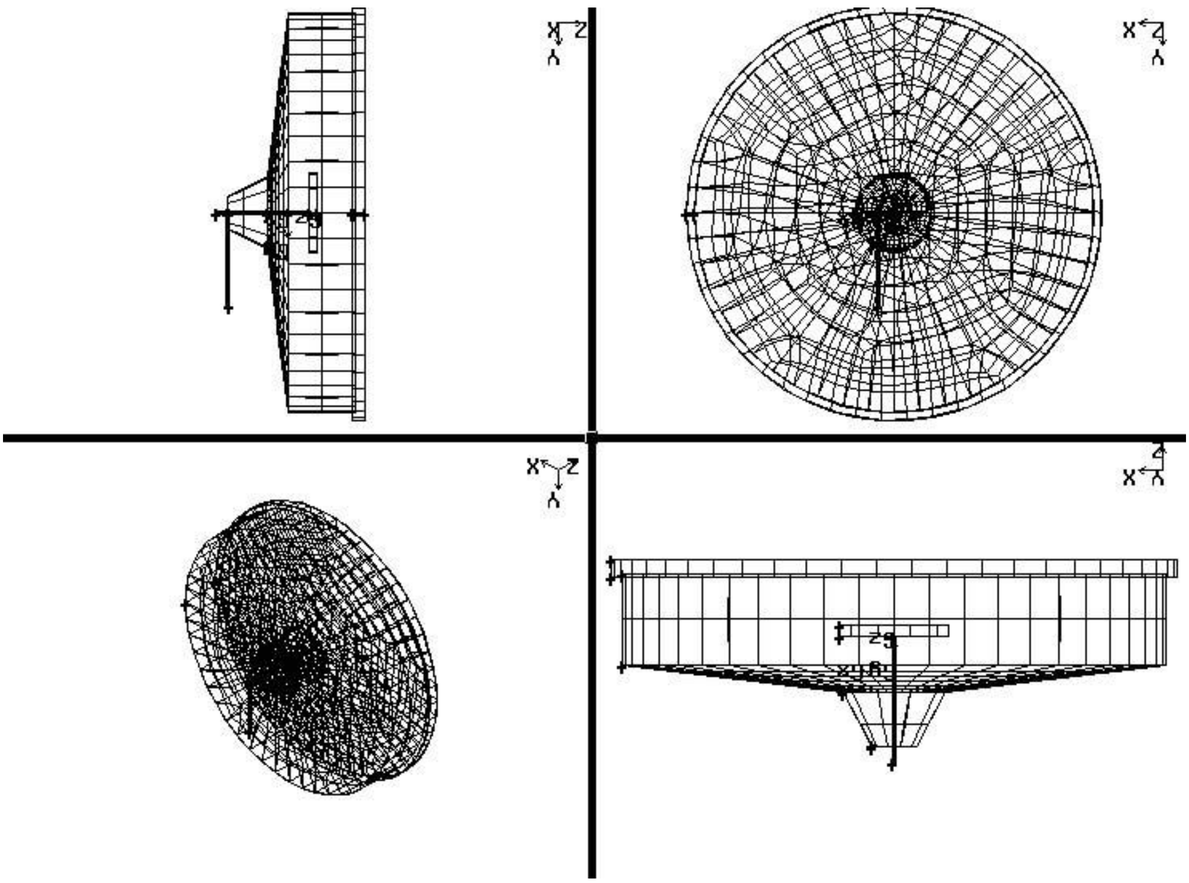


Figure 3.Meshing of swirl flow hydraulic clari-flocculator using Gambit 2.4 software in four different views

