Penerbit Akademia Baru

Journal of Advanced Research in Engineering Knowledge

Journal homepage: www.akademiabaru.com/arek.html
ISSN: 2600-8440

The Hydrological Performance Investigation of Green Roof

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ARTICLE INFO

Article history:
Received 5 June 2019
Received in revised form 4 September 2019
Accepted 12 December 2019
Available online 17 December 2019

Keywords:
Green roof; hydrological performance; natural fibres; filter; recycled waste materials; drainage layers

ABSTRACT

A green roof can be a way to navigate stormwater runoff and flooding in urban catchments in Malaysia. This is because green roofs can be used as temporary storage spaces and infiltration. This paper represents hydrological investigation findings in term of hydrograph and peak runoff for different types of materials used as drainage and filter layers. The data were collected from different test beds under simulated rainfall with the intensity of 200mm/h for 0%, 2% and 6% slope. Natural fibres were used as a filter layer and laid on top of the drainage layer. In this study, a total of 18 sets test beds with a dimension of 1.1 m x 1.17 m were used. This study used three types of waste materials (rubber crumbs, oil palm shells and polyfoam) and three types of natural fibres (coconut fibres, oil palm fibres and sugarcanes fibres). The result indicates that the combination of oil palm shells with sugarcanes fibres have the highest peak runoff value for 0%, 2% and 6% slope with a value of 4.01 mm, 6.29 mm and 7.77 mm respectively. Followed by oil palm shells with oil palm fibres (0%: 2.95 mm, 2%: 5.75 mm, 6%: 6.76 mm) and oil palm shell with coconut fibres (0%: 2.72 mm, 2%: 5.05 mm, 6%: 6.32 mm). The result proved that combination of oil palm shell and sugarcanes fibres performance better in peak runoff value compared to other materials.

1. Introduction

The concept of green roof nowadays is highly popular as it brings many benefits towards the environment and promotes a sustainable lifestyle. Green roofs can be categorized according to its growing media thickness, vegetation type, accessibility, the need for maintenance and origin. According to Berndtsson *et al.*, [1], vegetated roofs can play an important role in modern urban drainage because of its ability to slow down and reduce runoff response. Many researches discovered that green roofs have numerous environmental benefits such as reduce flood risk, improve rainwater runoff quality, mitigate urban heat island, building energy saving and provide urban wildlife habitat. Green roof is usually consists of vegetation layer, substrate layer, filter layer, drainage layer and waterproofing layer. Extensive green roofs are established with thin substrate

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layers, supports smaller plants and typically maintenance free. The total depth of an extensive green roof is normally less than 150 mm [2-12]. As cited by Hathaway *et al*., [13] in his studies demonstrated that shallower substrate depths and steeper roof slopes resulted in greater runoff from the GR. The thinner implementations which typically less than 200 mm is known as extensive GR and are established with thin substrate layers, support smaller plants and typically maintenance free [1,14]. Voyde *et al*., [11] fixed its target maximum wet weight somewhat arbitrarily set at 100 kg/m^2 as its green roof design goal and work backwards to calculate the depth of the substrate layer (50 mm).

In Malaysia, climate is considered as a dry hot all over the year with heavy rain on specific periods. Due to its geographical location with an average rainfall over 2000 mm per year, is prone to suffer from floods and flash floods especially during cyclical monsoon cold surge episodes which are characterized by extreme rainfall from roughly November to February [15]. The conventional roof of buildings in Malaysia is made from concrete and zinc. Thus, green roofs may work as a source control measure as they have capability of retaining the rainfall by and distributing the runoff slowly through the green roof layers. This technology helps in reducing the runoff discharges which contributing to reduce flash floods. Several researches have highlighted the importance of green roof application including the ability of green roof to retain stormwater [10], delay peak discharge time [3] and attenuate peak discharge volume [4,9].

