

TREATMENT OF PALM OIL MILL EFFLUENT (POME) SUPERNATANTS USING AEROBIC ATTACHED-GROWTH SYSTEM: TRICKLING FILTER AS A CASE STUDY

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Abstract. This paper discusses the efficiency of a trickling filter to treat Palm Oil Mill Effluent (POME) supernatants. POME supernatants were obtained via two treatments. In Treatment 1, gravity sedimentation was used to remove settleable solids. In Treatment 2, both settleable solids and colloidal particles were removed using 350 ppm of alum. The influents were allowed to trickle over biomass attached to 1 m high random PVC solid support. Below $1 \text{ m}^3/\text{m}^2\text{-day}$, the filter demonstrated Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) removal efficiencies of more than 90.0%. At $2.53 \text{ m}^3/\text{m}^2\text{-day}$, the influent with Treatment 1 gave a COD removal efficiency of 40.3%, but increased to 83.1% when the influent with Treatment 2 was used. This was ascribed to the removal of non-diffusible organics during Treatment 2. The removal efficiencies decreased with an increase in hydraulic loading due to limitations in the hydrolysis of non-diffusibles into soluble substrates. With recirculation ($\alpha=1$), higher BOD and COD removals were achieved below $7.0 \text{ m}^3/\text{m}^2\text{-day}$, attributed to lower organic loading and the recycling of active enzyme and biomass to the system. The influent with Treatment 2 demonstrated higher sludge production due to higher conversion of soluble substrates into insoluble biomass. Hydrolysis of non-diffusible organics mainly took place at upper reaches of the filter column while lower reaches were involved in oxidizing the organic substrates.

Keywords: POME, trickling filter, diffusible organic, coagulation, recirculation

Abstrak. Kertas kerja ini membincangkan tentang kecekapan penuras curur dalam merawat supernatan kumbahan kilang kelapa sawit (POME). Supernatan POME diperoleh menerusi dua jenis perawatan. Dalam Perawatan 1, pengendapan graviti digunakan untuk menyingkir pepejal boleh mendak. Perawatan 2 digunakan untuk menyingkir pepejal boleh mendak dan gumpalan partikal dengan menggunakan 350 ppm alum. Influen dialurkan secara titisan pada biojisim yang terlekat pada penyokong pepejal rawak PVC setinggi 1 m. Penuras curur berupaya menyingkir lebih daripada 90.0% dari keperluan oksigen biologi (BOD) dan keperluan oksigen kimia (COD) di bawah $1 \text{ m}^3/\text{m}^2\text{-hari}$. Pada $2.53 \text{ m}^3/\text{m}^2\text{-hari}$, influen dengan Perawatan 1 menghasilkan kecekapan penyingkiran COD sebanyak 40.3%, berbanding 83.1% bila Perawatan 2 digunakan. Perkara ini berlaku berikutan penyingkiran bahan organik tak boleh resap semasa Perawatan 2. Kecekapan penyingkiran menurun dengan meningkatnya bebanan hidraulik kerana wujudnya kelemahan dalam hidrolisis bahan tak boleh resap kepada substratum larut. Dengan edaran semula ($\alpha=1$), penyingkiran BOD dan COD yang lebih tinggi dicapai di bawah $7 \text{ m}^3/\text{m}^2\text{-hari}$. Pencapaian ini disebabkan oleh bebanan organik yang lebih rendah serta pergedaran semula enzim dan biojisim yang aktif kepada sistem. Perawatan 2 menghasilkan enap cemar yang lebih tinggi kerana penukaran substratum boleh larut kepada

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biojisim tak boleh larut. Hidrolisis bahan organik tak boleh resap didapati berlaku secara aktif pada bahagian atas penuras cucur sementara bahagian bawahnya cenderung mengoksidakan substratum organik.

Kata kunci: POME, turas cucur, bahan organik bolehresap, penggumpalan, alir semula

1.0 INTRODUCTION

The palm oil industry, apart from being a major foreign exchange earner for Malaysia, is also identified as the single largest source of water pollution. It produces a large volume of highly polluting effluents, for instance, 2.5 tonnes of Palm Oil Mill Effluent (POME) is generated for every tonne of crude palm oil produced [1]. Typical quality of POME is given in Table 1.

Trickling filter has a great potential to serve as an alternative treatment system for a strong industrial wastewater like POME. It offers a non-energy intensive process with far less operating area requirement. Generally, this biofiltration process is able to withstand shock load and influent quality fluctuation [3]. Trickling filter is densely populated by a wide range of microorganisms, of which facultative bacteria are predominant [4]. With aerobic, anaerobic as well as nitrifying bacteria populating the trickling filter, the wastewater can be treated with high efficiency using this treatment method [5].

