CHAPTER IV

RESULTS AND DISCUSSION

4.1 Effect of control parameters on the effluent concentrations and removal of the organic parameters when using primary wastewater from the Si Phraya WWTP as influent for TF and RBC systems

4.1.1 Effect of HLR on the effluent concentrations and removal of $SBOD_5$, $BDOC_{28}$, $BDOC_5$, DOC, UV_{254}, and SUVA when using primary wastewater from the Si Phraya WWTP as influent for TF system

The TF process was operated at three different HLRs, which were 3, 7 and 9 m^3/m^2-day. The process had pH ranging from 7.25-7.34 and 7.57-7.65 for influent and effluent, respectively. The effluent pH slightly increased from the influent pH (Figure 4.1). This probably occurred from the ammonia production of ammonification and endogenous respiration of microorganisms, which could react with water to form ammonium icn.

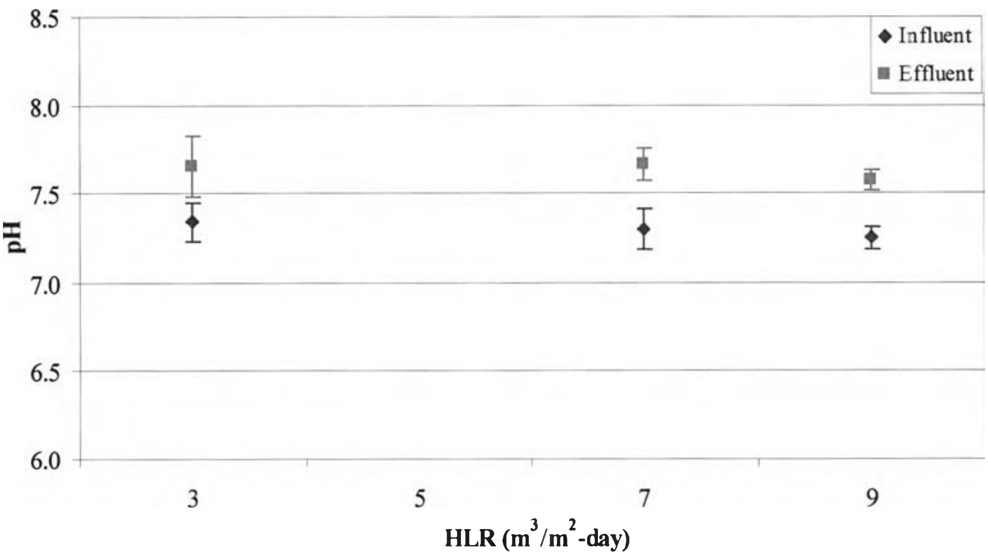

Figure 4.1 pH of influent and effluent when using primary wastewater from the Si Phraya WWTP as influent for TF at different HLRs.

Figure 4.2 shows $SBOD_5$, $BDOC_{28}$, $BDOC_5$ and DOC of the influent and effluent of the TF system. Influent $SBOD_5$, $BDOC_{28}$, $BDOC_5$ and DOC values were relatively low compared to the typical values of primary municipal wastewater and varied considerably among different batches of wastewater used at different HLRs. No trend was observed between the organic parameters of the effluent and HLR; effluent $SBOD_5$, $BDOC_{28}$, $BDOC_5$ and DOC were not much different across different HLRs. This might be because of the relatively low values of the influent organic concentrations. The standard deviations (SD) of $BDOC_5$, $BDOC_{28}$ and DOC were smaller than that of $SBOD_5$ indicating higher precision of $BDOC_5$, $BDOC_{28}$ and DOC. Figure 4.3 indicates the organic parameter removal efficiencies versus HLR of the TF system. For all four parameters, the removal decreased with increasing HLRs as expected.