There are a few researchers in Malaysia looking into the hydrological performance of waste materials and ways on how the roof slopes influence the performance of green roofs. There were several literatures that studied the use of rubber crumbs in drainage layer in the green roof in terms of its hydrological properties; however, none on waste materials such as polyfoam and oil palm shells. In this study, different types of waste materials (rubber crumb, oil palm shells and polyfoam) and natural fibres (coconut fibre, oil palm fibre and sugarcanes fibre) were used in the green roofs system as drainage and filter layer. The aim of this study is to investigate the hydrological performance in term of hydrograph shape and peak runoff made from natural fibres (NF) as a filter and recycled waste materials (RWM) as drainage layers in the green roof (GR) to mitigate stormwater runoff.

2. Methodology

2.1 Experimental Setup

The study was carried out in hydraulic laboratory, Faculty of Engineering, University Malaysia Sabah. A total of 18 test beds were constructed with a dimension of 1.1 m x 1.17 m (Figure 1) and tested under the rainfall simulator. The duration of simulation rainfall was 15 minutes. The value for outflow was taken for an hour continuously with five minutes interval. The rainfall intensity set for these experiments are based on the Malaysia Urban Stormwater Manual guideline for constructing roof gutters, which are 20-year and 100-year annual recurrence interval of 15 minutes duration for Kota Kinabalu. The rainfall intensity for the simulator used in this study was based on return period of annual maximum rainfall in Inanam, Kota Kinabalu. The data were collected from different test beds under simulated rainfall with the intensity of 200 mm/h and testing was done for 0%, 2% and 6% of slope. The design of green roof layers is shown in Figure 2.

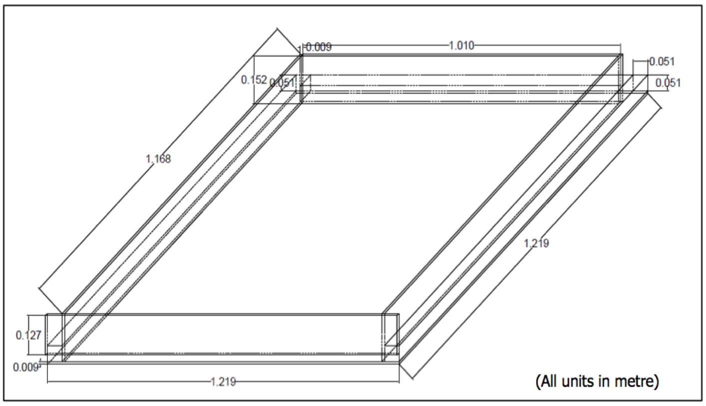

Fig. 1. Test bed design

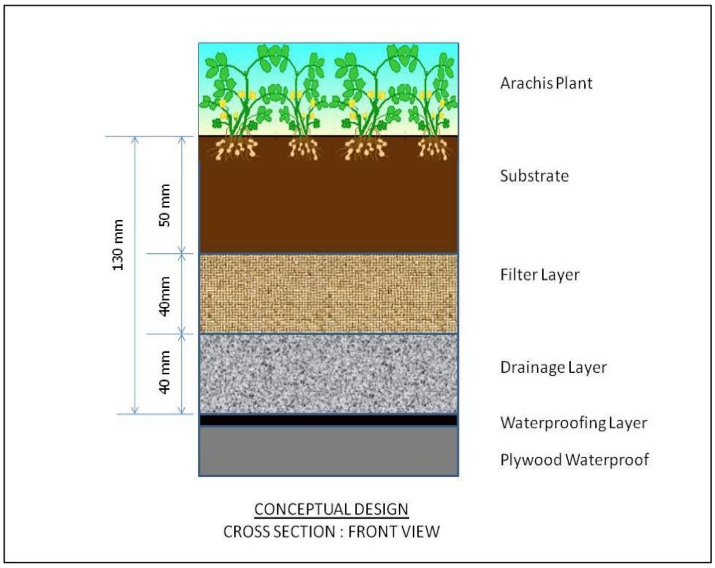

Fig. 2. Green roof design layers

2.2 Materials

Waste materials and natural fibres used in this study were collected locally in Sabah. Three types of recycled waste were selected for each test bed, which are rubber crumbs, oil palm shell, and polyfoam. Natural fibres acted as the filter layer in green roofs are placed on top of the drainage layer. Natural fibres chosen are coconut fibre, oil palm fibre and sugarcanes fibres. The plant used in the green roof system is Arachis Pintoi. Figure 3 show different types of materials and plants used in green roof design. Table 1 indicates key component names for each material.