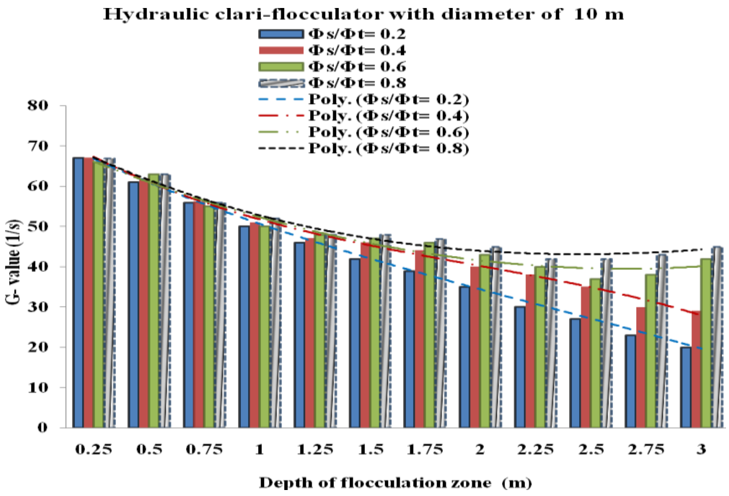
2.3 CFD modeling

The RNG k-ε model is the most appropriate model for simulation of swirl flow hydraulic clari-flocculator; it provides an option to signify the impacts of swirling by modifying the turbulence viscosity appropriately. Furthermore, RNG k-ε model is proper for low Reynold's number and near wall flows which occurs in sedimentation tanks (Ayoub et al., 2013; Bridgeman et al., 2009).

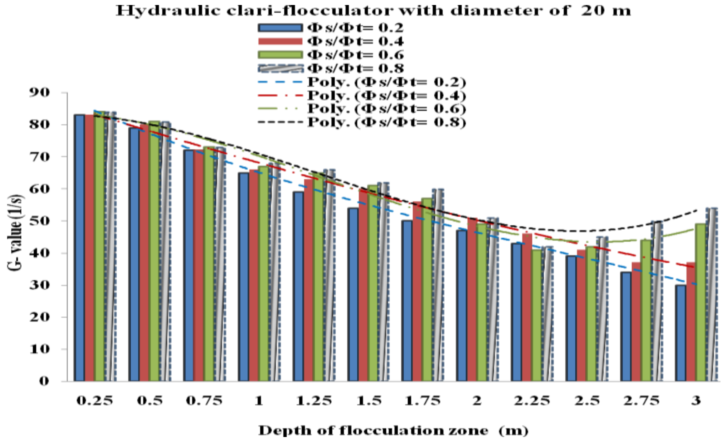
3 RESULTS AND DISCUSSION

3.1 Effect of diameter aspect ratio on tapering of velocity gradient in the flocculation zone

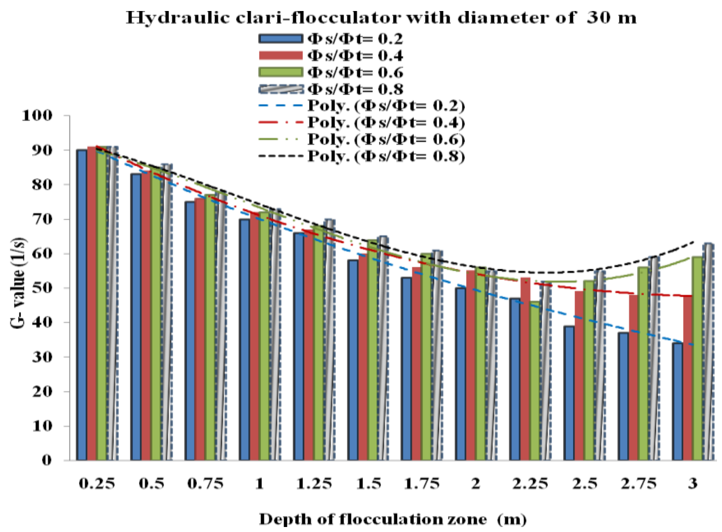
The tapering of velocity gradient (G-values) with flocculation depth resulted from CFD simulation was observed and outlined as shown in figure (4). Different sizes of the clari-flocculator that ranges between 10-40 m were investigated considering the effect of diameter of sludge hopper to diameter of the clari-flocculator ratio (diameter aspect ratio). Polynomial regression was applied for observation of tapering of G-values resulted from CFD simulation. The average G-values ranges between 50-75 s^{-1} with corresponding of clari-flocculator diameter range between 10-40 m. Moreover, it is noticed that G-values are tapered regularly through flocculation depth in case of diameter aspect ratios between 0.2-0.4 with all sizes of the clari-flocculator. However, G-values are tapered to about 70% only of the flocculation depth after that G-values ascends to the end of the flocculation zone in case of diameter aspect ratios between 0.6-0.8 with all sizes of the clari-flocculator. This could happen as a result of the sharp decline in the sectional area between flocculation and sedimentation zones due to increasing of diameter aspect ratio. The ascending of G-values adversely affects the flocculation process and treatment effectiveness. Hence, the optimum diameter aspect ratio ranges between 0.2-0.4 from viewpoint of tapering of velocity gradient.