In a trickling filter, the microorganisms grow as a biofilm on an immobile solid support over which the liquid flows in thin sheets. Substrate must be transported from the bulk of the liquid into the interior of the biofilm. In the presence of particulates, this process faces both external and internal resistance to mass transfer [6,7]. Non-diffusible organics have to be hydrolysed by extracellular enzymes to compound sufficiently small to be diffusible [8]. This is the rate-limiting step in the organic stabilisation process in a trickling filter system [7]. Most of the organic substrates in

Table 1 Typical quality of fresh POME [13]

Parameter*	Range	Mean
BOD**	10250 – 47500	25000
COD	15500 – 106360	53630
TS	11450 – 164950	43645
SS	410 – 60360	19020
O&G	130 – 86430	8370
NH ₃ -N	0 – 110	35
T-N	180 – 1820	770
pH	3.8 – 4.5	4.1

(*): All in mg/l except pH.

(**): 3 days @ 30°C.

POME are of sizes that do not allow diffusion into the biofilm [9]. As such, the removal of this fraction is the critical step in ensuring the high efficiency of a trickling filter.

The purpose of this study is to gauge the performance of a trickling filter as a model of aerobic attached-growth system to treat POME supernatants. The influents were prepared via gravity sedimentation, in combination with chemical coagulation so that they were without most of their settleable solid and colloidal particulate. The performance of the filter was scrutinised on the basis of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) removal efficiencies, which were flow rate-independent and corresponding removal rates, which are flow rate-dependent. The effects of recirculation as the only way through which hydraulic and organic loadings could be adjusted independently on the filter's efficiency were also characterised. Attempts were also made on characterising the behaviour of sludge production, as well as the profile of biomass attachment on the solid support of the trickling filter.

2.0 MATERIALS AND METHODS

2.1 Preparation of POME Supernatants

The preparation of the trickling filter influents was as summarised in Table 2. The supernatant obtained through Treatment 1 contained only soluble solids and colloidal particles as the settleable solids had been removed in the sedimentation process. Further removal of both settleable solids and colloidal particles was achieved with Treatment 2. For both treatments, the pH of the influents was adjusted to 6 using a Sodium Hydroxide (NaOH) solution.

Table 2 Preparation of POME supernatants as influents to the trickling filter

Treatment	Description
1	POME was first mixed with water at a ratio of 1:5 and allowed to settle for 20 minutes. Upper layer supernatant was then siphoned out and its pH was adjusted to 6 using NaOH solution.
2	POME was first mixed with water at a ratio of 1:5. 350 ppm of alum was then added and allowed to settle for 20 minutes. Upper layer supernatant was then si phoned out, its pH was adjusted to 6 using NaOH solution.

2.2 Trickling Filter Set-up

The trickling filter was constructed as schematically shown in Figure 1. It comprised of a holding tank, a pump, a filter column, a flow distributor, and a settling tank. The filter column was prepared using a 4" internal diameter PVC pipe. The solid supports for biofilm attachment (Figure 2) were prepared using tubes for packing of P-DIP devices in semiconductor industry that were cut into units of approximately 15 mm

