Tertiary Treatment of Palm Oil Mill Effluent (POME) Using Moving Bed Biofilm Reactor (MBBR)

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Abstract: The additional tertiary treatment of palm oil mill effluent is important to make sure the effluent is compliance with the standard discharge parameters stated by Department of Environment (DOE). Mixed Bed Biofilm Reactors (MBBR) is the most economic biological methods and did not involve any chemical usage in the treatment. Additionally, it also need less maintenance and require minimum supervision as the biodegradation process will occur naturally**.** This study aims to determine the efficiency of mixed bed biofilm reactor (MBBR) to treat the palm oil mill effluent (POME) wastewater and to do a comparative study between the efficiency of palm oil mill effluent wastewater treatment by the moving bed biofilm reactor (MBBR) and by the maturation pond. Sample A is a POME wastewater originated from palm oil mill having stabilization ponds as their secondary wastewater treatment and maturation pond as the tertiary treatment. Sample A specifically taken at the influent and effluent of maturation pond for this study. On the other hand, sample B, C, and D was taken from palm oil mills practicing stabilization pond as the secondary and mixed bed biofilm reactors as the tertiary POME wastewater treatment. Sample was specifically taken from inlet and outlet of mixed bed biofilm reactor for comparison purposes. The samples was taken and tested for different dates and the pattern was observed. The dissolved oxygen (DO) concentrations for influent sample A ranged 7.21 - 8.96 mg/L while sample B, C and D ranged 7.84 - 11.78 mg/L. The dissolved oxygen (DO) concentrations for effluent sample A show the lowest record for every sample testing which ranged between 2.1 - 3.6 mg/L while sample B,C and D ranged 4.28 - 6.88 mg/L. The biological oxygen demand (BOD) for influent sample A was always exceeding 100 mg/L and vice versa for sample B, C and D meanwhile the BOD for effluent sample B, C and D ranged between 21.6 - 54.6 mg/L which is compliance with the discharged standard and sample A did not. As calculated, the BOD removal efficiency for sample A ranged between 6.41 - 21.65 % which is lower than sample B which is ranged 35.58 - 55.44 %, sample C ranged 17.55 - 43.06 % and sample D ranged 56.18 - 65.49%. On the other hand, the COD removal efficiency for sample A recorded between 12.78 - 34.75 %, sample B recorded 53.89 - 75.5 %, sample C recorded 65.63 - 79.82 % and sample D 74.55 - 79 % as the highest. Sample B, C and D also possess higher turbidity removal efficiency for every sample testing which give out reading around 49.41 - 79.89 % efficiency compared to sample A which only have 2.83 - 20.56 % efficiency. After all, sample B, C and D remove more suspended solid for 51.71 - 80.73 % efficiency compare to sample A which only having efficiency level of 16.27 - 37.88 % in removing the suspended solids from the POME wastewater. In short, mixed bed biofilm reactor (MBBR) has a high efficiency in removing BOD, COD, turbidity and suspended solids from the POME wastewater, and the efficiency level is higher than the treatment via maturation pond.

Introduction

The liquid element originated from palm oil mill effluent (POME) is rich in organic matter that generated mainly from the extraction, washing and cleaning process in the mill. This palm oil mill effluent need to be treated thoroughly as it contain high amount of cellulosic material, fat, oil and grease [1]. Besides, substantial amounts of solids, suspended solids and total dissolved solids also can be found. In general, the average biochemical oxygen demand (BOD) value is in the range of 10,250 - 43,750 mg/L and its average chemical oxygen demand (COD) value lies within the range of 15,000 - 100,000 mg/L [1]. The Department of Environment of Malaysia (DOE) has recently revised and upgraded the regulations for the industrial and non-industrial wastewater control including effluent standards for palm oil mill which states that the wastewater effluent from palm oil mill manufacturer must contain no more than 100 mg/L of BOD, 400 mg/L of COD and 400mg/L of suspended solids [1]. In complying with these regulations stated, an effective wastewater treatment system to treat organic based POME wastewater is required.

As the biological treatment method is economic and the treatment efficiency is higher [2]. This approach seems to be the most suitable way to treat organics matters in POME wastewater. The POME wastewater can first treated through anaerobic digestion which includes the usage of cultivated bacteria in the stabilization pond which later on will reduces large amount of organic matter and generates biogas as one of the side valuable effluent.[3]. However, to meet the standards of DOE regulations, further tertiary treatment is required to decrease more BOD and COD level in the POME wastewater. The activated sludge process with the ability of organic matter removal via the oxygen supply for the bacteria activity has recently been used for POME wastewater treatment [4]. Economically, the biological method is the most preferable since the operational cost is relatively lower than other chemical and physical methods.

For the last few years, the interest in the moving-bed biofilm reactor (MBBR) process has been growing in order to treat both industrial and municipal wastewater treatments. MBBR was in advantages, as they can operated in confined space, no sludge bulking problem, high tolerance to load impact and their less dependence on the final sludge separation causing to the lack of sludge return[5-8]. Currently, there are plenty of wastewater treatment plants worldwide has practicing MBBR to their treatment line and 400 of them were categorized as large-scale company [9].

MBBR basic approach which to increase the bacteria activity efficiency by providing them thousands of biofilm carriers as a protected surface area to support their growth within the cells has created great interest [10]. Some researchers had diversify the application of MBBR not only to treat organic-based wastewater but also to treat wastewater rich in pesticides [11], phenol [12] and municipal wastewater [10].

As mentioned earlier, POME wastewater treated from the anaerobic digestion needs further treatment to comply with the DOE regulations. Thus, it is the focus of this study to :

1) Determine the efficiency of mixed bed biofilm reactor (MBBR) to treat the palm oil mill effluent (POME) wastewater.
2) To do a comparative study between the efficiency of palm oil mill effluent wastewater treatment by the moving bed biofilm reactor (MBBR) and by the maturation pond as the tertiary treatment.

The sample was collected from the palm oil mill around Kulai and Pekan Nenas District and the parameter measured in this study was limited into dissolve oxygen, DO (mg/L), biological oxygen demand, BOD (mg/L), chemical oxygen demand, COD (mg/L) and turbidity, (NTU).

Previous Studies

Generation of waste in palm oil mill

In extracting the palm oil from the fresh fruit, huge quantities of waste are produced in the palm oil mill. The process results in generation of liquid waste commonly known as palm oil mill effluent (POME) that generated mainly from the oil extraction, washing and cleaning process in the mill and these contains cellulosic material, fat, oil and grease. Palm oil mill effluent also contains substantial quantities of solids, suspended solids and total dissolved solids (18,000 - 40,000 mg L^{-1}). These solids known as palm oil mill sludge (POMS) which produced from the extractions of the leaves, trunk, decanter cake, empty fruit bunches, seed shells and fiber from the mesocarp [1].