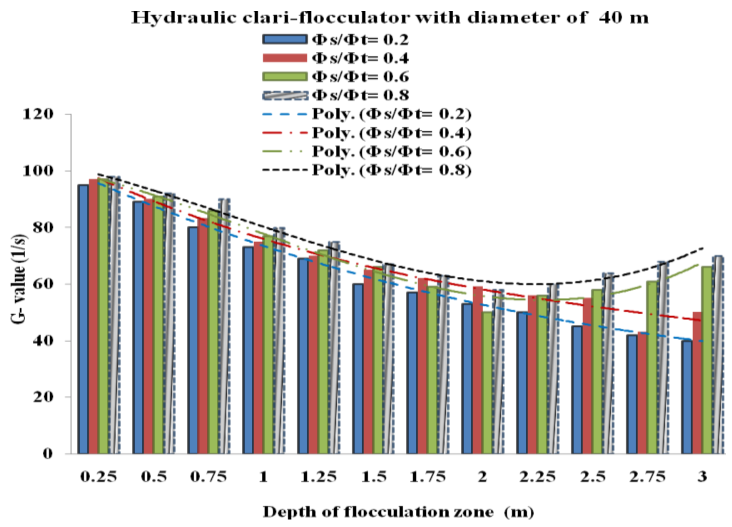
(a)



(b)



(c)

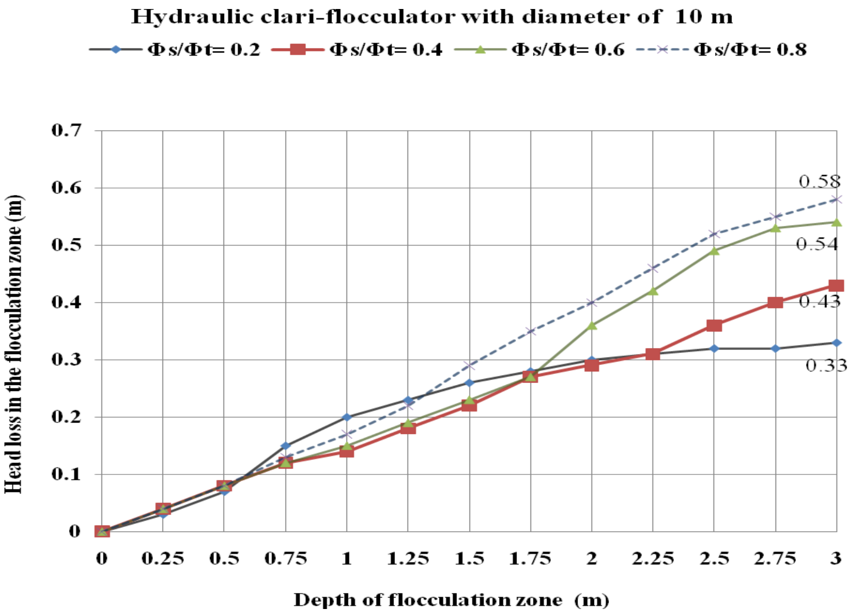


(d)

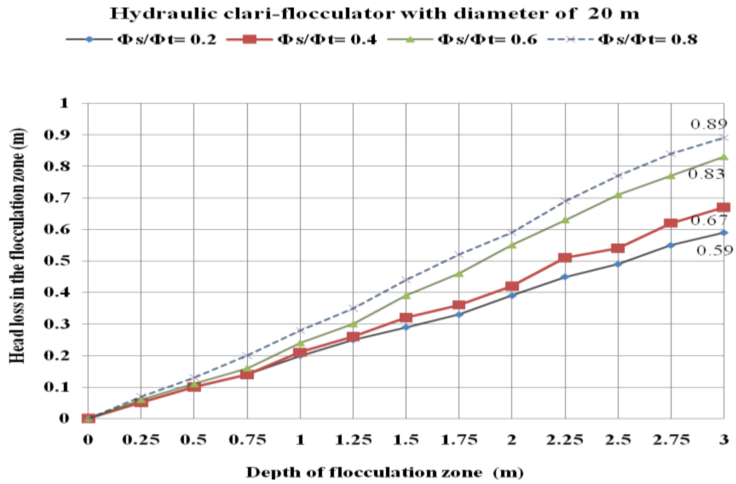
Figure 4.Tapering of velocity gradient (G-values) with flocculation depth in the different clari-flocculators with diameter of (a) 10m, (b) 20m, (c) 30m, (d) 40m