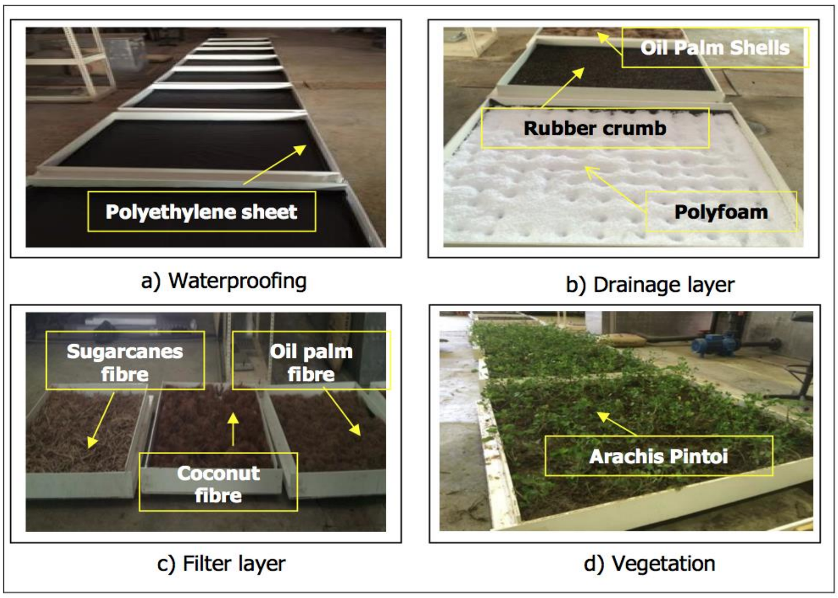

Fig. 3. Green roof designs

Table 1
Key to Component Names

Green Roof Layer	Component Name	Key
Waterproofing	Control	C
Waterproofing Drainage	Rubber crumb	RC
	Oil palm shell	OPS
	Polyfoam	PF
Waterproffing Drainage Filter	Rubber crumb with sugarcane fibre	RCSF
	Rubber crumb with coconut fibre	RCCF
	Rubber crumb with oil palm fibre	RCOPF
	Oil palm shell with sugarcane fibre	OPSSF
	Oil palm shell with coconut fibre	OPSCF
	Oil palm shell with oil palm fibre	OPSOPF
	Polyfoam with sugarcane fibre	PFSF
	Polyfoam with coconut fibre	PFCF
	Polyfoam with oil palm fibre	PFOPF

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	Rubber crumb with oil palm fibre	RCOPF
	Oil palm shell with sugarcane fibre	OPSSF
	Oil palm shell with coconut fibre	OPSCF
	Oil palm shell with oil palm fibre	OPSOPF
	Polyfoam with sugarcane fibre	PFSF
	Polyfoam with coconut fibre	PFCF
	Polyfoam with oil palm fibre	PFOPF

2.3 Hydrological Performances Test

The hydrological performance of green roof in this study involved the performance investigation of runoff hydrograph shape and peak runoff. The test beds with treatments were tested under the rainfall simulator for hydrological performance. To test the effect of the green slope on the hydrological performance, a different slope with 0%, 2% and 6% were set up. The three stages are waterproofing with drainage layer (stage 1), waterproofing with drainage and filter layer (stage 2) and waterproofing with drainage, filter, substrate and vegetation layer (stage 3). Table 2 shows the stages with different combination of waste materials and natural fibres.

Table 2
Specimens for each stage

	Specimen							
	Waterproof layer	Waste materials			Natural Fibres			Plant
		OPS	RC	PF	SF	CF	OPF	Arachis Pintoi
Control	x							
Stage 1	x	x						
	x		x					
	x			x				
Stage 2	x	x			x			
	x	x				x		
	x	x					x	
	x		x		x			
	x		x			x		
	x		x				x	
	x			x	x			
	x			x		x		
	x			x			x	
Stage 3	x	x			x			x
	x	x				x		x
	x	x					x	x
	x		x		x			x
	x		x			x		x
	x		x				x	x
	x			x	x			x
	x			x		x		x
	x			x			x	x