Palm oil mill effluent (POME)

The milling process of palm oil was classified into a dry and wet process. In Malaysia, the wet process is the most typical method of extracting palm oil from the palm fresh bunches.

The extraction of crude palm oil from the palm fresh bunches will go through a series of steaming and squeezing in boiler and incinerators. The process of milling one ton of fresh fruit bunch requires 1.5m^3 of water which 50% of it will be discharge as one of the liquid by product, known as palm oil mill effluent (POME), while the rest of water consumed was lost as the wash water, leakage and steam in the boiler blow down [13]. According to [14] the raw POME from the palm oil milling process containing 95-96% water, 4-5% total solids and 0.6-0.7% oil content which included in the total solid are suspended solid which are mainly from the palm fruit mesocarp generated from the separator sludge and hydrocyclone wastewater.

Parallel to the high milling process of palm oil, the amount of the solid and liquid waste also shooting up. [15] stated that 31 million ton of fresh fruit bunch was produced per annum and gives out more than 10 million tons of POME as their liquid by product apart from 7.7 million tons of empty fruit bunch, 6.0 million tons of fiber and 2.4 million of fruit shells. In May 2001, the total crude palm oil produced was 985, 063 tons and together with it is a total 1,477,595m^3 of water used in the milling process that released 738,797m^3 of POME.

Wastewater composition depends mainly on the season, raw matter quality and the particular operations being conducted at any given time. Normally, palm oil mill wastewater is low in pH ranging about 4 - 5, because of the organics acid produced in the fermentation process. Wastewater also contains high concentration of protein, carbohydrate, nitrogenous compounds lipids and mineral that can cause considerable environmental problems if discharged untreated. Table 1 shows the characteristics of raw POME while Table 2 shows the POME effluent discharge standards.

Table 1: Characteristics of raw POME

Parameter	**Mean**	**Range**
pH	4.2	3.4 - 5.2
Biological oxygen demand (BOD)	25,000	10,250 - 43,750
Chemical oxygen demand (COD)	51,000	15,000 - 100,000
Total solids	40,000	11,500 - 79,000
Suspended solids	18,000	5,000 - 54,000
Volatile solids	34,000	9,000 - 72,000
Oil and grease	6,000	130 - 180,000

Table 2: POME effluent discharge standards

Parameter	**Value**	**Regulatory discharge limit**
pH	4.7	5.0 - 9.0
Biological oxygen demand (BOD)	25,000	100
Chemical oxygen demand (COD)	50,000	-
Total solids	40,500	-
Suspended solids	18,000	400
Volatile solids	34,000	-
Oil and grease	4,000	50

Palm oil mill effluent treatment technologies

In treating POME, land application can be one of the disposal alternatives. However, discharging the untreated POME on the land will eventually results in clogging and water logging on the soils and will cause harm to all the vegetation in contact. Despite of that, this problem can be solved by the controlled quantities of POME at a time which can give enough time to the soil structure to fully absorb the POME before additional POME were added. Other than that, POME also can be eliminated by direct discharge to the water body as it is consider as non-toxic residual. However, this can cause the depletion of the oxygen level in the water, thus endangered the aquatic life and will be harmful whenever consumed [16].

Physical and chemical pretreatment. Screening, sedimentation and oil removal which is in the secondary treatment in biological treatment system is among the physical pretreatment of POME. According to [17] the developed pretreatment system also consists of acidification pond and flocculation treatment. They also show that both centrifugation and coagulation has better pretreatment quality that by filtering method. Chemicals used to treat POME can be alum, aluminiumchlorohydrate, aluminium sulfate etc. In some practice, chitosan (poly D-glucosamine), a natural organic polyelectrolyte can effectively remove most of the suspended organics matter content. However, it is less efficient in removing dissolved organics matter [17].

Biological treatment. Anaerobic process is one of the biological treatments to treat the organics waste of POME [18]. Therefore, ponding system is defined as the most conventional and cheap method of treating POME. Since 1982, pond system has been applied in Malaysia and they are classified as waste stabilization pond [19]. Even this method only required minimum cost, it does need a spacious area to satisfy the long HRT for the effective performance. It also gave out unpleasant odor and biogas that are harmful to the environment.

Moving bed biofilm reactor (MBBR)

In Kulai Palm oil mill, implementation of MBBR system as their tertiary treatment was since 2013. This treatment was proved can reduce the BOD level in the effluent up to 50 ppm and now, this technology was widely used by other palm oil factories in Johor. The POME from algae pond was pumped into the aeration tank where the oxygen was supplied. Then, in clarifier tank, the heavier sludge and impurities will manually settle down to the bottom of the tank before the clear water flow to the reactor bed for the advanced biological treatment to occur. Before the treated wastewater can be flowed into the final discharged tank, it will be clarified again in clarifier tank for getting the extra clear water as the final effluent.

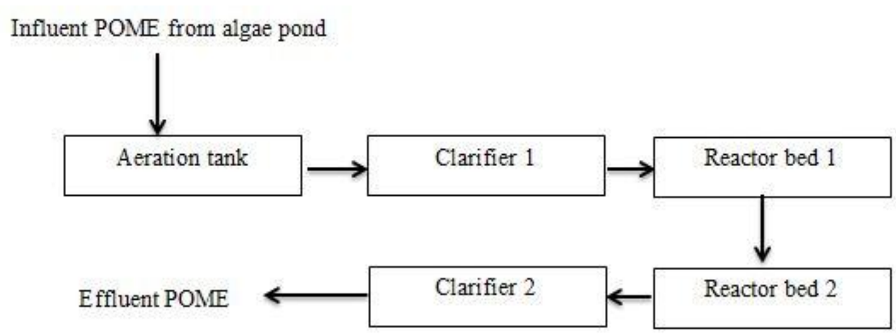

Figure 1: MBBR treatment Line

In brief, the MBBR system is the advance practice of activated sludge process, which the sludge was aerated and involve the usage of bacteria and microbes in the treatment line. The major different is just the bacteria was carried by thousands of biofilm carrier which increases the productivity of treatment by providing a protected surface area to support the growth of bacteria within the cells. Below is the close up view of biofilm carrier which provides a large protected area to support the growth of bacteria within the cells. Thus, the high density population of bacteria can provide a high rate biodegradation within the system while offering process reliability and can operate at ease.