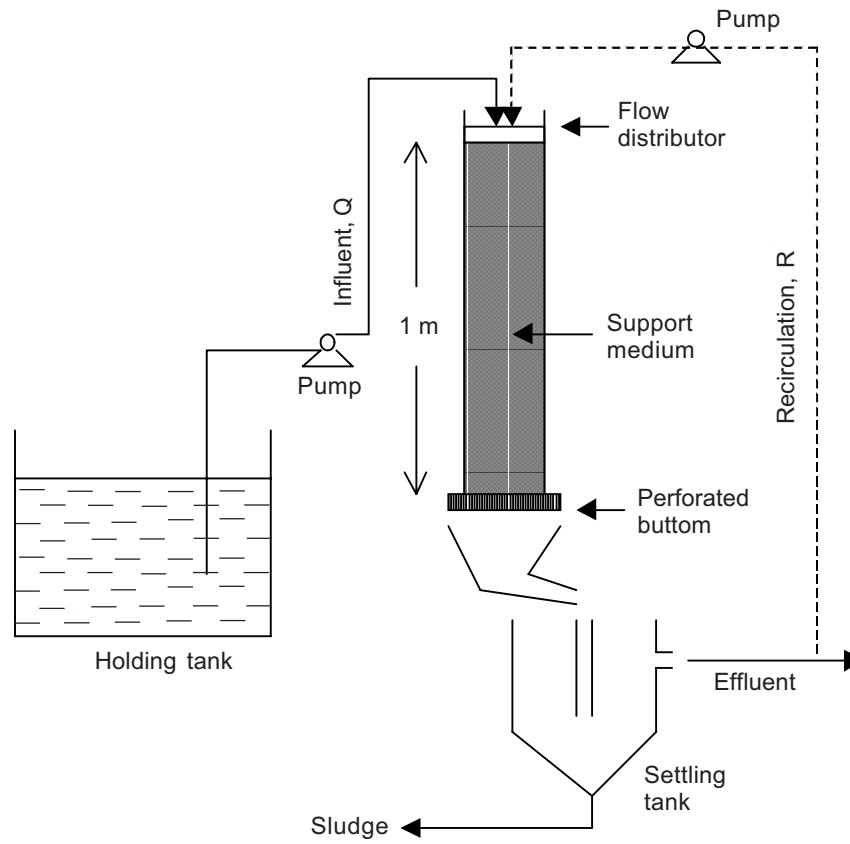


Figure 1 Schematic diagram of trickling filter used

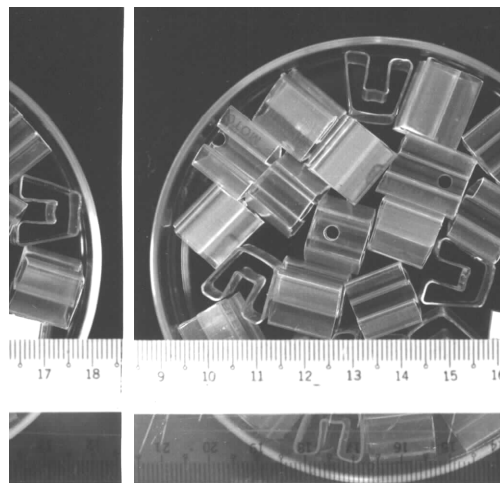


Figure 2 The trickling filter solid support used for biomass attachment

Table 3 Physical properties of the solid support

Physical property	Value/type
Material of built	PVC
Average length	15 ± 1 mm
Density	1330 kg/m ³
Void space	88%
Mass/unit volume	162 kg/m ³

length. The solid supports were randomly packed in the filter column so that the overall height was 1 m. The physical properties of the solid support are given in Table 3.

The hydraulic loading to the filter was calculated as the amount of influent (both untreated and recirculation flows) applied to the filter's cross sectional area.

$$\text{Hydraulic loading} = \frac{Q + Q_R}{A} \quad (1)$$

where Q was the raw influent flow (m³/day), Q_R was the recirculation flow (m³/day), and A was the cross sectional area of the filter (m²). The organic loading rate (OLR) was calculated as the primary influent COD applied to the filter, with no regards to the chemical oxygen demand (COD) contribution from the recirculated flow.

$$\text{OLR} = \frac{\text{COD loading}}{V_m} \quad (2)$$

where COD loading represented the COD applied to the filter (kg/day), while the volume of filter media (V_m) considered both the volume of support bed and the void (m³). The recirculation ratio (α) was defined as the ratio of the recirculated flow (Q^R) to the primary influent flow rate (Q).

$$\alpha = \frac{Q_R}{Q} \quad (3)$$

The BOD and COD removal rates (kg/day) were calculated as:

$$\text{Removal rate} = Q(\text{OD}_{\text{inf}} - \text{OD}_{\text{eff}}) \quad (4)$$

where OD was either BOD or COD, and the subscript inf and eff denoted influent and effluent, respectively.

The sludge production rate (kg/day) was defined as:

$$\text{Sludge production rate} = Q(\text{SS}_{\text{in}} - \text{SS}_{\text{out}}) \quad (5)$$

where SS_{in} and SS_{out} represented the concentration of suspended solids at the inlet and outlet of the settling tank respectively.

The trickling filter was operated under room temperature ($29 \pm 2^\circ\text{C}$) throughout the experiment. The pre-calibrated peristaltic pumps were used to vary the flow rate of the influent and consequently varied the hydraulic loading to the filter.

2.3 Start-up

During the start-up, the filter was seeded with a mixture of fresh POME and POME anaerobic sludge (1:1) to introduce initial biomass attachment to the solid support. The filter was then operated for 4 weeks in a loop flow with intermittent replenishment of the wastewater using the same mixture. All the tests were conducted according to APHA standard methods [10].

2.4 Biomass Dry Weight

Biomass attachment study was performed by dividing evenly the filter column into four imaginary zones. 50 units of solid supports were taken out from each zone and dried at 105°C for 6 hours.

3.0 RESULTS AND DISCUSSION

3.1 Changes in Organic Loading Rate with Hydraulic Loading

The quality of fresh POME and influents pumped into the trickling filter after Treatment 1 and Treatment 2 are shown in Table 4. In order to facilitate the calculation of process variables, mean values were used as the initial concentrations. Figure 3 shows changes in the organic loading rates (OLR) with changes in hydraulic loading. The R^2 value obtained for every type of influent suggested that only a maximum remaining of 1.6% of the variance in the OLR was associated with a variation in influent COD. The figure also shows that recirculation could increase the hydraulic loading to the filter.

Table 4 Quality of fresh POME and influent to the filter after Treatment 1 and Treatment 2

Parameter (mg/l)	Fresh POME		After Treatment 1		After Treatment 2	
	Range	Mean	Range	Mean	Range	Mean
BOD*	22352 – 27305	25029	2660 – 2930	2805	2420 – 2518	2494
COD	39178 – 70083	58800	4928 – 5379	5080	3463 – 4373	3952
SS	18464 – 29140	23707	550 – 660	596	90 – 183	139

(*): 3 days @ 3°C .