3.2 Effect of diameter aspect ratio on head loss in the flocculation zone

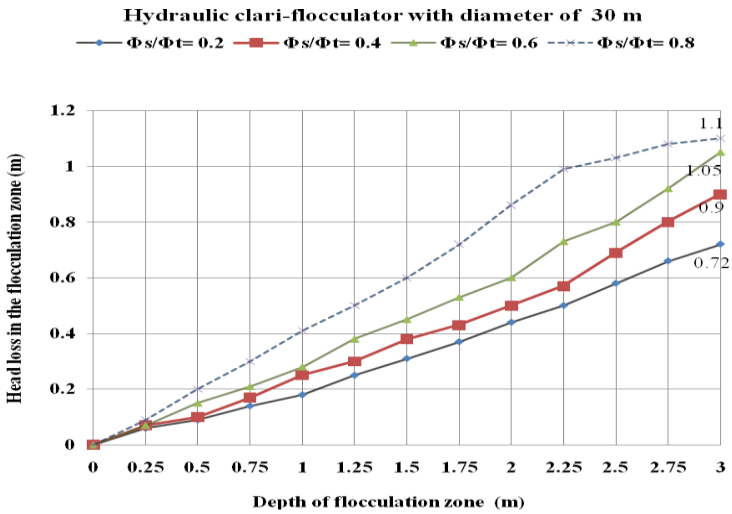
Figure (5) shows the head loss with flocculation depth resulted from CFD simulation with different sizes of the clari-flocculator that ranges between 10-40 m considering the influence of diameter of sludge hopper to diameter of the clari-flocculator ratio (diameter aspect ratio). The ascending of head loss values can be observed with different slopes corresponding to diameter aspect ratio as well as different values related to different sizes of the clari-flocculator. The average head loss values reaches to 0.47-0.98 m with corresponding of clari-flocculator diameter range between 10-40 m. Furthermore, it is noticed that rate of head loss growth is more sharpness with diameter aspect ratio between 0.6-0.8 than diameter aspect ratio between 0.2-0.4. This could happen as a result of the sharp decline in the sectional area between flocculation and sedimentation zones due to increasing of diameter aspect ratio. Therefore, the optimum diameter aspect ratio ranges between 0.2-0.4 from viewpoint of head loss increase.


Hydraulic clari-flocculator with diameter of 10 m
Φs/Φt= 0.2
Φs/Φt= 0.4
Φs/Φt= 0.6
Φs/Φt= 0.8
Head loss in the flocculation zone (m)
Depth of flocculation zone (m)
0.58
0.54
0.43
0.33

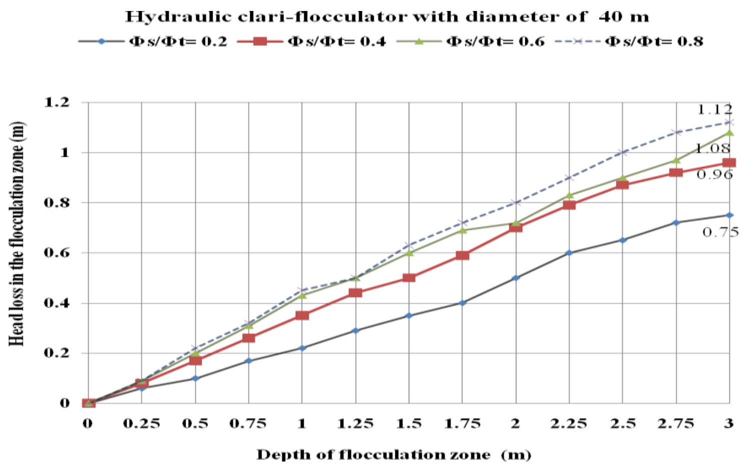
(a)