Figure 2: Mixed bed biofilm reactor during tank cleaning

Figure 3: The reactor bed containing thousands of Biofilm Carriers

Figure 4: The close up view of Biofilm Carriers that provide enclosed space to support the growth of microorganisms

Methodology

In brief, this study was to determine the effectiveness of MBBR treatment line as compared to POME wastewater treated via maturation pond, by comparing the effluent quality from each treatment. To achieve the objectives, the following steps were taken in order to review the problems, to collect and analyze data and finally to come up with a reasonable findings.

Problem Identifications

Due to the increasing standard of POME quality to be discharge, an advance tertiary POME wastewater treatment is needed. However, the highly effective membrane technology and chemicals coagulants usage are expensive and need high maintenance, thus will cause a lot of money to the palm oil industrialist. Thus, the biological POME treatment method (MBBR) which dealing with natural existing bacteria is the most economic yet efficient in biodegrading process and a study regarding the effectiveness is needed.

Information Review

By referring to the staff and chemical engineer of Felda Palm Industries Sdn. Bhd (FPISB),a brief explanation about moving bed biofilm reactor was given. MBBR technology also had been studied earlier from different perspectives by individuals and organizations, besides referring to the information from the suppliers.

Samples Collection

Sample A was collected from palm oil mill in district of Pekan Nenas, which implement stabilization pond as the secondary treatment and make use of maturation pond as their tertiary treatment. Additionally, sample B is originated from district of Kota Tinggi and sample C and D was collected in palm oil mill in district of Kulai. Sample B, C and D was treated also via stabilization ponds followed by moving bed biofilm reactor as the tertiary POME wastewater treatment. For each palm oil mill, influent and effluent samples was taken from the tertiary treatment line and taken to the laboratory for further testing.

Experimental Method

The samples collected from the influent and effluent tertiary wastewater treatment line was analyzed in term of biological oxygen demand (BOD), chemical oxygen demand (COD), turbidity and suspended solid based on Standard Methods for the Examination of Water and Wastewater [20]. The dissolved oxygen value was taken in-situ by using DO meter, while laboratory testing was done to determine BOD, COD and turbidity of POME wastewater samples. The characteristics of a typical POME wastewater samples are given in Table 1.

Results and Discussion

BOD Removal Efficiency

Four POME wastewater samples which are sample A, B, C and D collected from four different palm oil mills was involved in this study. These samples were tested via in-situ testing for DO, while undergoes laboratory testing to check the BOD, COD and turbidity level of the samples.

The DO level in the influent of tertiary treatment for sample A, B, C and D are shown in Figure 5. The values of DO in the influent of maturation pond for sample A are always the lowest compared to samples entering MBBR treatment. This may happen as the results of algae overgrow inside the algae ponds which then the outflow will directly further treated in the maturation pond. The overgrow algae will have a crucial competition for oxygen to digest the organic matter, thus causing the dissolve oxygen inside the POME wastewater to be critically depleted.

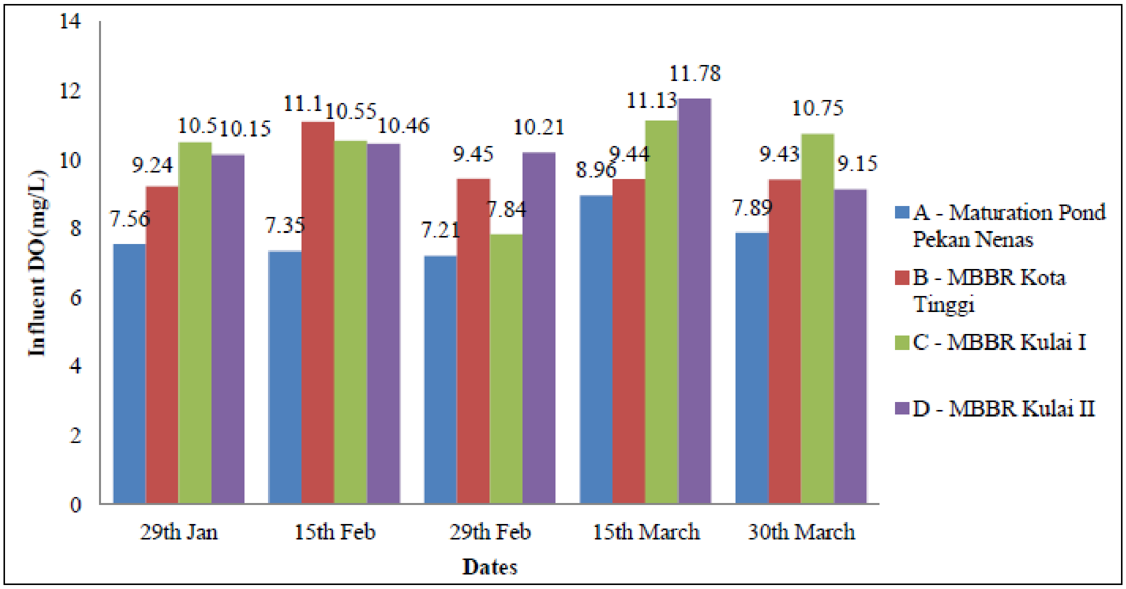

Figure 5: Influent DO level (mg/L)

The effluent DO values at different sample testing date are given in Figure 6. The DO concentration of all testing for sample A is always the lowest which is within the range of 2.1mg/L on 29th January and 3.6 mg/L on 30th March, as the maturation pond do not induce any additional oxygen to enhance the microorganisms activity during waste digestions. However, samples B, C and D display higher DO level between 4.28 - 6.88 mg/L as the samples had undergoes aeration as the first step in the MBBR reactors.

The samples are then tested in the laboratory to determine the BOD level of each inlet and outlet of treatments. The histograms in Figure 7 clearly shows that inlet sample A possess the highest oxygen demand compared to three other samples and it remains from 29th January until 30th March. This may happen as the result of low dissolve oxygen concentration in the wastewater originated from the anaerobic secondary treatment line.