3.2 BOD and COD Removal Efficiencies

The profiles of BOD and COD removal efficiencies are depicted in Figures 4 and 5, respectively. It is noted that removal efficiencies of more than 90.0% for both parameters

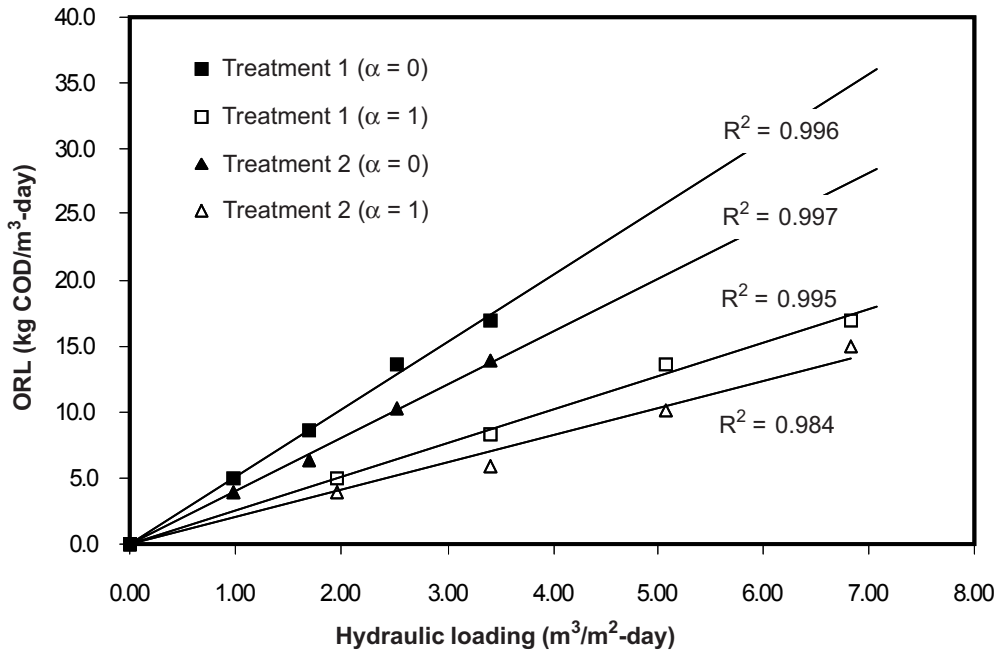


Figure 3 Organic loading rate (OLR) as a function of hydraulic loading for both types of influent, with ($\alpha=1$) and without recirculations

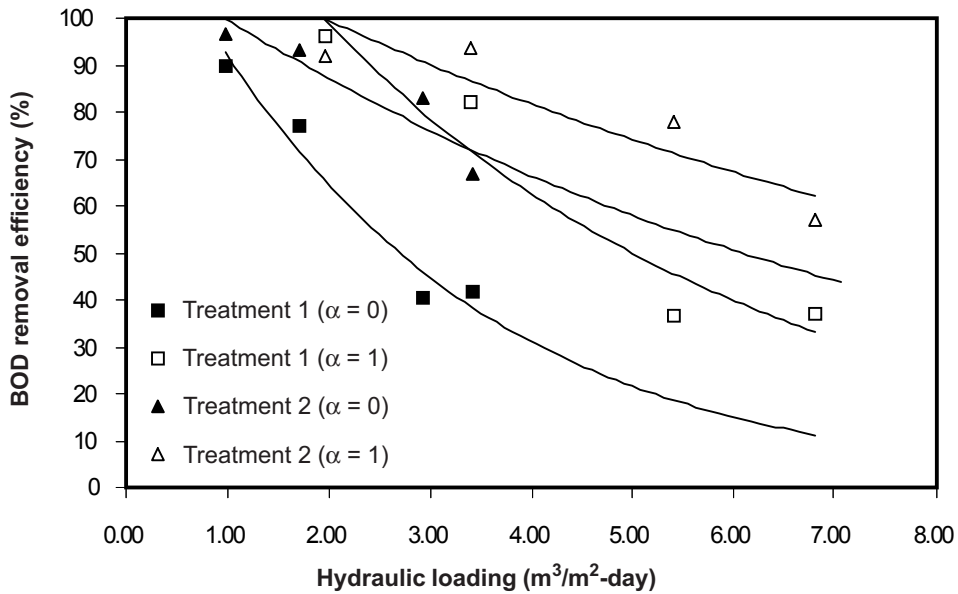


Figure 4 Changes in the BOD removal efficiencies as a function of hydraulic loading for both types of influent, with ($\alpha=1$) and without recirculations

were achieved below $1 \text{ m}^3/\text{m}^2\text{-day}$, regardless of the type of influent used. These removals were considered high compared to other conventional treatment methods such as ponding or activated sludge. The removal of colloidal particles through chemical coagulation (Treatment 2) had sharply increased the efficiency of the filter. For example, at a hydraulic loading of $2.53 \text{ m}^3/\text{m}^2\text{-day}$, a COD removal efficiency of 40.3% was achieved for influent with Treatment 1 (Figure 5). When the influent with Treatment 2 was used, the corresponding removal efficiency increased to 83.1%.