	Specimen							
	Waterproof layer	Waste materials			Natural Fibres			Plant
		OPS	RC	PF	SF	CF	OPF	Arachis Pintoi
Control	x							
Stage 1	x	x						
	x		x					
	x			x				
Stage 2	x	x			x			
	x	x				x		
	x	x					x	
	x		x		x			
	x		x			x		
	x		x				x	
	x			x	x			
	x			x		x		
	x			x			x	
Stage 3	x	x			x			x
	x	x				x		x
	x	x					x	x
	x		x		x			x
	x		x			x		x
	x		x				x	x
	x			x	x			x
	x			x		x		x
	x			x			x	x

Fig. 4. Testing under a rainfall simulator

3. Results

The hydrological performance investigations are involving the investigation of runoff hydrograph shape and peak runoff. The experimental green roofs are set up for complete green roof system on 0%, 2% and 6% of slope. The result on hydrological performances of GR using waste materials and natural fibres are discussed on each hydrological investigation. These results also give insights on hydrological performance of green roof using natural fibres as filter layer and waste materials as drainage layer for stormwater runoff mitigation.

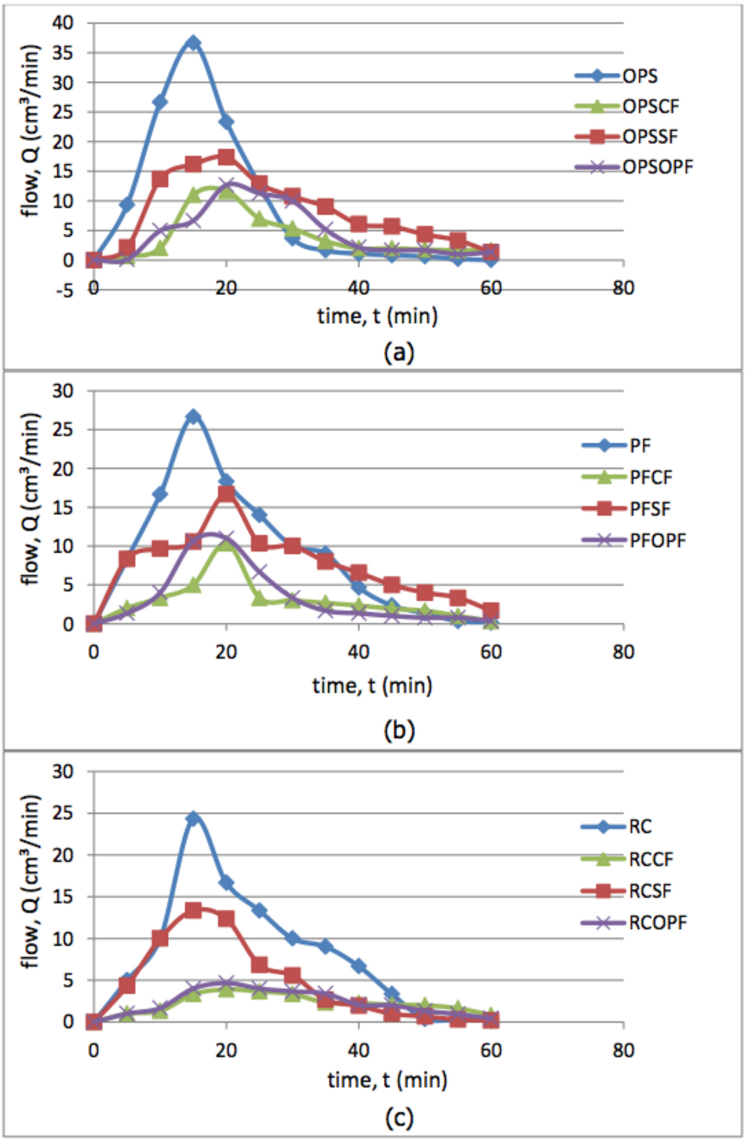

Fig. 5. Hydrograph shape of complete GR system made from RWM and NF on 0% slope: (a) OPS with NF, (b) PF with NF, (c) RC with NF