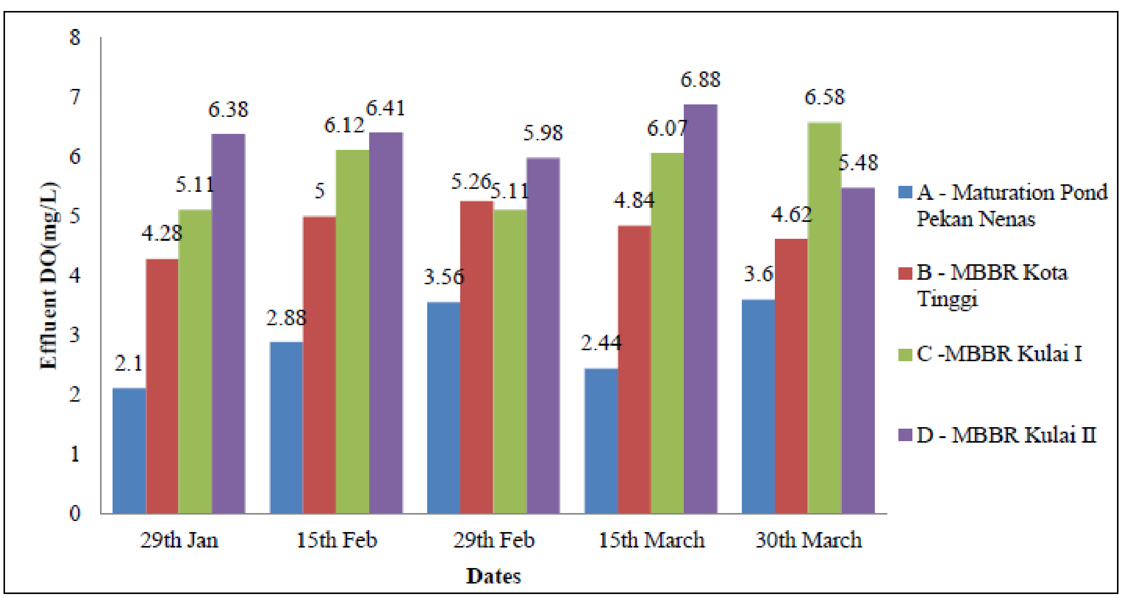

Figure 6: Effluent DO level (mg/L)

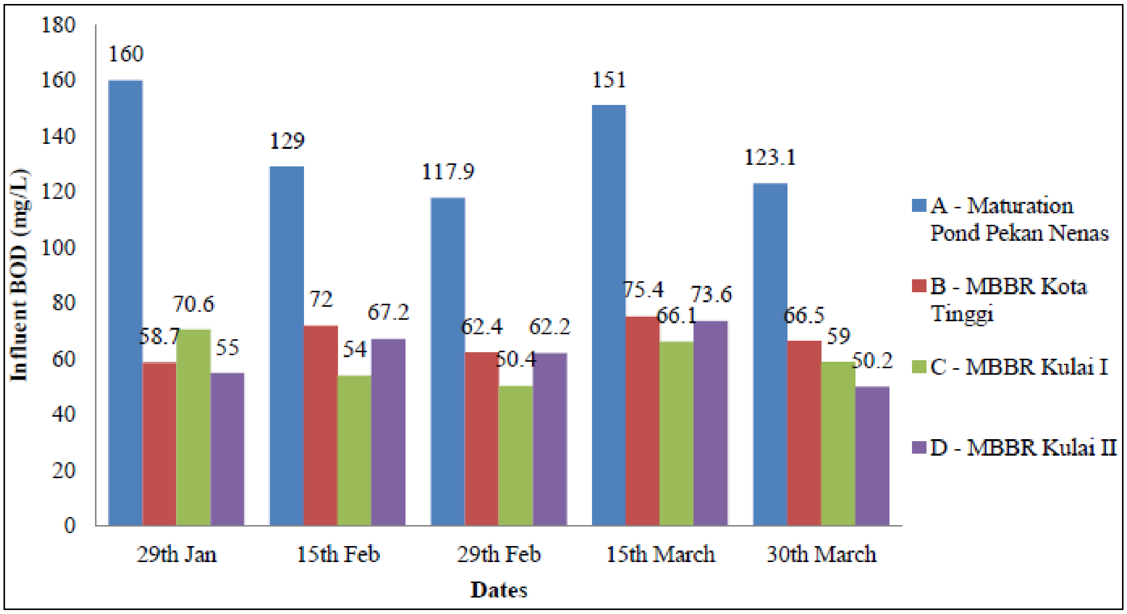

Figure 7: Influent BOD level (mg/L)

As shown in Figure 8 and Figure 9, the BOD level pattern for all samples are almost the same as BOD readings for sample A are still high after going through tertiary treatment of maturation pond, which exceeding 100 mg/L BOD standard discharge limit except for 29th February. This is due to the main function of this pond which is not to reduce the BOD level, but to remove the pathogens, nutrients and possible algae. On the other hand, sample B, C and D that had undergo aeration that enhanced by the additional moving bed that circulates around the reactors showing a significant impact when the BOD can be reduced up to 65.49% efficiency for sample D on 15th March which initially 73.6 mg/L then was reduced into 25.4 mg/L as the outflow.

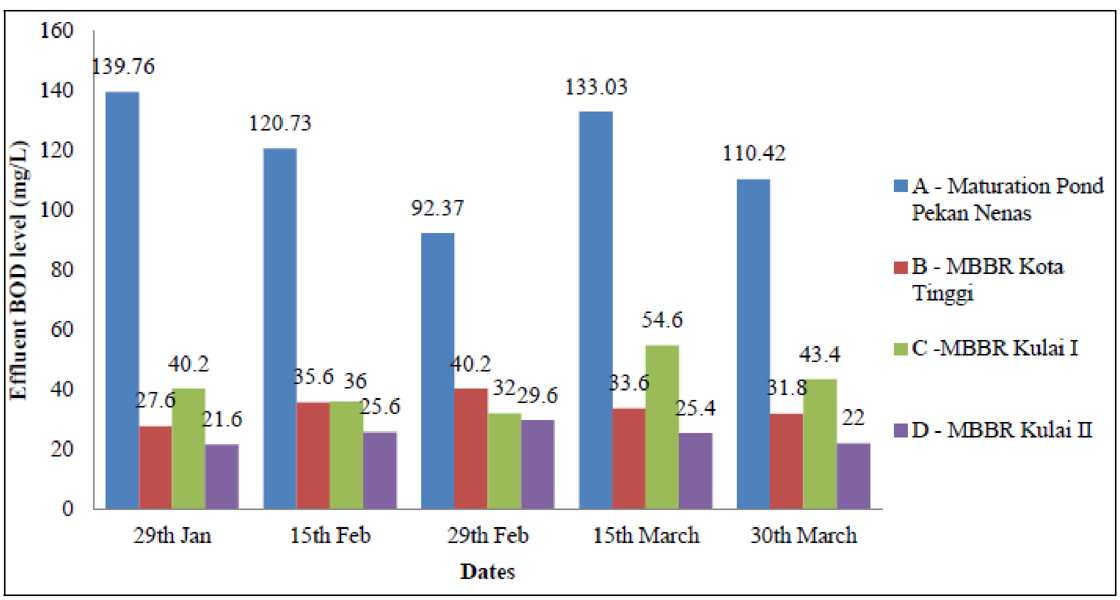

Figure 8: Effluent BOD level (mg/L)

