

The effect of artificial support material existence on removal of organic and nutrient in laboratory scale using plug flow reactor (PFR)

Sarah Aphirta^{1,*}, Prayatni Soewondo², Nida Maisa Zakiyya², Dyah Wulandari Putri², and Barti Setiani Muntalif²

¹Environmental Engineering Master Program, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung

²Program Study of Environmental Engineering, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung

Abstract. Artificial support material was examined to determine the removal capacity of organic pollutants and nutrients on laboratory scale using PFR system. The experiment was performed using artificial water with similar characteristics to Cikapayang River in three PFRs of 10.78 L. The PFRs were made of PVC pipes filled with an inert chemical substrate as an artificial support material. The process of pollutants removal in the PFR relies on a biological layer (biofilm) grown on the surface of the material support. Three type of C:N:P ratio used in this study were 30:15:1, 75:25:2, and 180:35:3. The results showed that the maximum removal efficiency of TSS, TN, TP, and COD in the preliminary tests were 85%, 87%, 71% and 79%, respectively. Moreover, the maximum water absorption capacity result was up to 30.8%. Organic substrate removal rate compared with first order and Stover-Kincannon substrate removal models prediction. The best fit model for this experiment was Stover-Kincannon model, with the average correlation coefficient up to 90% for all of the three reactors. SEM analysis shown that the microorganisms shape is coccus with the average size of 5 μm .

1 Introduction

Population growth in urban areas triggers the development of various activities, cause pollution, especially anthropogenic pollutants. The emergence of pollution without integrated prevention and repair efforts will have a very serious negative impact on environmental degradation. The growth of population will increase the consumption of clean water which has implications for increasing the amount of wastewater and also the risk of effluent disposal into rivers, lakes or the sea, so that wastewater treatment is needed in order to reduce contaminants which enter the environment [1].

In general, cities in Indonesia still lack the facilities and infrastructure for wastewater treatment which is characterized by the lack of a centralized and integrated wastewater management system. Nowadays, centralized wastewater management system has only been implemented in 11 (eleven) cities in Indonesia with a low service coverage [2]. About 90% of wastewater in Indonesia is channeled through drainage network in the city without being treated and ends up in the river as a receiving water body. Inorganic compounds (ammonia, nitrate and phosphate) which trigger the growth of aquatic biota, contribute to the phenomenon of eutrophication in

receiving water bodies that contain effluent wastewater [1].

It is known that Bandung, especially the area of South Bandung, such as Dayeuh Kolot and Majalaya, experiences heavy floods which regularly occur every year. Bandung is still implementing the drainage function with a combination system, in addition to functioning as a drainage of rainwater, it also functions as a domestic sewage system that drains liquid and solid waste from households. Due to the topography of the Bandung basin and the meandering and low elevation of the Citarum River, there are areas that are critical of the threat of standing water, namely the Bojongsoang and Tegallular Areas [2].

Artificial support material technology offers practical and sustainable solutions to meet the challenges of water resource management. The raw material for this artificial support material comes from volcanic lava which is 100% natural and environmentally friendly material, has a very large porosity which is indicated by water retention capacity of 92% with a weight of 120 kg/m^3 . This technology function as a biopore and infiltration well and has a high permeability and can be produced in different densities. As a filter, this artificial support material has a hydraulic conductivity value of 7 mm/sec [3]. Previous research located on agricultural land in Netherland has

* Corresponding author: aphirtasarah@gmail.com

shown the potential for very effective removal of 90% organic material, 42% total phosphate, and 40% total nitrogen using material support compared to straw [3].

This method could be adapted in Indonesia. While the government urge on Citarum River revitalization and improving water quality in receiving water bodies, attached growth biological treatment using artificial support material in the drainage system or water bodies become an alternative technology to support sustainable management of natural resources in Indonesia and help the implementation of environmentally drainage concept.

This study focused on the lab scale experiment by using artificial water similar to Cikapayang river as one of the tributary of Citarum River. Organic removal would be evaluated by mathematical model, while the artificial support material would be observed to get to know the attached biomass characteristics.

1.1 Theoretical development

Mathematical models are used to test hypotheses, determine the importance of relationships between variables, guide experimental designs, and to evaluate experimental results [4].

In this study, first order substrate removal and Strover-Kincannon model were used to find out the model of the biological process in the reactor.