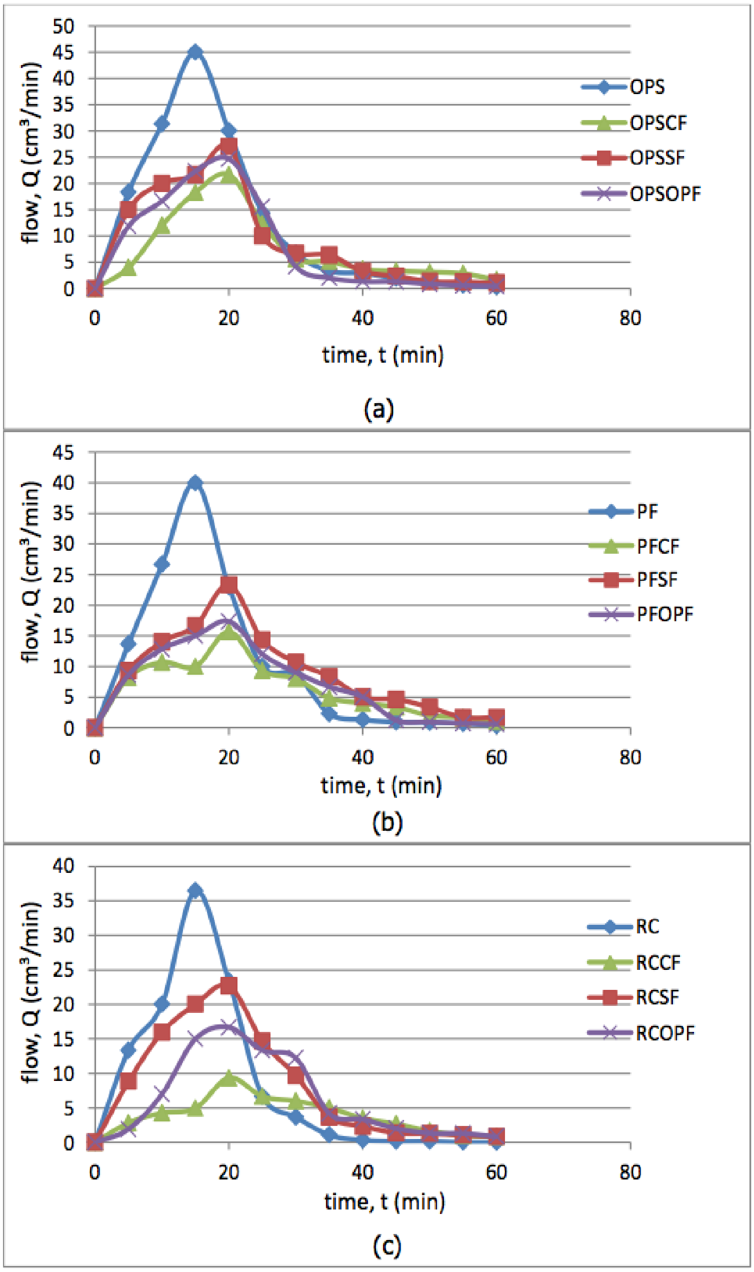

Fig. 6. Hydrograph shape of complete GR system made from RWM and NF on 2% slope: (a) OPS with NF, (b) PF with NF, (c) RC with NF