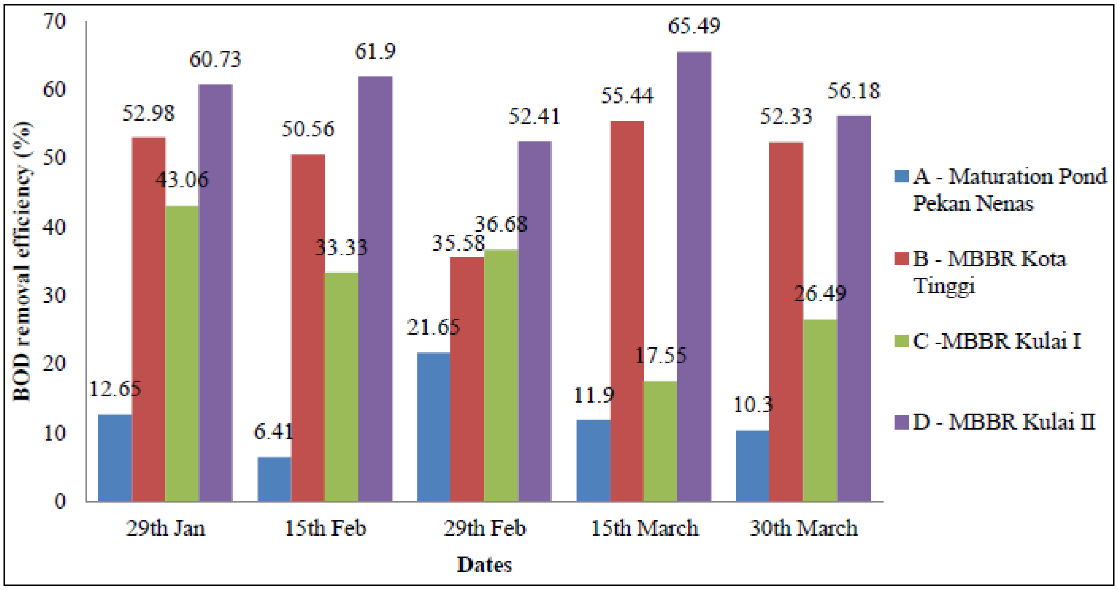

Figure 9: BOD removal efficiency (%)

COD Removal Efficiency

Figure 10 clearly shows that the COD level is worrisome for sample A which the readings recorded within the range of 2034 mg/L on 15th March and 2405 mg/L during the end of the same month. This high values is always higher if compared to sample B, C and D which the COD readings are never exceeding 2000 mg/L for all sample testing. The moving bed biofilm reactor assumed to be more effective due to the fact that the circulating medium in the MBBR enhance the distribution of liquid flow and oxygen transfer. This would enable the unsettled waste to be treated directly so the effluent COD of sample treated via MBBR came out lower than via maturation pond.

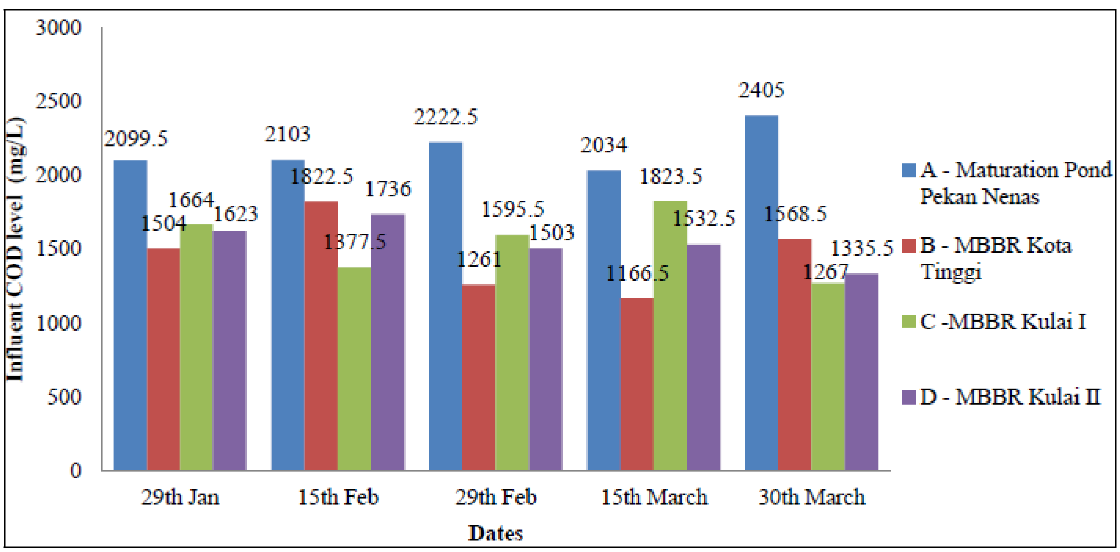

Figure 10: Influent COD level (mg/L)

For the effluent sample in Figure 11, sample A still maintaining the high COD readings even after treated via tertiary treatment of maturation pond. The highest was recorded on 30th March (1807.5 mg/L) and the lowest was recorded on 29th January (1370 mg/L). For sample B, the COD reading ranged 343 - 777 mg/L, sample C ranged 308.5 - 556.5 mg/L and sample D ranged 280.5 - 473 mg/L.

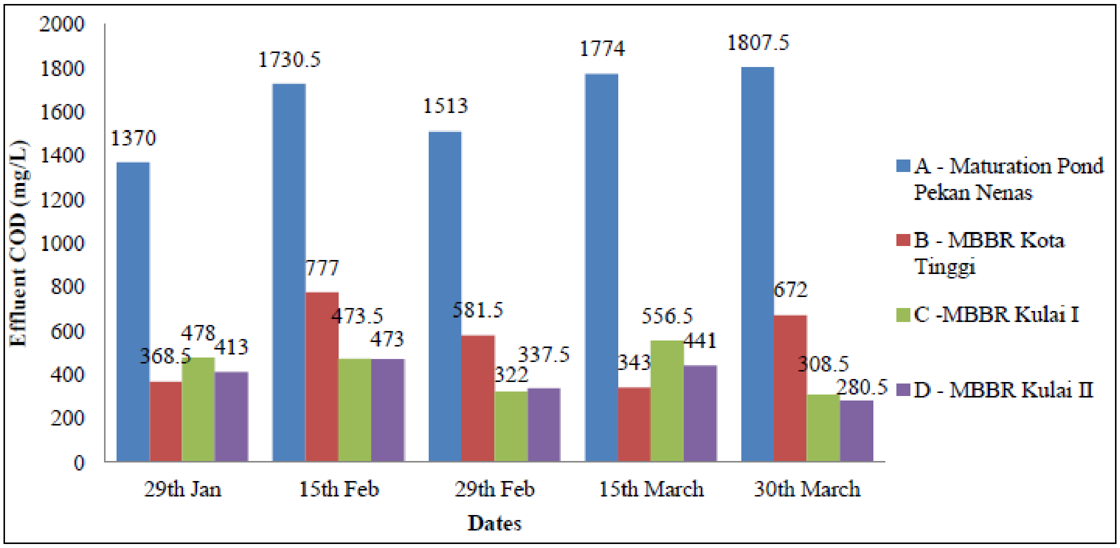

Figure 11: Effluent COD level (mg/L)

