A REVIEW ON THE DESIGN CRITERIA OF BIOLOGICAL AERATED FILTER FOR COD, AMMONIA AND MANGANESE REMOVAL IN DRINKING WATER TREATMENT

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ABSTRACT

The design criteria of biological aerated filter (BAF) were reviewed in order to design an effective process for organic and inorganic contaminants removal in drinking water, particularly, COD and ammonia removal. The review was mainly focused on the height and diameter dimensions for the BAF process system as well as the removal efficiency and the type of media used. In addition, the review also included the effect of biofilm growth, reactor configuration, aeration and backwash system to the BAF process in order to select the best design configuration for the BAF systems. Based on the removal efficiencies data, two correlation graphs were plotted; (a) COD removal efficiencies against the H/D ratio and (b) H/D ratio against BAF height, in order to correlate the relationship between removal efficiency and BAF dimensions; height and diameter. The determined BAF height and diameter were 1.5 m and 0.16 m respectively, operated in an upflow mode and is supported by plastic media for biofilm growth and attachment. The expected removal efficiency of COD and ammonia is to be within 80-90%.

Keywords: *Ammonia, Biological Aerated Filter, Drinking Water, Manganese*

1.0 INTRODUCTION

Nowadays, the source for drinking water was polluted by organic and inorganic contaminants such as organic contaminants: chemical oxygen demand (COD), total organic carbon (TOC), and inorganic contaminants: ammonia, nitrite, phosphorus, sulphur, and heavy metals. These contaminants cause a high negative impact to the environment and living things if their concentrations in drinking water exceed the regulated limits. The major pollutants in drinking water are COD and ammonia, while heavy metal especially manganese is the minor pollutant. The presence of ammonia in drinking water was caused by a few sources such as fertilizer industries, sewage matters, agricultural activities and discharged leachate. The high concentration of ammonia in drinking water is a potential cause for oxygen depletion, toxicity of fish, eutrophication of surface water [1], complication on chlorination process due to the creation of chloramines [2], nervous system damage and deteriorating taste and odour of water [3]. Meanwhile, the high manganese concentration causes several problems such as water discoloration, metallic taste, odour, turbidity, biofouling and corrosion, staining of laundry and plumbing fixture [4]. In water treatment plants in Malaysia, there is no special treatment for manganese since the concentration of the manganese in the water resource is already below the regulated limit but it will then accumulated and deposited along the piping systems of water supply. Hence, it will later cause stain and odour problems water supply.

COD, ammonia and manganese can be removed chemically or biologically in drinking water treatment. Biological treatment process is preferable than chemical treatment process, since there is no need for extra chemical addition, high filtration rate, and low operation and maintenance cost [5- 6]. Biological aerated filter (BAF) is known as one of biological treatment methods in wastewater treatment but not in drinking water treatment. It was developed in late 1970*s* and 1980*s* to treat wastewater from slaughterhouse and pulp-mill industries [7]. The system consists of submerged particulate medium bed with supplied air [8]. Among advantages of BAF are it is a flexible reactor and able to perform solids separation as well as aerobic biological treatment, the space requirement for the treatment is also small [9], it provides a small footprint with a large surface area, easy construction and has ability to treat high organic loads [10]. According to Rother *et al*. [11], BAF offers advantages over the standard activated sludge process, wherever slow growing biomass is involved, a good and virtually suspended-solids-free effluent quality is required and a shortage of a space that requires high specific volumetric degradation rates.

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Due to the capability of BAF system in wastewater treatment, the aim of the present work was to come out with a preliminary design of BAF system based on the review which mainly focuses on the BAF dimensions of height and diameter in order to remove COD and ammonia as major pollutant and manganese as minor pollutant in drinking water treatment. The review also includes the BAF process such as biofilm growth, aeration and backwash system to achieve a high COD, ammonia and manganese removal.