1.1.1 First order substrate removal model

The rate of change of substrate concentration in the system by assuming a first order model for substrate removal can be stated as follows [5]:

$$-\frac{dS}{dt} = \frac{QS_0}{V} - \frac{QS}{V} - k_1S \quad (1)$$

During pseudo-steady-state conditions, the rate of change of substrate concentration due to accumulation ($-dS/dt$) is ignored and the above calculation can be modified as follows:

$$\frac{S_0 - S}{HRT} = k_1S \quad (2)$$

The value of k_1 can be obtained by plotting $((S_0-S)/HRT)$ versus S in equation (2).

1.1.2 Strover-Kincannon model

In this model the rate of substrate use is expressed as a function of the rate of organic load by kinetic monomolecules for biofilm reactors such as RBC or biological filters. This model can be stated as follows [6]:

$$\frac{dS}{dt} = \frac{U_{max} \times (Q \times S_0 / V)}{K_B + (Q \times S_0 / V)} \quad (3)$$

Where (dS/dt) , the rate of use of the substrate is defined in equation (3).

$$\frac{dS}{dt} = \frac{QS_0}{V} \times (S_0 - S) \quad (4)$$

Equation (5) is obtained from linearization of equation (4) as follows:

$$\frac{V}{Q \times (S_0 - S)} = \frac{K_B}{U_{max}} \frac{V}{Q \times S_0} + \frac{1}{U_{max}} \quad (5)$$

2 Methods

2.1 Artificial water

Water characteristics used in this study were rainwater which is potentially polluted by gray water waste, where the water used is artificially made with the addition of chemicals so that its characteristics resemble water in the Cikapayang River in 2018.

Three variations of the C:N:P ration used in this study were 30:15:1, 75:25:2, and 180:35:3, the composition of artificial wastewater can be seen in **Table 1**.

The synthetic wastewater was prepared using glucose ($C_6H_{12}O_6$) as the carbon source, NH_4Cl as nitrogen source, KH_2PO_4 as phosphorus source, clay for TSS.

As for VSS, some addition of active microorganisms was taken from activated sludge of domestic WWTP in Bandung Jayakarta Hotel.

Table 1. Artificial wastewater composition

Parameter	Source	Concentration Variation (mg/L)		
		30	75	180
COD	$C_6H_{12}O_6$	30	75	180
Total Nitrogen	NH_4Cl	15	25	35
Total Phosphate	KH_2PO_4	1	2	3
TSS	Clay	90		
VSS	Activated sludge from aeration tank	2000		

2.2 Reactor configuration

This experiment was carried out with a laboratory scale reactor made of PVC pipe with a volume of 10.78 L and a dimension of 1.4 m (length) \times 0.165 m (diameter). PVC pipe along the 1.4 m with a diameter of 6 inches or equivalent to 165 mm halved in parallel, installed 6 (six) 1 cm porous bulkhead. Dimensions of artificial material support of 3.0 cm \times 3.0 cm \times 3.0 cm with a volume of 27 cm^3 results in the amount of media (material support) of 14 media per sampling point by taking into account the fill fraction below 70%, and placed at 7 (seven) sampling points along the reactor. Placement of media in the reactor is carried out by stratification and there is no variation in the placement or amount of media for the 3 (three) typical reactors. The scheme of the experimental system in the form of a reactor configuration in this study can be seen

By using water absorption capacity variable, the absorption capacity media could be calculated. The test was performed by placing a block of media (size 3 cm × 3 cm × 3 cm) in a 100 mL of measuring cup. The residence time of the media were varied in 4 variations: 5 minutes, 3 hours, 24 hours, and 90 hours. After the residence time, media was taken to get the remaining volume. The percentage of absorbed water in the media was counted as the water absorption capacity.

3 Results and discussion

3.1 Preliminary test

This preliminary test is intended to see the ability of artificial material support in removing organic pollutants and nutrients for a specified time of 3 hours, 24 hours, and 90 hours with the assumption that there is no growth of biomass in the system.