Hydraulic clari-flocculator with diameter of 20 m
Φs/Φt= 0.2
Φs/Φt= 0.4
Φs/Φt= 0.6
Φs/Φt= 0.8
Head loss in the flocculation zone (m)
Depth of flocculation zone (m)
0.89
0.83
0.67
0.59

(b)


Hydraulic clari-flocculator with diameter of 30 m
Φs/Φt= 0.2
Φs/Φt= 0.4
Φs/Φt= 0.6
Φs/Φt= 0.8
Head loss in the flocculation zone (m)
Depth of flocculation zone (m)
1.1
1.05
0.9
0.72

(c)



(d)

Figure 5.Head loss with flocculation depth in the different clari-flocculators with diameter of (a) 10m, (b) 20m, (c) 30m, (d) 40m

3.3 Effect of diameter aspect ratio on sludge accumulation in the sludge hopper

The percentage of sediments accumulation in the sludge hopper was observed by CFD simulation and outlined in figure (6) as indicated by a series of diameter aspect ratios (Φs/Φt) (i.e. 0.2,0.4,0.6,and 0.8) for different sizes of swirl flow hydraulic clari-flocculators (i.e. 10,20,30, and 40m). It can be noticed that increasing of diameter aspect ratio from 0.2 to 0.4 improves gathering of sludge, while, increasing of diameter aspect ratio from 0.6 to 0.8 contrarily influences gathering of sludge because of breaking of flocs as a result of ascending of G-values as well as narrow down the cross-sectional area between flocculation and sedimentation zones at level of sludge hopper. Therefore, the optimum diameter aspect ratio ranges between 0.2-0.4 from perspective of sediments accumulation. On the other hand, the percentage of sediments accumulation is relatively diminishes with expansion of clari-flocculator diameter. This could happen as a result of difficulty to control the hydraulic mixing with increasing of clari-flocculator diameter that adversely affects the treatment effectiveness in general.

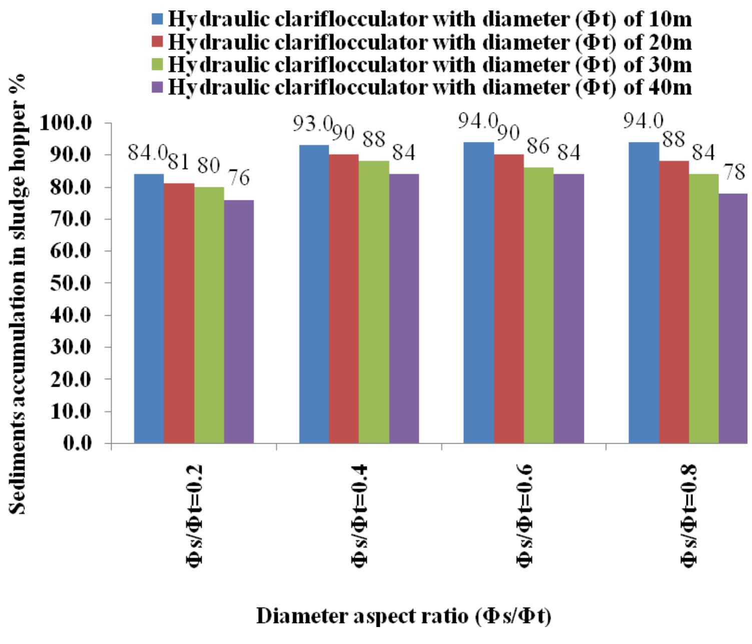


Figure 6.The percentage of sludge accumulation in the sludge hopper versus diameter aspect ratio in the different clari-flocculator sizes

4 CONCLUSIONS

The best sizing of sludge hopper and investigation of the optimum diameter aspect ratio by CFD are the main objectives of the present study for optimal configuration of swirl flow hydraulic clari-flocculators. The obtained results reveal that values of velocity gradient are tapered regularly through flocculation depth in case of diameter aspect ratios between 0.2-0.4 with all sizes of the clari-flocculator. In addition, the optimum diameter aspect ratio ranges between 0.2-0.4 from viewpoints of head loss increase as well as sediments accumulation in the sludge hopper. Therefore, the optimum diameter aspect ratio ranges between 0.2-0.4 for optimal configuration of swirl flow hydraulic clari-flocculators in terms of tapering of velocity gradient, head loss in the flocculation zone, and collection of sediments in sludge hopper.

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