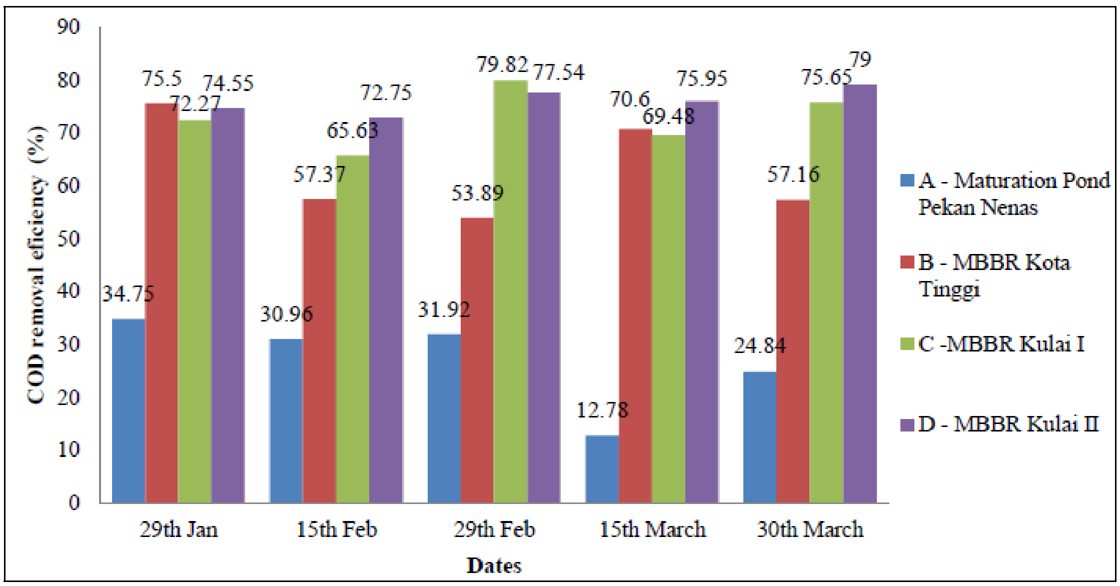

Figure 12: COD removal efficiency (%)

Referring the efficiency of COD removal in Figure 12, sample A show the least COD removal as low as only 12.78% and the highest only 34.75%. Meanwhile for the sample B, C and D, the COD removals are always lower than sample A, which sample B ranged 53.59 - 75.5%, sample C ranged 72.27 - 79.82% and sample D ranged 74.55 - 79% proving the earlier assumption was right.

Turbidity Removal Efficiency

As expected from the observations, Figure 13 showing sample A has the highest turbidity reading throughout the series of sample testing. For the inlet sample for plant A taken on 29th January, the turbidity readings taken is 911.5 NTU and did not indicating any tremendous change for the following months until on 15th March when it reach 998.3 NTU. This is because the mill only will run the desludging process from the ponds during the middle and end of the year which is expected to be in June and December. Until that time, the turbidity of POME wastewater will continuously increasing. For sample B, C and D, the turbidity is relatively low. For sample B, the highest is on 29th February (412.25 NTU) and the lowest is on 29th January (351 NTU). At the same time, sample C shows the highest reading on 29th January (998.3 NTU) and being the least turbid on 15th March (179 NTU) while sample D gives the lowest turbidity readings among all other POME wastewater sample which is 294.5 NTU on 15th March and 173.05 NTU at the end of the same month.

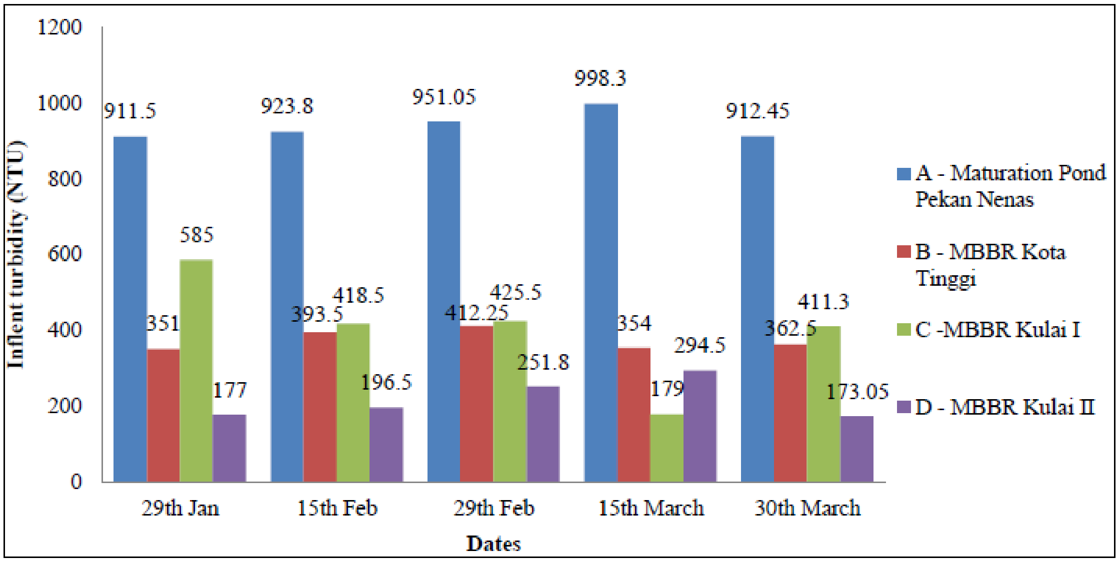

Figure 13: Influent turbidity (NTU)

As the effluent sample was tested in Figure 14, the pattern is remained the same. Sample A still maintained the high turbidity readings as high as 970 NTU on 15th March and can only decrease as low as 743.5 NTU on 29th January. For sample B, C and D, there is also a slight decrease after undergoes the tertiary treatment of MBBR which the lowest for sample B is 71.55 NTU on 15th March and the highest is 94.5 NTU on the previous month. Simultaneously, sample C displays the uppermost turbidity readings on 29th January (187.5NTU) and the littlest on 29th February (91.25 NTU) while sample D were having 97.95 NTU as the highest recorded turbidity reading and 47.5 NTU as the least turbid appearance. Turbidity level for sample B, C, and D relatively lower than sample A.