3.1.1 Total nitrogen removal

The removal efficiency of total nitrogen in the preliminary test was up to 87% with the lowest removal efficiency of 30%. Elimination of total nitrogen in three variations of total influent concentration of nitrogen can be seen in **Figure 2**. Elimination of nitrogen compounds in bioreactors can only occur using simultaneous nitrification and denitrification (SND) by denitrifying heterotrophic and nitrifying autotrophic bacteria [8]. In the case of an aerobic PFR system, the total nitrogen removal cannot be done thoroughly. In this experiment, influent concentration and HRT value affect the efficiency of total nitrogen removal in the system. In a HRT condition of 90 hours with an influent concentration of 25 mg TN/l, the highest removal efficiency was 87%. This can be due to the increase in HRT resulting in an increase in biofilm thickness due to a decrease in pressure so the nitrification process was starting to develop denitrification process with anoxic environmental conditions.

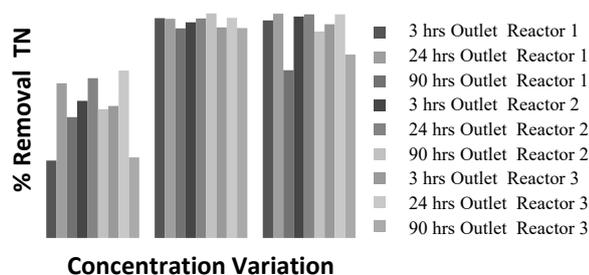


Figure 2. Total nitrogen removal in preliminary test

3.1.2 Total phosphate removal

The efficiency of total phosphate removal (**Figure 3**) in the preliminary test obtained the highest yield of 71% and the lowest yield of 15%. The biological process of

phosphate removal occurs in two stages; anaerobic and aerobic. The highest removal efficiency of total phosphate was found in 24-hour HRT with an influent concentration of 1 mg TP/l. The presence of phosphate compounds in the system in a dissolved form, so that the removal mechanism of total phosphate compounds can be through absorption, which according to [8] release of orthophosphate and accumulation of polyhydroxybutyrate (PHB) is achieved through absorption of phosphate in the aerobic area. In embedded growth systems, it is not possible to control the total phosphate removal in the system, as the value of solids retention time (SRT) is long enough and the release of biomass cannot be controlled. In the attached growth system, long SRT can cause a polyphosphate-accumulating organisms (PAO) accumulation, and the released orthophosphate is at a much higher level than influent concentration.

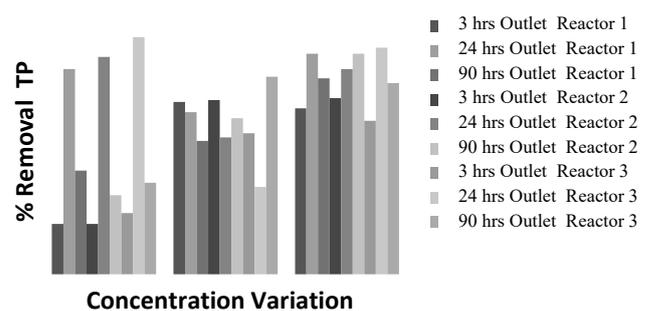


Figure 3. Total phosphate removal in preliminary test

3.1.3 Organic removal (COD)

The COD removal efficiency (**Figure 4 (a) and (b)**) in the preliminary test obtained the highest removal of 79% and the lowest removal of 30%. In the biological processing, organic matter acts as a basic energy needed by microorganisms. COD removal in the system can occur due to absorption mechanism so that it is absorbed into the pores of the media and absorption by aerobic microorganisms and psychochemical adsorption on the surface of biological floc. The highest efficiency of COD removal was found in HRT 3 hours with an influent concentration of 75 mg COD/l. In this case, assuming there is no growth of microorganisms in the system, the removal mechanism occurred was the organic molecules absorption into the fiber media. The COD removal process in the PFR system that showed a fluctuating results with a fairly good trend. Increasing and decreasing the value of COD removal at each point in the PFR is considerably because of the ability of the media to absorb organic compounds in dissolved form and flow velocity in the system. The media was placed in a randomly distributed system with a uniform amount, but the position of the media in the system also affects the absorption ability in absorption, where the media is spread evenly in the observation point will absorb more organic molecules that pass through the media.