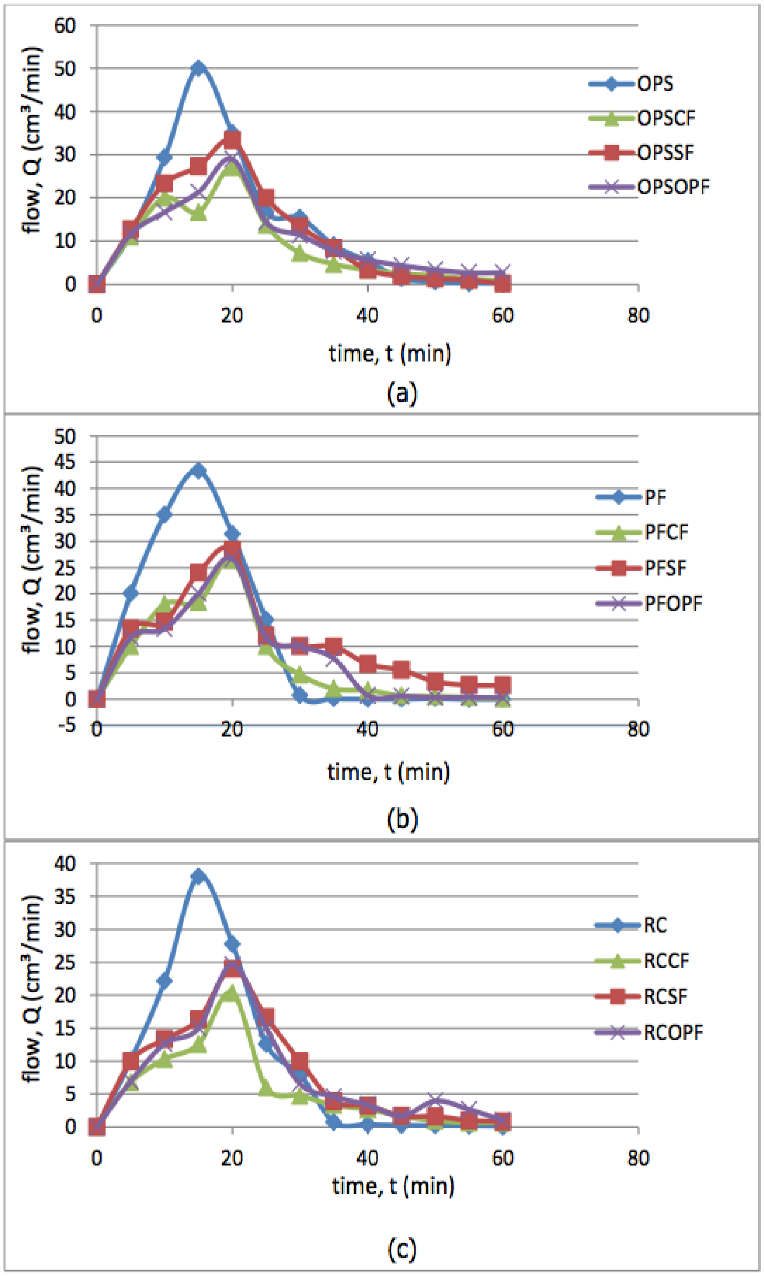

Fig. 7. Hydrograph shape of complete GR system made from RWM and NF on 6% slope: (a) OPS with NF, (b) PF with NF, (c) RC with NF

Table 3
Peak runoff of green roof system

Peak Runoff (mm)												
Materials												
Slope (%)	**0**	**2**	**6**	**0**	**2**	**6**	**0**	**2**	**6**	**0**	**2**	**6**
Waterproofing layer	**11.66**	**13.21**	**14.76**	-	-	-	-	-	-	-	-	-
Waterproofing with drainage layer	-	-	-	**8.55**	**10.49**	**11.66**	**6.22**	**9.32**	**10.10**	**5.67**	**8.50**	**8.86**
Waterproofing with drainage layer and filter layer	-	-	-	**6.22**	**8.55**	**10.10**	**5.35**	**7.73**	**8.12**	**4.66**	**6.99**	**7.61**
	-	-	-	**5.94**	**6.99**	**8.55**	**4.66**	**6.57**	**7.15**	**4.27**	**6.06**	**6.37**
	-	-	-	**5.59**	**6.45**	**7.38**	**4.27**	**6.22**	**6.99**	**3.19**	**5.05**	**6.06**
Waterproofing with drainage layer and filter layer, substrate and vegetation	-	-	-	**4.04**	**6.29**	**7.77**	**3.89**	**5.44**	**6.60**	**3.11**	**5.28**	**5.59**
	-	-	-	**2.95**	**5.75**	**6.76**	**2.56**	**4.04**	**6.22**	**1.09**	**3.89**	**5.75**
	-	-	-	**2.72**	**5.05**	**6.32**	**2.41**	**3.65**	**6.17**	**0.91**	**2.18**	**4.74**