As the hydraulic loading was increased, BOD and COD removal efficiencies significantly dropped, especially when POME with Treatment 1 was used as the influent. When the hydraulic loading was increased from 1.0 to $3.5 \text{ m}^3/\text{m}^2\text{-day}$, the BOD removal efficiency suffered a 51.0% drop when influent with Treatment 1 was used. With the removal of colloidal particles, in addition to settleable solid with Treatment 2, the corresponding drop in the removal was only 26.0%.

Figures 4 and 5 also suggest that with recirculation ($\alpha=1$), high removal efficiencies could be maintained over higher hydraulic loading. For example, a COD removal efficiency of 90.0% was achieved at a hydraulic loading of about $1 \text{ m}^3/\text{m}^2\text{-day}$ for the influent with Treatment 1 (Figure 5). With recirculation, the same efficiency was achieved at about $2.5 \text{ m}^3/\text{m}^2\text{-day}$. Generally, the effect of recirculation was more significant on COD removal efficiency compared to BOD removal efficiency.

Improvements in removal efficiencies after chemical coagulation were attributed to the absence of the non-diffusibles from the influent [11]. Colloidal particles were

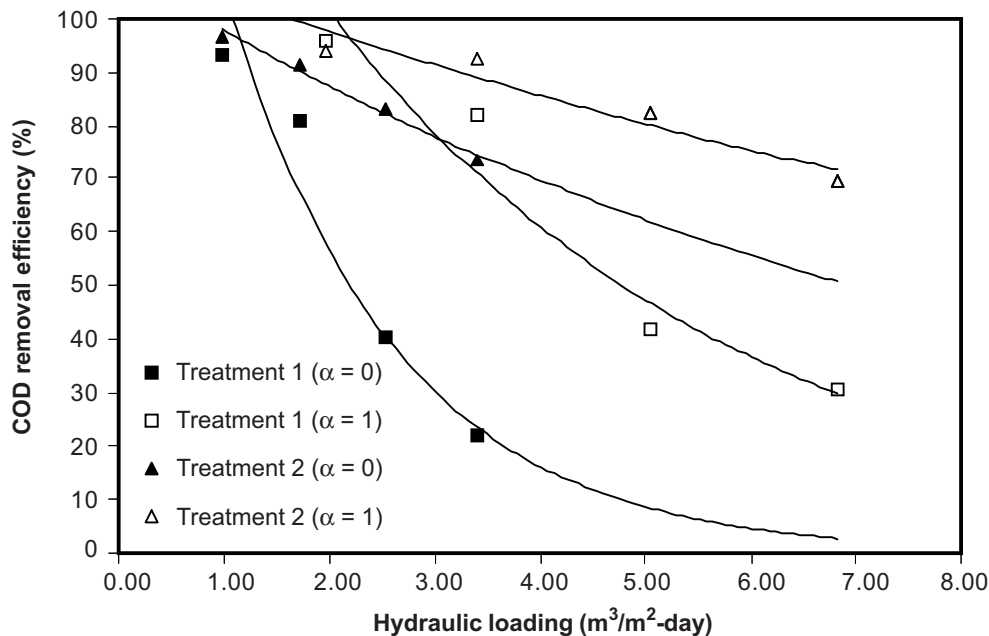


Figure 5 Changes in the COD removal efficiencies as a function of hydraulic loading for both types of influent, with ($\alpha=1$) and without recirculation

hydrolysed into soluble substrates before they could be utilised by the microorganisms in the filter system [12]. This stage was the rate limiting stage [7] in trickling filter system. The chemical coagulation process in Treatment 2 removed most of the colloidal particles leaving behind predominantly soluble organics that were direct substrates to the microorganisms in the biofilm.

A drop in BOD and COD removal efficiencies with increasing hydraulic loading were found to be steeper for influent with Treatment 1 as compared to that of with Treatment 2. This result indicated that hydrolysis of non-diffusibles into soluble substrates furnished more limiting effect to the overall organic stabilisation process. In this case, the removal rate of the external carbon source would decrease as the hydraulic loading increased, as explained by Rohold and Harremöes [7].

Recirculation at a ratio of 1, which was considered as low [13], improved BOD and COD removal efficiencies by weakening the strength of the influent to the trickling filter through the dilution effect by the effluent. As a consequence, the organic loading to the filter was lowered. However, recirculation also increased the hydraulic loading applied to the filter so that the effects of dilution were capped by the effects of mass transfer resistance. The higher flow rate of liquid over the biofilm at higher hydraulic loading also caused the excessive sloughing of the biofilm and enzymatic washout from the system.

Based on removal efficiencies of more than 90.0% for influents BOD and COD at about 3,000 ppm and 5,000 ppm, respectively, the trickling filter was found to be the potential alternative to the conventional ponding treatment system in treating POME. This treatment method offers some advantages such as lowering the operating area and energy requirements, while releasing less objectionable odour compared to ponding treatment method. In addition, the high removal efficiencies of more than 90.0% were achieved at an organic loading rate (OLR) of about 5 kg COD/m³-day. This OLR was significantly higher than 2.4 kg COD/m³-day that was reported for the ponding treatment method to achieve similar efficiency by Ma [2].