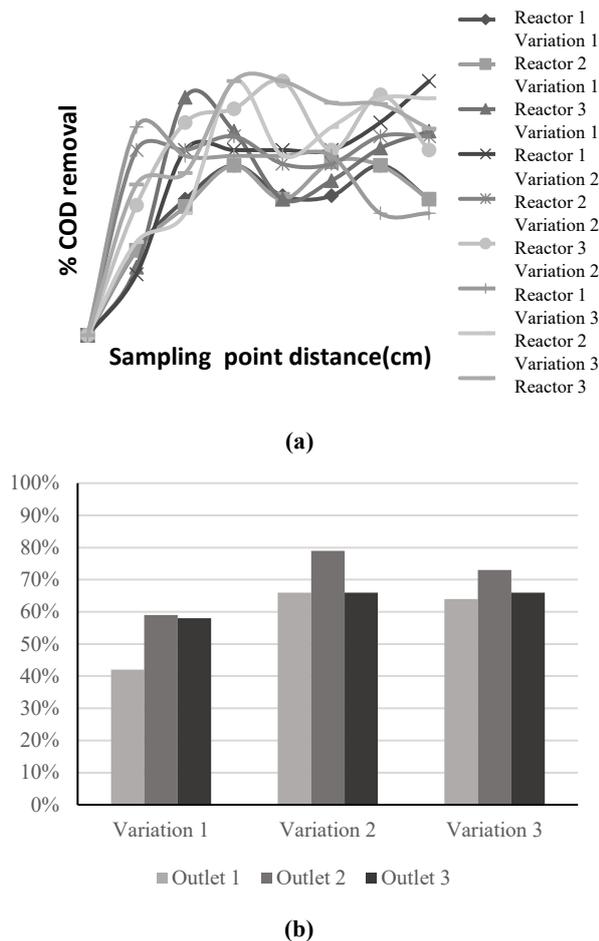


Figure 4. COD Removal in preliminary test in (a) different sampling point (cm) (b) three variation of HRT

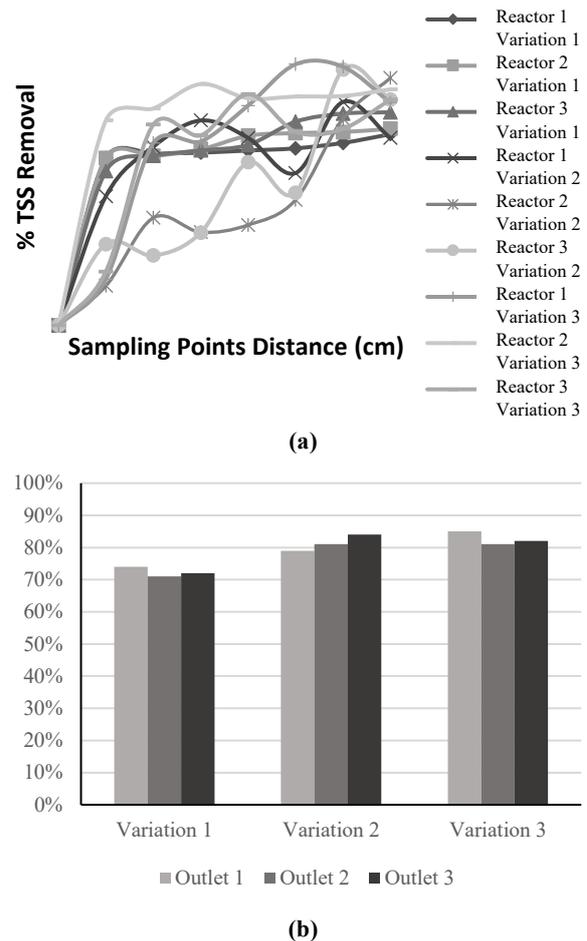


Figure 5. TSS Removal in preliminary test in (a) different sampling point (cm) (b) three variation of HRT

3.1.4 Total suspended solid removal

The TSS removal efficiency (**Figure 5 (a) and (b)**) in the preliminary test reached 85% with the minimum value of 71%. The removal mechanism of suspended particles could be occurred by filtration by the media inside the system. TSS parameters are compounds with the highest success rate in the preliminary test of the ability to remove pollutants by artificial support material. Filtered TSS particles then identified through changes in color and texture of artificial support material, where an 85% allowance is found in HRT 3 hours with an influent concentration of 90 mg TSS/l showing the media in reactor 1 is yellowish according to the TSS source used ie soil clay, and slam starts to form. The results of previous study [9] showed that the longer contact time in the filtration process, the better the diffusion and adhesion of adsorbate molecules takes place.