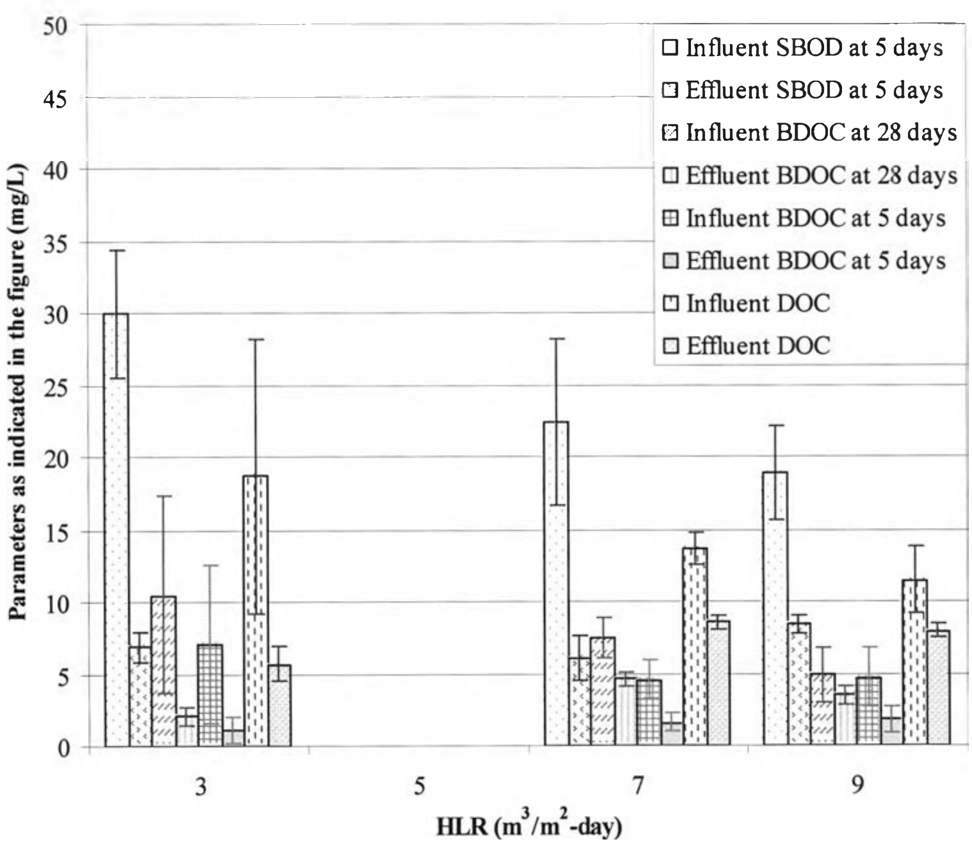

Figure 4.2 Influent and effluent $SBOD_5$, $BDOC_5$, $BDOC_{28}$ and DOC of TF at different HLRs when using primary wastewater from the Si Phraya WWTP as influent.