2.0 REQUIRED DESIGN CRITERIA FOR A BIOLOGICAL AERATED FILTER SYSTEM

2.1 Biofilm Growth

A biofilm grows on the surface of the BAF media and metabolises the organic matter in the drinking water. The optimal condition of the relevant microorganisms within BAF system can be maintained independently of hydraulic retention time in order to achieve high levels of nitrification, denitrification and phosphate removal [11-13]. According to Mann *et al*. [14], the main factors that influence the biofilm growth within BAF are flow rate and nutrient concentrations. Surface characteristics, such as surface area, porosity and surface roughness are another importance factors that influence the biofilm formation and concentration. Hence, the biodegradation of the pollutants by aerobic and anaerobic process treatment can be enhanced with a sufficient biofilm thickness on the surface area [15].

The growth rate of nitrifying bacteria is very slow [16] and therefore the nitrification process is problematic to the water and wastewater treatment. By controlling the nitrifying biofilm activity through the biofilm thickness in the BAF, the ammonia removal efficiency can be increased. According to Liu and Capdeville [16], the nitrifying biofilm thickness between 15-25 μm is a sufficient thickness for the optimal ammonia removal. In BAF system, nitrifying biofilm that grows and attaches on floating media is more suitable for the biofilm attachment than the sunken media [17].

2.2 Flow Configuration

The BAF system can be designed with two configurations either upflow or downflow mode [18] as shown in Figure 1. For the upflow BAF, the influent is introduced at the bottom of BAF and flows co-current with air while for the downflow BAF, the influent is fed at top of BAF and flows counter current to air [17]. Generally, the upflow BAF is worldwide applied for wastewater treatment [19] but presents some limitations for ammonia removal of wastewater [20]. In contrast, the upflow BAF has the ability to cope with higher influent flow rates, has longer operational cycle system, and can decrease odour problem occurring since the atmospheric air only contacts with treated effluent at the top of the BAF [17]. Despite, the downflow BAF also offers an advantage of better mixing and longer contact time of the air and water or wastewater which is conducive to oxygen transfer and biodegradation in the lower portion of the filter [21].

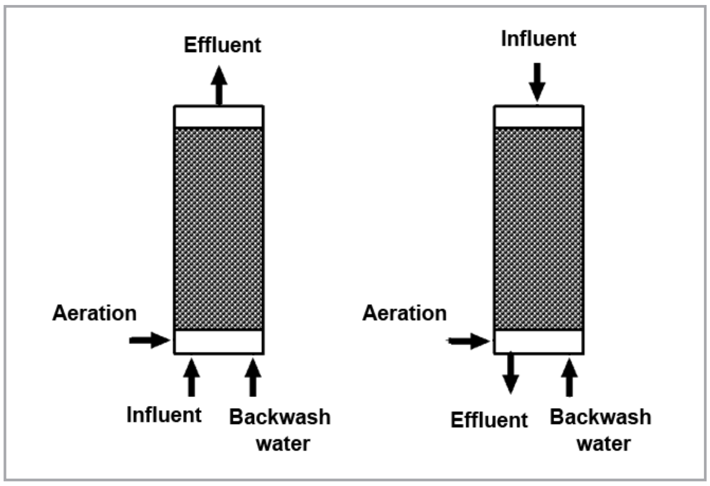

Figure 1: Schematic of (a) upflow and (b) downflow BAF

2.3 Aeration System

Aeration system is an important part in the BAF system to supply oxygen which can be at the bottom or bottom half of the BAF system. When the aeration supply is at the bottom of BAF, the nitrification occurs at first stage followed by denitrification, while for the aeration supply at bottom half of BAF, the nitrification and denitrification occur simultaneously. According to Asiedu [22], the removal of carbon and ammonia are predominant in the BAF system with aeration system at the bottom with suspended solids are also filtered well. However, only the upper section of BAF system can perform well for carbon and ammonia removal if the aeration is supplied at the bottom half of BAF system.