3.3 BOD and COD Removal Rates

Changes in BOD removal rates with hydraulic loading are shown in Figure 6. Without recirculation, the removal rate increased with increasing hydraulic loading until about 2.5 m³/m²-day. Further increase in the hydraulic loading caused the effect of flow rate increase to be more dominant, resulting in a reduction in the BOD removal rates. This was due to less contact time between the organic substrates and the biofilm in the trickling filter. Similar trend could also be observed in the COD removal rates except no drop in the COD removal rate was observed for the influent with Treatment 2 below 3.5 m³/m²-day (Figure 7).

Without recirculation, the influent with Treatment 2 gave higher BOD and COD removal rates. The predominantly soluble organics in the influent with Treatment 2 easily penetrated into the bacterial cells to be metabolised. Degradation of those soluble

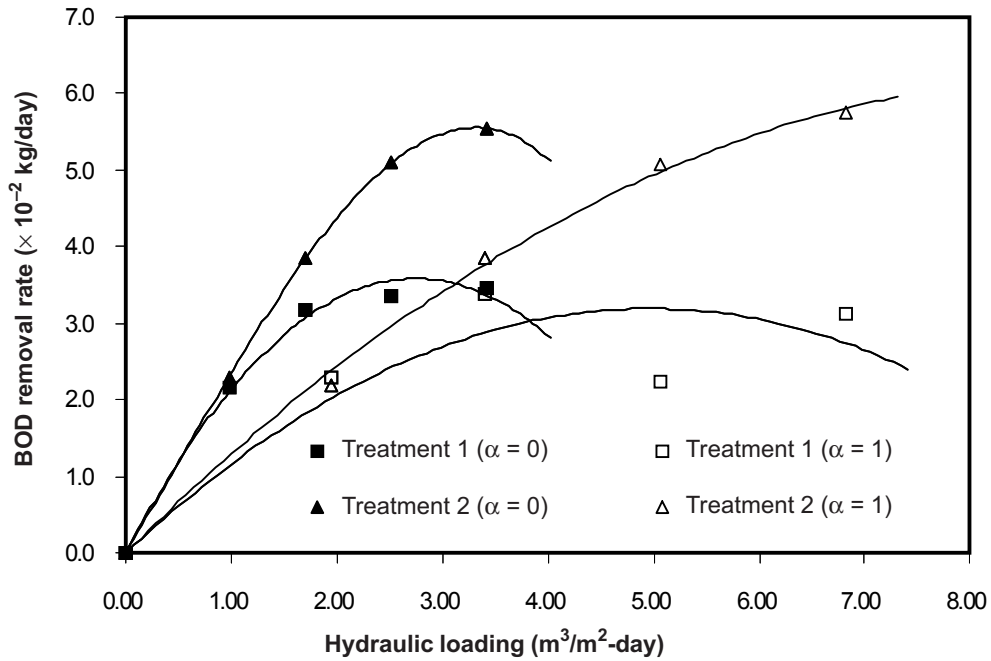


Figure 6 Changes in the BOD removal rates as a function of hydraulic loading for both types of influent, with ($\alpha=1$) and without recirculations

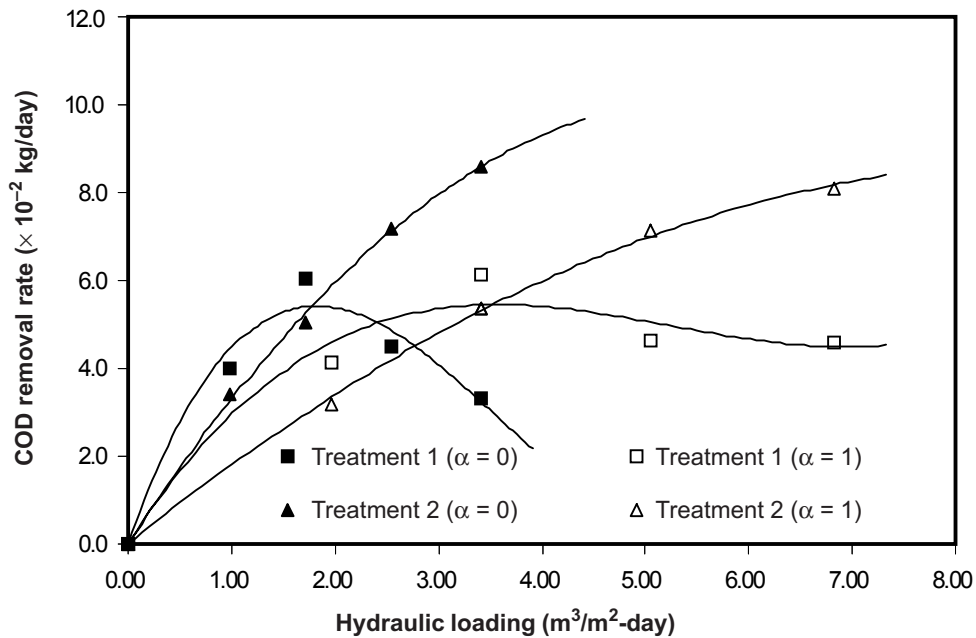


Figure 7 Changes in the COD removal rates as a function of hydraulic loading for both types of influent, with ($\alpha=1$) and without recirculations

organics then took place with the rate of metabolism as the limiting factor [12]. Since the rate of metabolism was several orders of magnitude higher compared to the rate of hydrolysis of non-diffusibles into soluble substrates [8], the higher removal efficiencies of BOD and COD resulted.