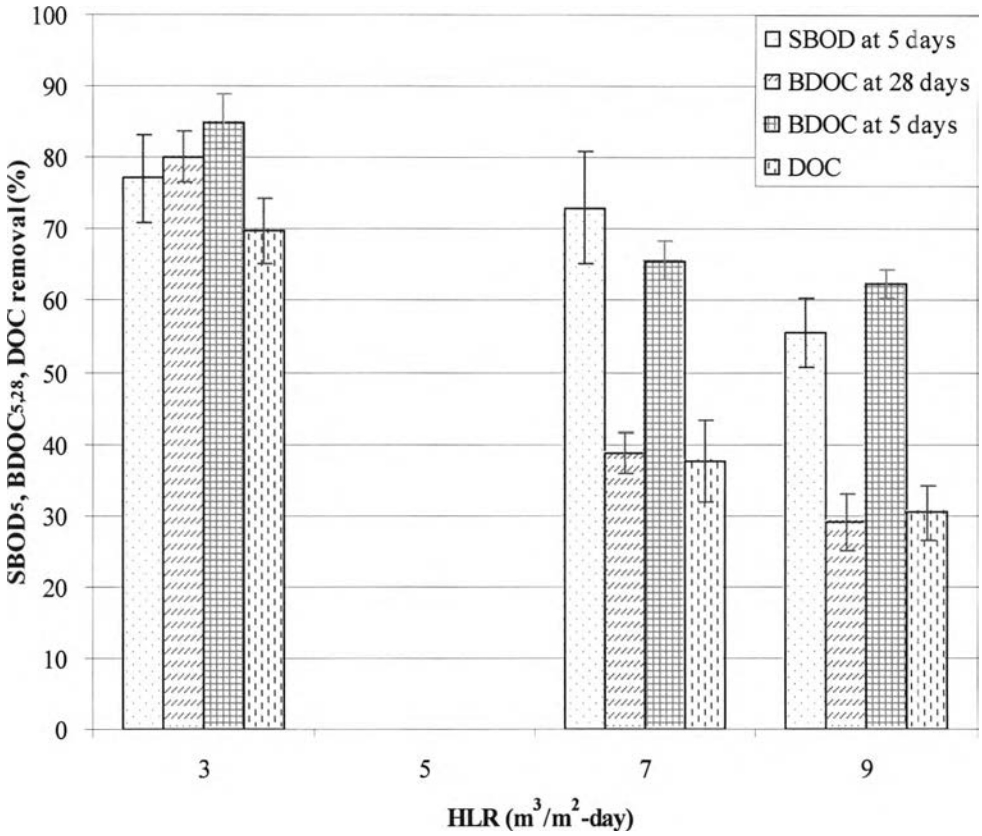

Figure 4.3 Relationships between $SBOD_5$, $BDOC_{28}$, $BDOC_5$ and DOC removal efficiencies of TF system and HLRs when using primary wastewater from the Si Phraya WWTP as influent.

Figure 4.4 illustrates the plot of influent and effluent UV_{254} against HLR. Influent and effluent UV_{254} at HLRs of 3, 7 and 9 m^3/m^2-day were 0.130, 0.153 and 0.149 cm^{-1}, and 0.124, 0.146 and 0.148 cm^{-1}, respectively. Very minimal differences between influent and effluent UV_{254} suggest that limited amounts of UV absorbing constituents, unsaturated double bonds and aromatic organic compounds, were removed in the TF. SUVA of the influent and effluent at various HLRs are shown in Figure 4.5. The effluent had higher SUVA than the influent because simple, low molecular weight, and biodegradable organics were removed and DOC remained in the effluent has higher proportions of hydrophobic, aromatic, high molecular weight, and biorefractory organics, which are the characteristics of water with high SUVA.

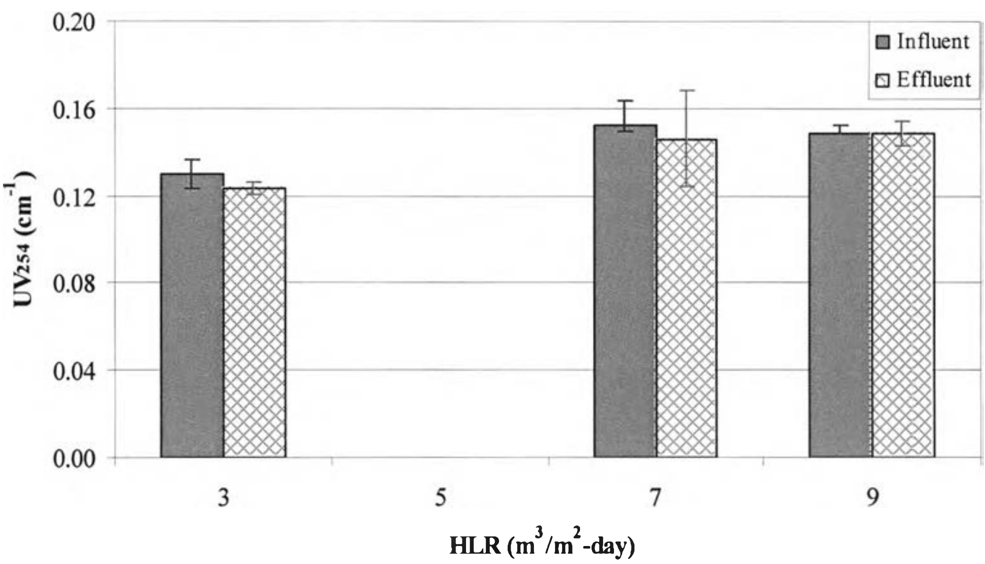

Figure 4.4 Influent and effluent UV_{254} of TF at different HLRs when using primary wastewater from the Si Phraya WWTP as influent.