A BAF system with sufficient oxygen supply will be a good condition for nitrifying biofilms growth and good removal of ammonia. If the aeration volume is higher than required, the nitrifying biofilm growth would be abraded and carried out of the BAF system with the effluent [23]. Rodriguez [24] noted that, low aeration volume or dissolved oxygen in the BAF can affect the nitrifying biofilm specific growth rate. Basically, the concentration of dissolved oxygen for nitrifying biofilms growth was 2-3 mg/L. Besides, without the aeration control, the good and stable process performance remains difficult especially for nitrification and denitrification [25]. Joo *et al*. [26] also reported that the nitrification efficiencies were consistently higher than 95% when the aeration supplied at superficial air velocity of 1.7cms^{-1}. The main consideration in the design of aeration system is the economic factor which is high power consumption required for the aeration operation [27]. Furthermore, the design optimisation of aeration efficiency can significantly improve the overall process economics [21].

2.4 Filter Media

A filter media is one of the main components in the BAF system besides the aeration and backwash system. The filter media has a noticeable influence on the hydraulic characteristics on oxygen-substrate transfer rate [21]. Therefore, the selection of a suitable BAF media is critical part in the design of operation and BAF process, to enable the effluent quality reached the regulated standard [17]. In any BAF system, there are two types

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of filter media; floating media such as plastic media, polystere pellets and polyurethane pellets, and sunken media such as ceramics, zeolite and sand. The filter media acts as a nitrifying and denitrifying biofilms attachment, provide a large surface area per unit volume to maintain a high amount of active biofilms and variety microbial populations. Furthermore, according to He *et al*. [13], the media also allows the reactor to act as a deep, submerged filter and incorporate suspended solids removal. The selection of filter media to enable the required effluent standard quality for ammonia removal is depending on some factors which is media type and sizes. Kent *et al*. [28] noted that the characterization of filter media was required to determine their suitability for biofilm growth and attachment, and ammonia removal.

2.5 Media Types

The selection of media types in BAF system consists of either floating or sinking media or dual media. The floating media has the specific gravity less than water, while the sunken media has greater specific gravity than water. In addition, the floating media is operated exclusively in an upflow configuration, while the sinking media may be operated either upflow or downflow configuration [17, 21, 22].

The floating media BAF offers some advantages than the sinking media which performs well for suspended solids (SS), COD and ammonia removal [17]. The well performance by the floating media was due to the compression of the bed caused by the buoyancy force of the media and air flow and liquid acting upward [17]. Furthermore, the floating media is also high resistant to low temperature shock and requires low backwash rate. On the other hand, the sinking media has faster recovery from temperature shocks as well as temperature increment [14, 29].

Based on a previous study by He *et al*. [13], they showed that BAF system with sinking media of zeolite and expanded clay as a filter media under condition of low temperature and ammonium shock load, the removal of COD and NH_3-N by these two media were about 88%, 75%, 80% and 62%, respectively. Additionally, Chang *et al*. [7] investigated the effect of zeolite and sand for the treatment of textile wastewater using a BAF system and found that, the COD and TKN removal efficiency were about 88%, 75%, 80% and 62% respectively.

It was shown that the sinking media especially zeolite was a suitable filter media in BAF system which has a high adsorption ammonia capacity. Since the cost of synthetic zeolite is very high and not economic for a pilot plant BAF, the floating media of plastic media and polystere pellets can be a better option which can also result in a high ammonia removal through the nitrifying biofilms attachment and biosorption treatment.

According to Lekang and Kleppe [27] who studied on the efficiency of nitrification in trickling filters using Leca media (sinking media) and Kaldness media (floating media), the removal efficiency was 100% and 85%, respectively. The oxygen consumption per gram to transform the TAN was 2.1 *mg* O_2 $L^{-1}min^{-1}$ for Leca media while only 1.0 *mg* O_2 $L^{-1}min^{-1}$ oxygen usage for Kaldness media.

2.6 Media Size

Media size affects the efficiency of BAF performances in treatment process as well as the removal of suspended solid, organic contaminants, and inorganic contaminants. The smaller size media offers a greater surface area per unit volume for biofilm development and minimises the required BAF volume, but high backwash frequent is required [30]. A larger media basically greater than 6 *mm* effectuates reduction in nutrient removal due to the less surface area for biofilm growth and attachment because of the high voidage in the BAF. However, low backwash rate is required for larger size media and decreases the operation and maintenance cost [17, 19, 31]. Consequently, different sized media have been recommended for different applications. According to Kent *et al*. [28] study, the BAF system using the smallest size media (2-4 *mm*) gave the optimum nitrification at loading rates up to 0.6 *kg* NH_4-N/m^3.d. However, BAF containing larger media sizes (4-8 *mm* and 5.6-11.2 *mm*) resulted low levels of nitrification above a loading rate of 0.2–0.4 *kg* NH_4-N/m^3.*d*.