When the recirculation was employed, the filter was found to be capable of sustaining high BOD and COD removal rates over higher hydraulic loading. Figures 6 and 7 show that optimum removal rates were achieved at a hydraulic loading of $5 \text{ m}^3/\text{m}^2\text{-day}$ for BOD or $4 \text{ m}^3/\text{m}^2\text{-day}$ for COD for influent with Treatment 1. With the influent from Treatment 2, no drop in BOD and COD removal rate was observed below $7 \text{ m}^3/\text{m}^2\text{-day}$.

The high removal rates of both BOD and COD with recirculation were due to several reasons. Apart from the reduction in the organic loading to the filter, it also increased the biological mass solids in the treatment system. Part of the washed out bacteria and enzymes were also returned to the system [13]. All these factors enabled higher organic stabilization efficiency to be achieved by the trickling filter.

3.4 Sludge Production

The profile of sludge production rates with hydraulic loading is shown in Figure 8. Both influents with Treatment 1 and Treatment 2 gave increasing sludge production rate with increasing hydraulic loading. At lower hydraulic loading and without

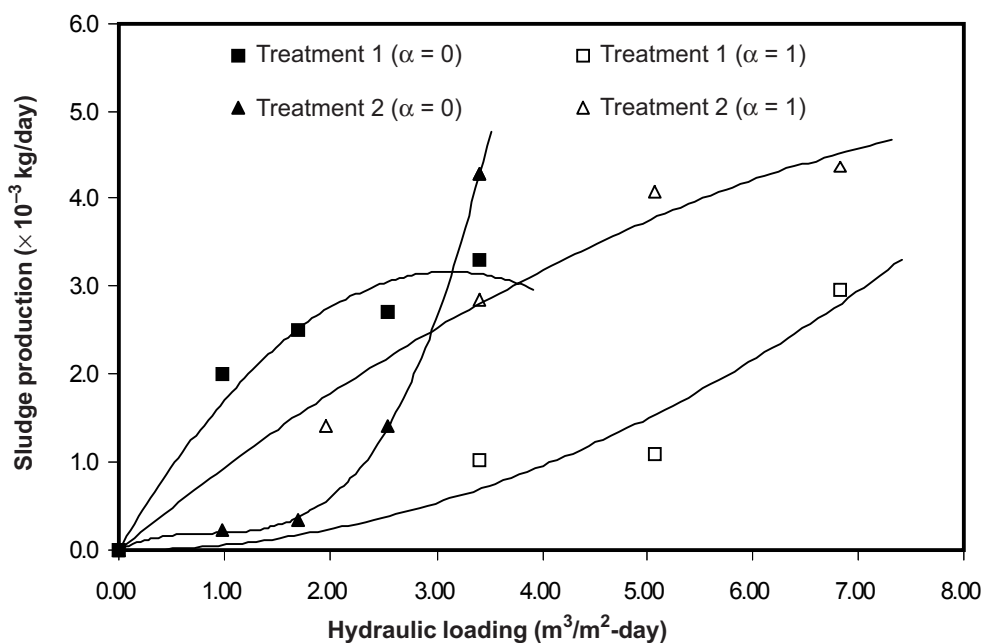


Figure 8 Changes in the sludge production rates as a function of hydraulic loading for both types of influent, with ($\alpha=1$) and without recirculations

recirculation, the influent with Treatment 1 demonstrated higher rates than that of Treatment 2. However, the sludge production for influent with Treatment 2 increased rapidly and exceeded that of influent with Treatment 1 at around $3 \text{ m}^3/\text{m}^2\text{-day}$. This result suggested that with the absence of most of settleable and colloidal solids in the influent with Treatment 2, more sludge was produced. The higher sludge production was ascribed to conversion of soluble substrates into insoluble biomass in the filter, coupled with more biomass sloughing at higher hydraulic loading.

When recirculation was used, the influent with Treatment 1 gave lower sludge production at lower hydraulic loading. This could be due to excessive amount of non-diffusible organics in the influent that were not utilized by the microorganisms in the biofilm. Thus, only small fractions of these organics were converted into non-soluble biomass. At a higher hydraulic loading, shear force caused by the liquid flow acted on the biofilm to promote excessive sloughing.