3.2 Aerobic continuous running system

The performance of removal of organic content in the PFR system under steady-state conditions can be seen in **Table 3**. The COD removal results indicate a fairly good

efficiency in all three variations of the experimental concentration, where the highest efficiency was 79% at HRT 2.7 hours with a concentration influent 75 mg COD/l, and the lowest efficiency of 47% at 19.4 hr HRT. In this experiment, the variation of HRT of 19.4 hours showed to be the lowest average removal (50.3%) compared to HRT of 2.7 hours and 7.7 hours. This might be caused by the slow flowrate of the water which resulting in changes of the flow direction in the media and affects the organic removal process by aerobic microorganisms attached to the media. According to [1] higher water flow velocity occurs in macropores and lower water flow velocity occurs in micropores.

3.3.1 First order substrate removal model

In the first order substrate removal model, the k_1 value was obtained from the plot line slope $(S_0-S)/HRT$ against S . **Figure 7 (a)** shows the results of the plot line $(S_0-S)/HRT$ against S , and the k_1 values for HRT 2.7 hours, 7.7 hours and 19.4 hours are 14.31/day, 10.40/day, and 0.99/day with correlation coefficients of 0.89, 0.98, and 0.94 respectively. The correlation coefficient (R^2) for 2.7 hour HRT indicates that the first order substrate removal model cannot be applied because the level of precision is

less than the maximum. According to [5], in the first order substrate type removal reaction model, the removal rate is initially high under conditions of high organic content, but progressively slows down as the utilization of organic matter in the system.

3.3.2 Stover-Kincannon model

In the Stover-Kincannon model, the K_B value is obtained from the slope of the plot line $V/Q (S_0-S)$ against $V/(Q \times S_0)$. Through linear regression, slope and intercept can be determined. The saturation constant value (K_B) and the

maximum substrate use rate (U_{max}) are calculated from the line plots in **Figure 7 (b)** and produce values of -3728.2 g l/day and -2000 mg COD l/day for HRT 2, 7 hours, -1860 gl / day and -1000 mg COD l/day for HRT 7.7 hours, -1097.5 g l / day and -500 mg COD l / day for HRT 19.4 hours These results indicate the removal of substrate by microorganisms during the time of contact and maximum substrate removal by aerobic organisms with respect to time. From the correlation coefficient for HRT 2.7 hours, 7.7 hours and 19.4 hours respectively 0.98, 0.99 and 0.99, the Stover-Kincannon model can be used to predict behavior and design in the system PFR in this case.

Table 3. Experimental data obtained under steady-state conditions at nine different HRTs

Parameter	HRT (h)								
	2.7	2.7	2.7	7.7	7.7	7.7	19.4	19.4	19.4
Operation period (day)	0-10	11-20	21-30	0-10	11-20	21-30	0-10	11-20	21-30
Influent COD (mg/l)	30	75	180	30	75	180	30	75	180
Efluent COD (mg/l)	13	16	64	13	26	48	16	32	96
Removal Efficiency COD (%)	57	79	64	57	65	73	47	57	47