2.7 Media Height and Shape in BAF

The media packing in the BAF system can be operated either partially or fully packed. Suja' *et al*. [32] showed that the partially packed BAF had a comparable performance with the fully packed BAF in the removal of carbon and nitrogen pollutants. According to Delin *et al*. [9], the greatest increment of removal efficiency occurred at the top 100 *cm* of media height and within the first 100 *cm*, the COD removal efficiency was between 42.6% and 54.7% whatever the lower and higher hydraulic loading was.

The roughness and shape of the media also influences the BAF system performance with the rough media provided a greater surface for biofilm growth and attachment [17, 33]. According to Tan [17], the irregular media has been reported to improve the BAF performance compared to spherical media.

2.8 Backwash System and Operational Approach

In order to prevent the reactor from clogging and maintain the nitrifying biofilm activity, backwash system should be provided to remove excess solids and biomass accumulated on the media. Backwash system is important to the BAF to maximise the length of the treatment cycle while minimizing the energy consumption [17]. The backwashing should be conducted efficiently to avoid the supporting media from being damaged and interference on the nitrifying biofilm growth. According to Mendoza-Esposino and Stephenson [21], underwashing can bring out short operating cycle and possible solid breakthrough. Meanwhile, overwashing can cause reduction of biomass which eventually leads to poor performance.

The backwash for BAF system using floating media can be operated by reversing the flow of water through the system while for sinking media could either be concurrent if an upflow BAF or counter current for downflow BAF configuration [22]. Xie *et al*. [23] studied that a turbulent-flow backwashing method using '*air shots*' could be applied to BAF system using floating media. This backwash method is more effective than the conventional backwashing method which is discharging sloughed biofilm

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was softer and the clogging biomass was removed very well.

The effective backwashing depends on the frequency and volume of backwash cycle. Sufficient frequency for backwashing in BAF system can prevent the media from being clogged and promote the well biofilm growth and attachment. Xie *et al*. [23] reported that for the low backwash frequency, the removal of both BOD and T-N nitrification was also low. Normally, when the BAF is used for the secondary treatment, backwashing is performed every 24 to 48 *h*, while for the tertiary treatment backwashing is usually carried out on a weekly basis [34].

3.0 DESIGN JUSTIFICATION OF A BIOLOGICAL AERATED FILTER SYSTEM

In order to remove COD, ammonia and manganese in drinking water treatment, a BAF process system will be designed based on the literature review which mainly focuses on the COD removal as well as BAF dimensions of height and diameter. This system consists of a reactor column, filter media, aeration system, backwash system, peristaltic pump and compressor as shown in Figure 2.

3.1 BAF Column and Configuration

The BAF column was designed using clear PVC with 1.5 *m* high and 0.16 *m* diameter. The clear PVC was chosen for its cheaper cost, chemical resistance, no corrosion, and easier to transport and install. The diameter and height of column was determined based on the data obtained from the literature review in Table 1. As summarised in Table 1, the BAF system showed a good performance at a height of 1-2.5 *m* and a diameter of 0.1-0.3 *m* with COD removal efficiency of 70-93%. Meanwhile the NH_3-N removal efficiency reached 46-98% at a height and diameter of 0.75-2.5 and 0.05-0.15 *m* respectively. Due to insufficient data of ammonia and manganese removal, the estimated dimensions of BAF were based only on the COD removal as a primary pollutant. Based on the data, the correlation of COD removal was plotted against the ratio of BAF dimensions: height and diameter as shown in Figure 3.