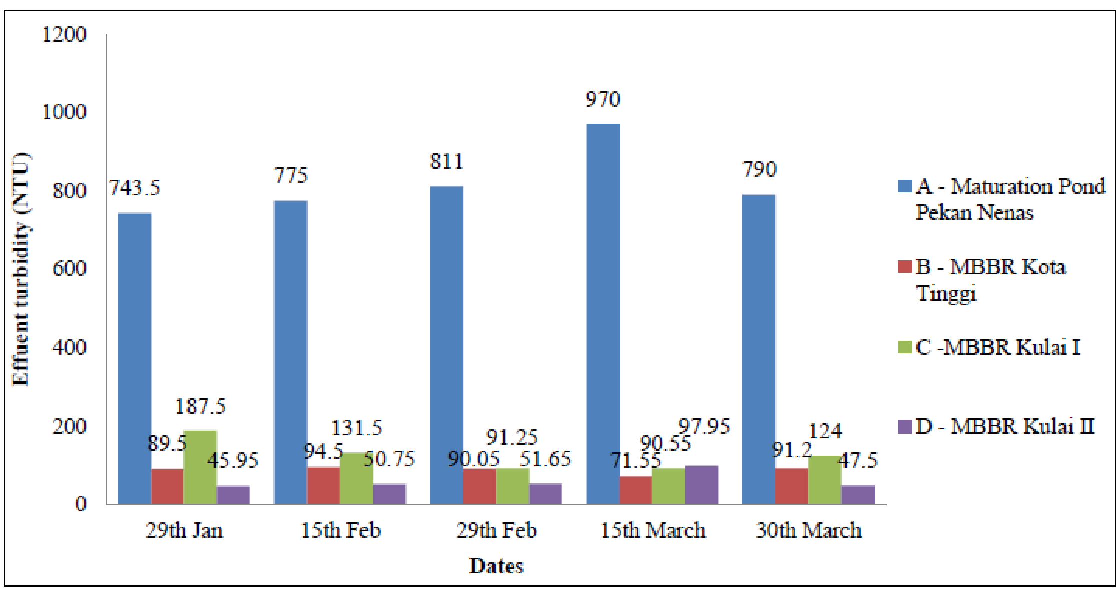

Figure 14: Effluent turbidity (NTU)

Figure 15 shows that on 29th January, sample B reached the highest turbidity removal efficiency (74.5%) and maintained this pattern for the 15th February (75.98%), 15th March (79.79%) and 30th March (74.84%). On the contrary, sample A continuously displays the least turbidity efficiency.

This had proved upon the double clarifying system in the MBBR treatment can speed up the settlement of particulate, separating clear water and solids so that clearer water can come out as the effluent.

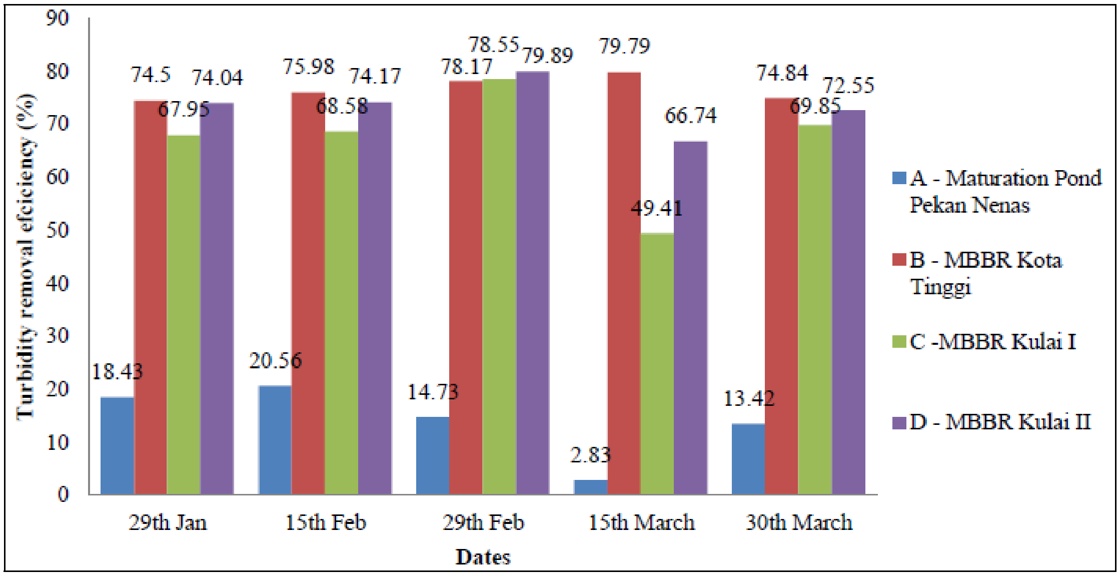

Figure 15: Turbidity removal efficiency (%)

Suspended Solids Removal Efficiency

As shown in Figure 16, the suspended solid for the influent in plant A is always the highest among the other three plants. The suspended solids readings entering the secondary treatment line is around 18,000 mg/L had reduced into less than 1000 mg/L when the POME wastewater entering the maturation pond in plant A. The trend remains the same for the next two months which the suspended solids reading was maintained around 900 mg/L to 1000 mg/L. In contrast, the suspended solids reading for plant B, C and D is much lower than plant A each time the POME wastewater sample was tested.