		Peak Runoff (mm)											
Materials		**C**			**OPS**			**PF**			**RC**		
Slope (%)		**0**	**2**	**6**	**0**	**2**	**6**	**0**	**2**	**6**	**0**	**2**	**6**
Waterproofing layer		11.66	13.21	14.76	-	-	-	-	-	-	-	-	-
Waterproofing with drainage layer		-	-	-	8.55	10.49	11.66	6.22	9.32	10.10	5.67	8.50	8.86
Waterproofing with drainage layer and filter layer	SF	-	-	-	6.22	8.55	10.10	5.35	7.73	8.12	4.66	6.99	7.61
	OPF	-	-	-	5.94	6.99	8.55	4.66	6.57	7.15	4.27	6.06	6.37
	CF	-	-	-	5.59	6.45	7.38	4.27	6.22	6.99	3.19	5.05	6.06
Waterproofing with drainage layer, filter layer, substrate and vegetation	SF	-	-	-	4.04	6.29	7.77	3.89	5.44	6.60	3.11	5.28	5.59
	OPF	-	-	-	2.95	5.75	6.76	2.56	4.04	6.22	1.09	3.89	5.75
	CF	-	-	-	2.72	5.05	6.32	2.41	3.65	6.17	0.91	2.18	4.74

Table 3 shows the peak runoff data extracted from the hydrograph. For waterproofing with drainage layer (Stage 1), OPS has the highest peak runoff (0%: 8.55 mm; 2%: 10.49 mm; 6%: 11.66 mm). Then followed by PF with a range of 6.22 mm (0% slope) to 10.10 mm (6% slope) and finally RC with the lowest peak runoff among the drainage layer (0%: 5.67 mm; 2%: 8.50 mm; 6%: 8.86 mm). Comparing with the control, all the materials used in the drainage layer of GR system reduced the value of peak runoff, as some of the water are being absorbed and filtered before the water passing through the drainage layer.

For the test bed GR on stage 2 (waterproofing with drainage and filter layer) and stage 3 (waterproofing with drainage layer, filter layer, substrate and vegetation), peak runoff is reduced after each stage. Addition of the GR layer causes a reduction in the peak runoff through the water absorption by GR and distributes the runoff slowly through the release of the excess water that is in the substrate pores [4,5].

For the complete GR system made from NF as filter layer and RWM as drainage layer (Stage 3), the combination of OPS with SF have the highest peak runoff value on 0% 2% and 6% of slope with a value of 4.01 mm, 6.29 mm and 7.77 mm, respectively. Followed by OPS with OPF (0%: 2.95 mm, 2%: 5.75 mm, 6%: 6.76 mm) and OPS with CF (0%: 2.72 mm, 2%: 5.05 mm, 6%: 6.32 mm).

Peak runoff on the cases where only drainage layer is considered, water can easily pass through the medium [16]. But after the substrate was added on top of the drainage layer, the peak runoff has been reduced. This was caused by the effect of substrate layer that has an ability to retain water and also due to the effect when water passes down through the soil particles to fill the pores in drainage layer. Thus, causes reduction value in the peak runoff. For the slope factors shows a linear relationship where the peak runoff increases as the slope are higher.

4. Conclusions

The result indicates that the combination of oil palm shells with sugarcanes fibres have the highest peak runoff value for 0%, 2% and 6% of slope with a value of 4.01 mm, 6.29 mm and 7.77 mm, respectively. Followed by oil palm shells with oil palm fibres (0%: 2.95 mm, 2%: 5.75 mm, 6%: 6.76 mm) and oil palm shell with coconut fibres (0%: 2.72 mm, 2%: 5.05 mm, 6%: 6.32 mm). The results proved that combination of oil palm shell and sugarcanes fibres give better performance in peak runoff value compared to other materials. From the investigations of green roofs made from natural fibres and recycled waste materials, it can be concluded that it is possible to further in developing the green roofs system for stormwater runoff mitigation using these materials. However, there is a need to study in-depth on the saturated hydraulic conductivity of the material used in drainage and filter layer of the green roof as it can improve the permeability of water to enhance the runoff and preventing clogging.

Acknowledgement

This research was funded by a grant from Ministry of Higher Education of Malaysia (Project Code: RAG0061-TK-2014) for the financial support and University Malaysia Sabah for the lab facilities.

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