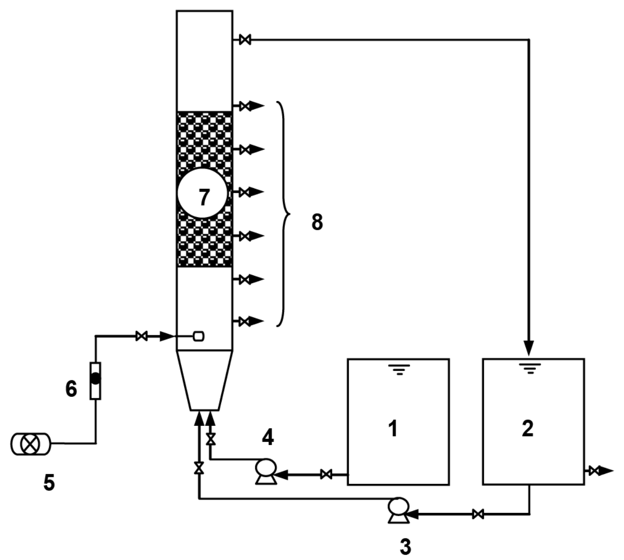

Figure 2: Schematic diagram of the biological aerated filter (BAF) process system; (1) Influent tank, (2) Effluent tank, (3) Backwash pump, (4) Peristaltic pump, (5) Compressor, (6) Flow meter, (7) Filter media, (8) Sampling port

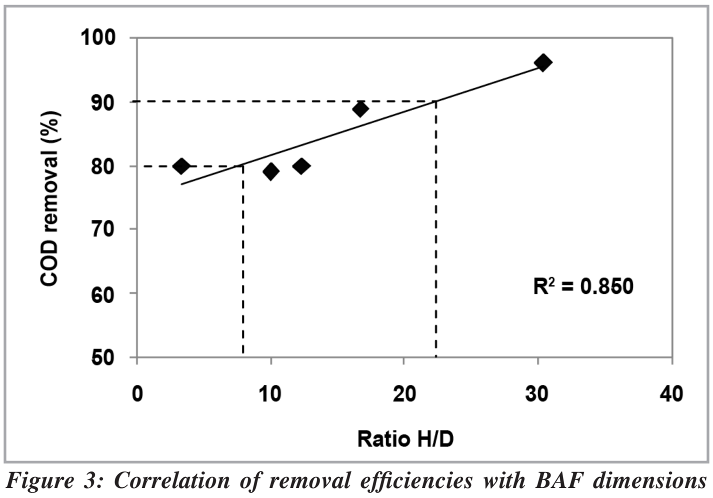

Figure 3: Correlation of removal efficiencies with BAF dimensions ratio

The plot showed that, the BAF dimensions ratio of 8 to 22 had a high COD removal efficiency in the range of 80-90%. As shown in Figure 4, another graph of H/D ratio was plotted against the height of BAF based on the data from Table 1, in order to determine the suitable height and diameter for a good COD removal. Based on the graph, the selected dimension ratio resulted in the BAF height of 1.5 to 2.7 *m* for the ratio of 8 to 22 to achieve the COD removal in range of 80-90%. The literature summaries also convinced that the bench scale BAF dimensions usually were in the range of 1.5-2.5 *m* and 0.1-0.2 *m* for the respective height and diameter (Table 1).

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Table 1: Summary of the biological aerated filter (BAF) performance