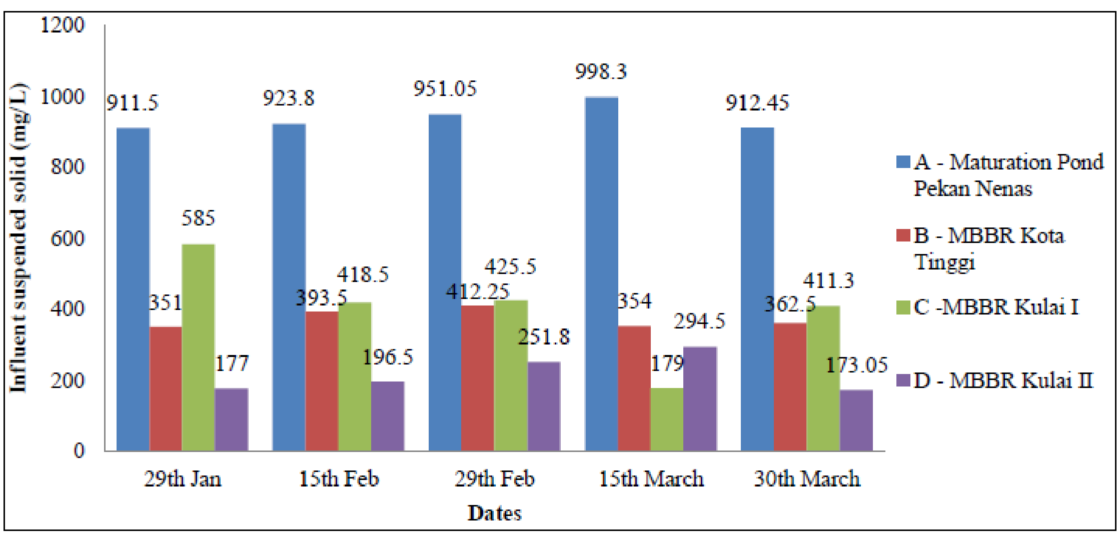

Figure 16: Influent suspended solid(mg/L)

After the POME wastewater entering the tertiary treatment of maturation pond, as in Figure 17, sample A showing a slight decrease in the suspended solids reading which is 743.5 mg/L as the lowest reading which is recorded in 29th January. However it is far higher when compared with suspended solids reading for sample treated via MBBR. This trend remains the same as sample A continuously having too high suspended solids reading, exceeding the POME wastewater regulatory discharge limit which is 400 mg/L.

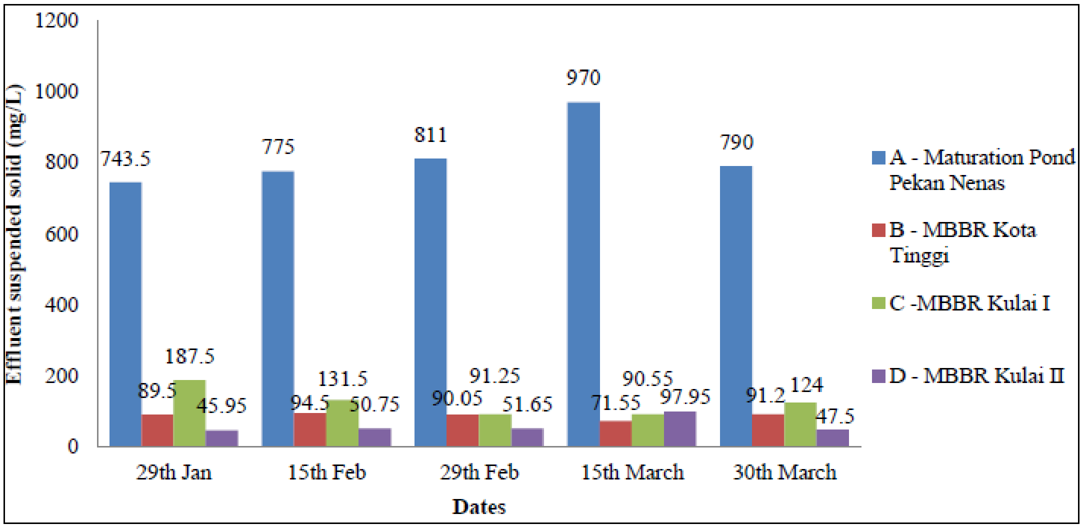

Figure 17: Effluent suspended solid(mg/L)

As displays by Figure 18, samples C tested on 29th January showing the highest suspended solids removal efficiency (73.75%), following by sample B (66.95%) and sample D (62.22%). Sample A which originated from maturation pond possess the lowest efficiency level which is only 37.88%. Sample B maintaining the highest suspended solids removal efficiency also for the next February and March by effectiveness of 77.12 - 80.73%, sample C by 51.71 - 75.19%, sample D by 32.83 - 62.22% while sample A constantly showing the least efficiency level. This difference of suspended solids removal efficiency between MBBR and maturation pond is also a positive effects of double clarifying systems in MBBR which has fastened the suspended solids settlement, compared to natural settlement that occur naturally in maturation pond.

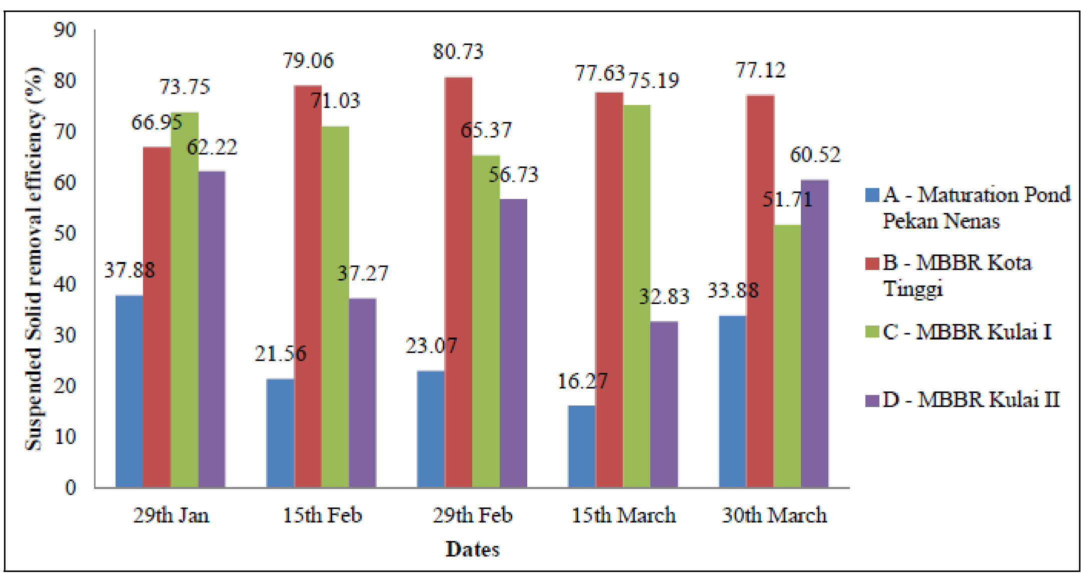

Figure 18: Suspended solid removal efficiency (%)

Conclusion

Mixed bed biofilm reactors have a high efficiency in removing BOD, COD, turbidity and suspended solids from the POME wastewater. The quality of the effluent in terms of BOD and suspended solids met the criteria of wastewater standard for palm oil mill effluent, whereas the maturation pond treatment method was not satisfactory for all parameters. The moving bed biofilm reactor (MBBR) seems to be more efficient than maturation pond system to treat the palm oil mill effluent wastewater.

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