3.5 Biomass Attachment on Solid Support

The biomass attached on the trickling filter solid support was in the form of biofilm that was predominantly inhabited by bacteria and fungi [6]. These microorganisms constituted the main producers of exopolysaccharide (EPS) materials which are secondary metabolites produced during stationary phase of microbial growth [14]. These materials imparted viscosity to the biofilm and enhanced immobilisation of microbial consortium, thus preventing its wash-off [6].

The profile of biomass dry weight attached to trickling filter solid support in different imaginary zones of the filter column is shown in Figure 9. It was found that the upper reach of the filter were predominantly occupied by biomass and it gradually decreased to the lower zones. For example, moving from zone 1 to zone 4 of the trickling filter, the amount of biomass dropped by almost 70%.

The mode of reaction in trickling filter column varied with location. The biofilm at the upper reach of the trickling filter column actively hydrolyzed non-diffusible organics into soluble substrates. Meanwhile, the biomass at the lower reach of the column received and utilized these soluble substrates as their external carbon source. Thus, the stabilisation of organics in the influent was achieved. It was observed in this study that the colour of the biomass at the lower zones of the filter was darker than that of the biomass at the upper zones. This observation suggested that the lower reach of the filter was actively involved in oxidizing organics in the water.

4.0 CONCLUSIONS

The BOD and COD removal efficiencies of the trickling filter in treating settleable solid-free POME exceeded 90% at a hydraulic loading of below $1 \text{ m}^3/\text{m}^2\text{-day}$. The higher BOD and COD removal efficiencies with the influent with Treatment 2 were due to two reasons. Firstly, the sedimentation of POME settleable solids and the

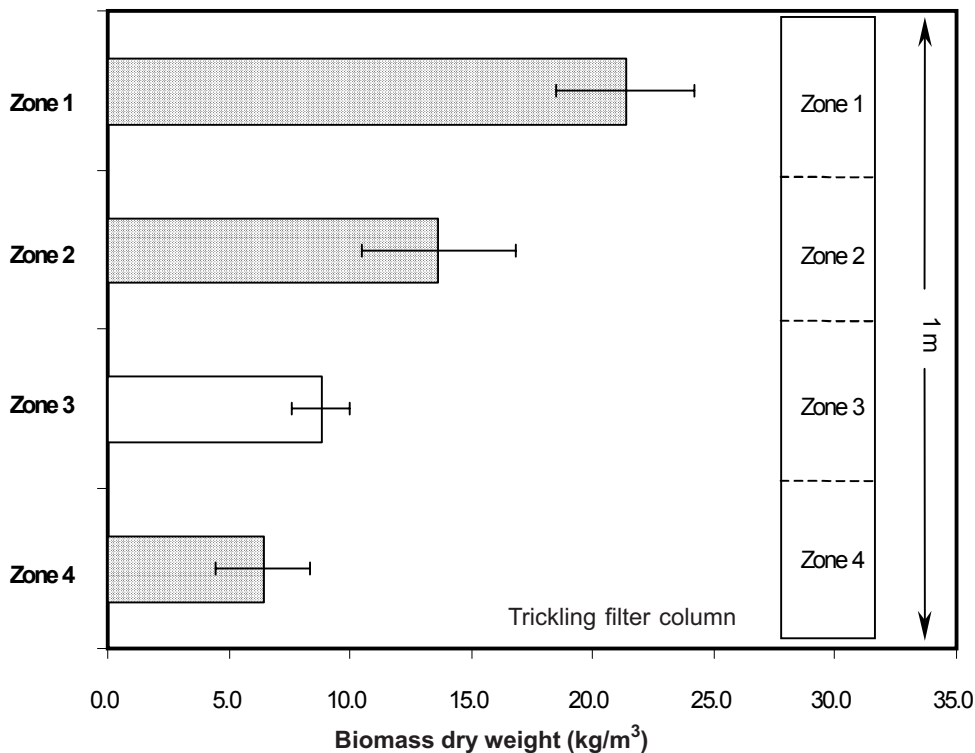


Figure 9 Biomass attachment on the trickling filter solid support (data presented by mean \pm s.d.)

chemical coagulation reduced the organic load applied to the filter. Secondly, these processes removed non-diffusible organics from the influent leaving behind mostly soluble organics. The BOD and COD removal efficiencies significantly decreased with an increase in hydraulic loading, due to limitations in the hydrolysis of non-diffusibles into soluble substrates. With recirculation ($\alpha=1$), the trickling filter demonstrated higher BOD and COD removal efficiencies and removal rates below a hydraulic loading of $7 \text{ m}^3/\text{m}^2\text{-day}$. This was attributed to lower organic loading and the recycling of active enzyme and biomass to the system. The influent with Treatment 2 demonstrated higher sludge production, due to higher conversion of soluble substrates into insoluble biomass. More biomass attachment was obtained at the upper reach of the filter column where the hydrolysis of non-diffusible organics actively took place. Meanwhile, the lower reach of the filter column was actively involved in oxidizing the organic substrates. In short, trickling filter can serve as an alternative method to efficiently treat POME.

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