References	Height (*m*)	Diameter (*m*)	Height/ Diameter ratio (H/D)	Media type	Reactor configuration	Organic/ ammonia load (kg/m^3d)	HRT (*h*)	Removal (%)	Wastewater type
[7]	0.33	0.18 height and 0.12 width	-	Zeolite, sand	Downflow	1.2-3.3 *kg* COD/m^3d, 1-3 *kg* SS/m^3d	-	Zeolite (COD:88%; SS:97%), Sand (COD:75%; SS:97%, TKN:80%)	Textile wastewater
[10]	2	0.2	10	Pure polypro-pylene,	Upflow	0.57-1.4 *kg* sCOD/m^3d	-	Sunken media (sCOD:68%; tCOD:59%; NH_3-N:9.9%) Floating media (sCOD:79%; tCOD:75%; NH_3-N:15.6%)	-
[13]	2.5	0.15	16.67	Zeolite, expanded clay	Upflow	-	0.95-1.43	Zeolite (COD:84.63-93.11%; NH_3-N:85.74-96.26%), Expanded caly (COD:82.34-93.71%; NH_3-N:85.03-93.2%)	Municipal wastewater
[14]	2	0.2	10	Pure polypro-pylene, plypropylene (60%)+ $CaCO_3$ (40%)	Upflow	0.486-1.397 *kg* SS/m^3d, 0.568-1.403 *kg* sCOD/m^3d	0.8-2.0	Sunken media (sCOD: 30-68%), Floating media (sCOD:40-75%)	Wastewater
[17]	2.12	0.1	21.2	Polystyrene	Upflow			COD:71.7-92, NH_3-N:46.7-95.3, TN:35.2-88.3, PO4-P: 23	Synthetic wastewater
[18]	5.3	0.43	12.33	Crystal quartz sand	Upflow	0.01-0.07 *kg* NH_4-N/m^3d 0.1 *kg* COD/m^3d	-	>80% COD 97% NH_4-N	Leachate
[20]	2.5	0.15	16.67	Puzzolane particles	Upflow	1.2 *kg* NH_3/m^3d 0.6-9.6 *kg* COD/m^3d	-	100% NH_4+ removal when no COD TOC : 40, 60, 90% when COD/NH_4+ 0.5,1,& 4	Synthetic wastewater

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Table 1. Summary of the biological aerated filter (BAF) performance (continued)

References	Height (m)	Diameter (m)	Height/ Diameter ratio (H/D)	Media type	Reactor configuration	Organic/ ammonia load (kg/m^3d)	HRT (h)	Removal (%)	Waste treatment
[23]	1.4	Sectional area 0.77 x 0.53 = 0.408 m^2	-	Polystere foam pellets, D = 4mm	Upflow	0.7 kg BOD/m^3d, 0.16 kg T-N/m^3d.	-	BOD:83-96%; NO_x-N/T-N:77-86%	Domestic wastewater
[26]	0.75	0.05	15	Expanded polyurethane pellets	Upflow	2 kg NH_4^+-N/m^3d	-	NH_4^+-N:95%; NO_2^--N accumulated:60%	Synthetic wastewater
[30]	3.15	0.2	15.75	Foamed clay	Downflow	12 kg COD/m^3d, 4 kg SS/m^3d	SM: 0.8 - 1.6, LM: 0.9 - 1.8	sCOD : > 70%, sBOD : > 96%, Nitrification : not stabilise	Wastewater
[35]	3.7	0.3	12.33	Plastic, ceramic	Upflow, downflow	4.87 kg TBOD/m^3d 3 kg SS/m^3d	-	>20 mg TBOD and >25 mg SS correspond organic loading	Raw water
[36]	3.165	0.104	30.43	Sand (anoxic 10 mm ; oxic 5 mm)	Upflow	NH_3-N : 0.15-0.19 (100-200% recirculation)	sCOD : 3, Nitrification : 3, Total N_2 : 4-6	sCOD : 96% at 100, 200, and 300% recirculation), Nitrification : 96% at 200 and 300% recirculation, Total N2 : 80% at 300% recirculation	Synthetic wastewater
[37]	1	0.3	3.33	Expanded clay	Upflow, downflow	> 20 kg COD/m^3d	-	COD:80%; BOD5:85%; SS:19%	Citrus wastewater
[38]	0.2	0.1	2	Synthesized polymer	Upflow	1.07 kg COD/ m^3d	4	B350M (TOC:78%; oil:94%): B350 (TOC:64%; oil:86%)	Oil
[39]	2	0.15	13.33	ceramic	upflow		9.6		Synthetic wastewater
[40]	1.6	0.1	16	Sludge-fly ash ceramic particles (SFCP)	upflow	0.36	2	COD:90, NH_3-N: 98, TN:70	Synthetic wastewater

Table 2: BAF configuration design process

Reactor configuration	Height, H (*m*)	Diameter, D (*m*)	H/D ratio	Media type	Treatment type	Contaminants removed	Expectation removal (%)
Upflow	1.5	0.16	9.38	Plastic media	Drinking water	COD, ammonia, and manganese	80-90%

Hence, the BAF system will be designed with an upflow mode of which the feeding is introduced at the bottom column and the flow was co-current with the air supply. The literature review showed that, the upflow mode is worldwide applied for water and wastewater treatment [20]. Other consideration factors that influence in the designed BAF configuration are the upflow BAF has the ability to cope with higher influent flow rates, has longer operational cycle system, and can decrease odour problem [17]. The summary of the BAF configuration design is summarised in Table 2.