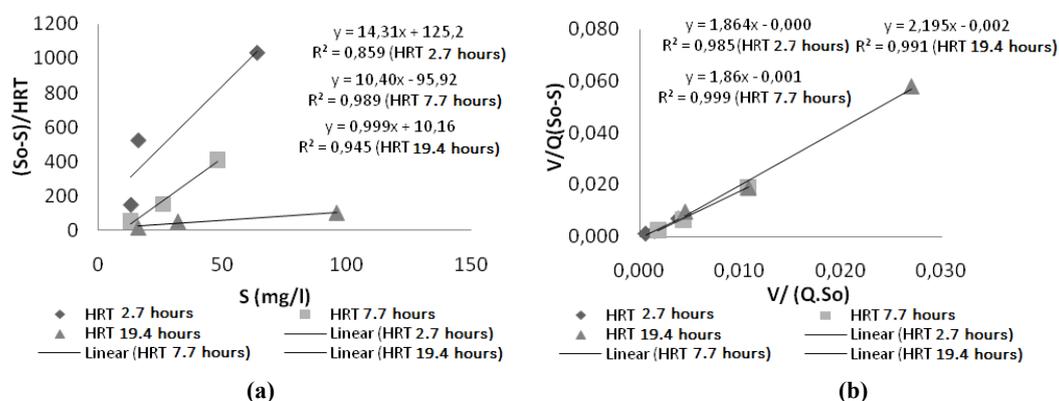


Figure 7 (a) First order substrate removal model **(b)**Stover-Kincannon model

3.3 SEM observations

SEM analysis used to observe the growing biomass in the media during seeding. **Figure 8** shows the appearance of microorganisms that utilize the substrate and nutrient source in the system, where the microorganisms are attached to the surface of the media and covered by filtered clay into the media. Three sample cell size captured in the figure were 5.28 μm , 5.19 μm and 5.27 μm . The shape of microorganism cells detected on the surface of the artificial support material is coccus. Based on **Figure 8**, it can be seen that artificial support media displays an essentially lacunar structure with crossed fibres and scattered balls [1].

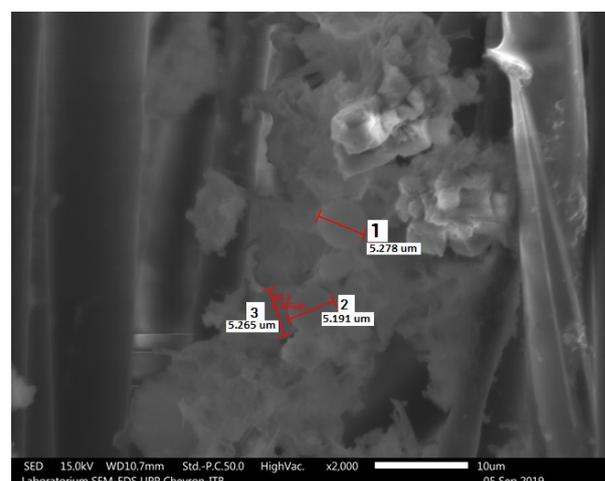


Figure 8 Solid matrix structure using SEM analysis

3.4 Water absorption capacity test

With the residence time of 5 minutes, 3 hours, 24 hours, and 90 hours, the absorption capacity of the media is 24%, 31%, 19%, and 23% for each residence time. The highest efficiency is obtained at a residence time of 3 hours by 31% of water absorbed into the media. At a residence time of 24 hours there is a decrease in efficiency, it is indicated that at this time the media is starting to experience saturation with aquadest absorption, and efficiency was going back to increase at a residence time of 90 hours. Based on the 2017 Drainblock Catalog, the tested media are cleanblocks that are used for preliminary treatment as biological wastewater treatment, where the surface of the media can allow bacterial colonization. According to [10] in a saturated rockwool slice structure condition, the direction of flow spread horizontally.

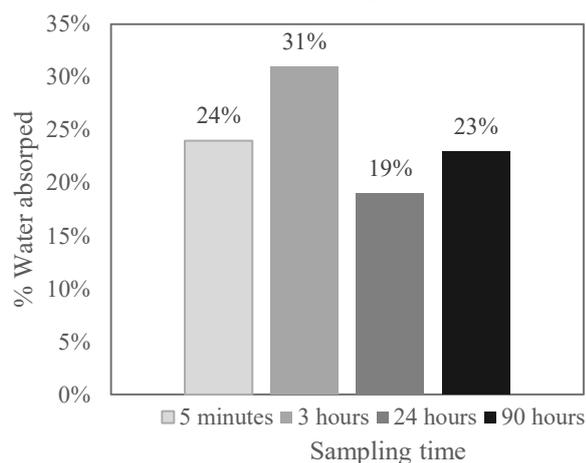


Figure 9. Water absorption capacity

5. Conclusion

The removal efficiency of total nitrogen, total phosphate, COD, and TSS in the preliminary test obtained the highest results of 87%, 71%, 79%, and 85%, respectively. While the removal mechanism of dissolved compound molecules such as total nitrogen, total phosphate, and COD were absorbed by artificial support material, TSS is removed was by filtration mechanism. After three different HRTs were examined, organic removal performance shown that the highest efficiency was 79% at 2.7 hours HRT with an influent concentration of 75 mg COD/l, and the lowest efficiency by 47% on HRT 19.4 hours.

The Stover-Kincannon model can be used to predict behavior and design in the PFR system in the case of this experiment with correlation coefficients for HRT 2.7 hours, 7.7 hours and 19.4 hours respectively of 0.98, 0.99, and 0.99. After seeding,

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