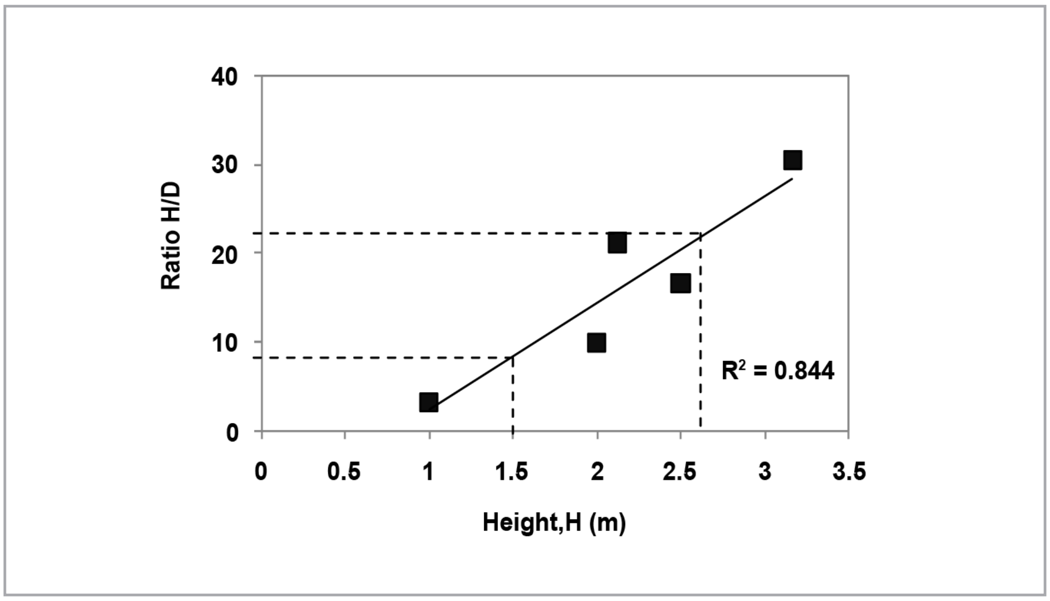

Figure 4: Correlation of height and diameter ratio with BAF height

In this BAF system, floating media (*plastic media*) is chosen as the filter media due to larger surface area to support the biofilm growth and attachment and it is more economic. Tan [17] reported that floating media has capability to perform well for COD and ammonia removal with removal percentage of 71-92% and 47-95%, respectively.

3.2 Aeration and Backwash Operational

The aeration system is designed at the bottom of the BAF column and compressor is used to supply the air to the reactor (Figure 2). An air diffuser is used in order to make the air supply smooth and homogenous within the BAF. The dissolved oxygen is maintained about 2-3 *mg/L* for nitrifying biofilm growth [24]. Backwash system is provided to remove clogging solids and biomass accumulated on the media. The backwashing will be carried out efficiently to avoid the supporting media from being damaged. The backwash water is pumped simultaneously with backwash air at the bottom of the column using water pump and compressor, respectively. The backwashing frequency will be twice a week depending on the solid and biomass accumulated on the biomass.

4.0 CONCLUSIONS

As a conclusion, the correlation data based on the literature review showed that a BAF dimension with H/D ratio of 8 to 22 has a good removal for COD of 80-90%. The best height and diameter of 1.5 *m* and 0.16 *m*, respectively were chosen based on the correlation. The upflow mode is selected with the aeration is introduced at the bottom of BAF, and plastic media is using as a filter media for biofilm growth and attachment. The expected removal efficiency of COD and ammonia is to be within 80-90%.

5.0 ACKNOWLEDGEMENT

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