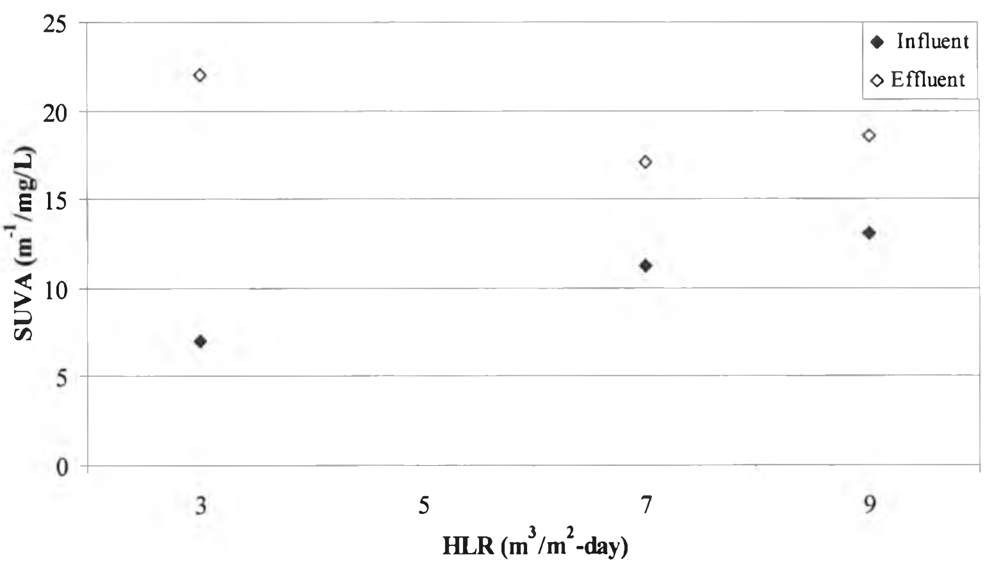

Figure 4.5 Influent and effluent SUVA of TF at different HLRs when using primary wastewater from the Si Phraya WWTP as influent.

4.1.2 Effect of HLR on the effluent concentrations and removal of $SBOD_5$, $BDOC_{28}$, $BDOC_5$, DOC, UV_{254}, and SUVA when using primary wastewater from the Si Phraya WWTP as influent for RBC system

The RBC process was operated at three different HLRs: 0.08, 0.12 and 0.16 m^3/m^2-day. Influent and effluent pH profiles were shown in Figure 4.6. They were similar to those of the TF. Increases of pH after the treatment could be explained using the same reasons provided earlier in the TF section.

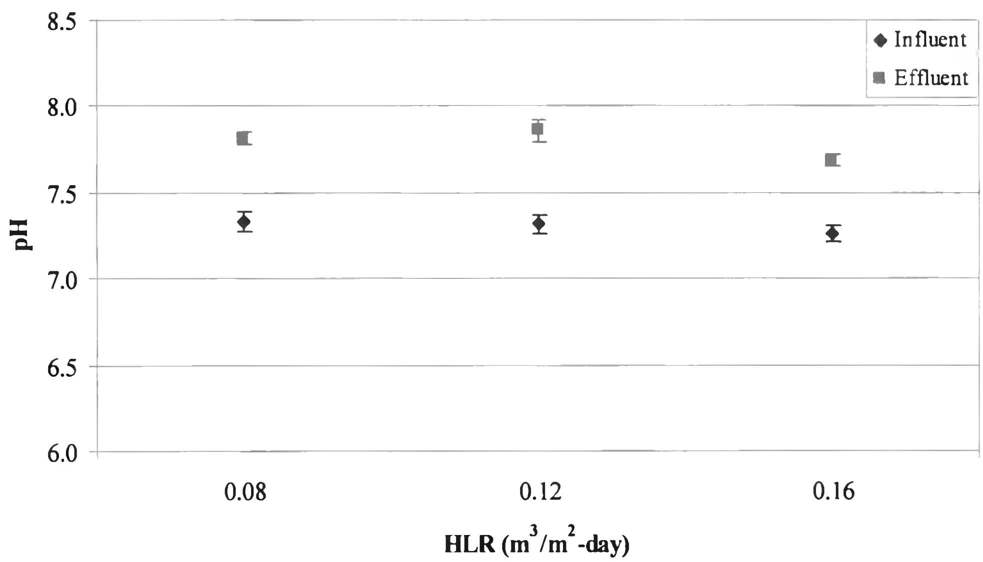

Figure 4.6 pH of influent and effluent when using primary wastewater from the Si Phraya WWTP as influent for RBC at different HLRs.

Shown in Figures 4.7 and 4.8 are $SBOD_5$, $BDOC_{28}$, $BDOC_5$ and DOC of the influent and effluent, and their removal efficiencies at different HLRs, respectively. At higher HLRs, effluent organic concentrations should be higher while lower organic removal should be observed. Only $SBOD_5$ and $BDOC_5$ tended to follow these trends. The disagreement with the theory for $BDOC_{28}$ and DOC may be attributed low and inconsistent organic concentrations in the primary wastewater used in the experiment.

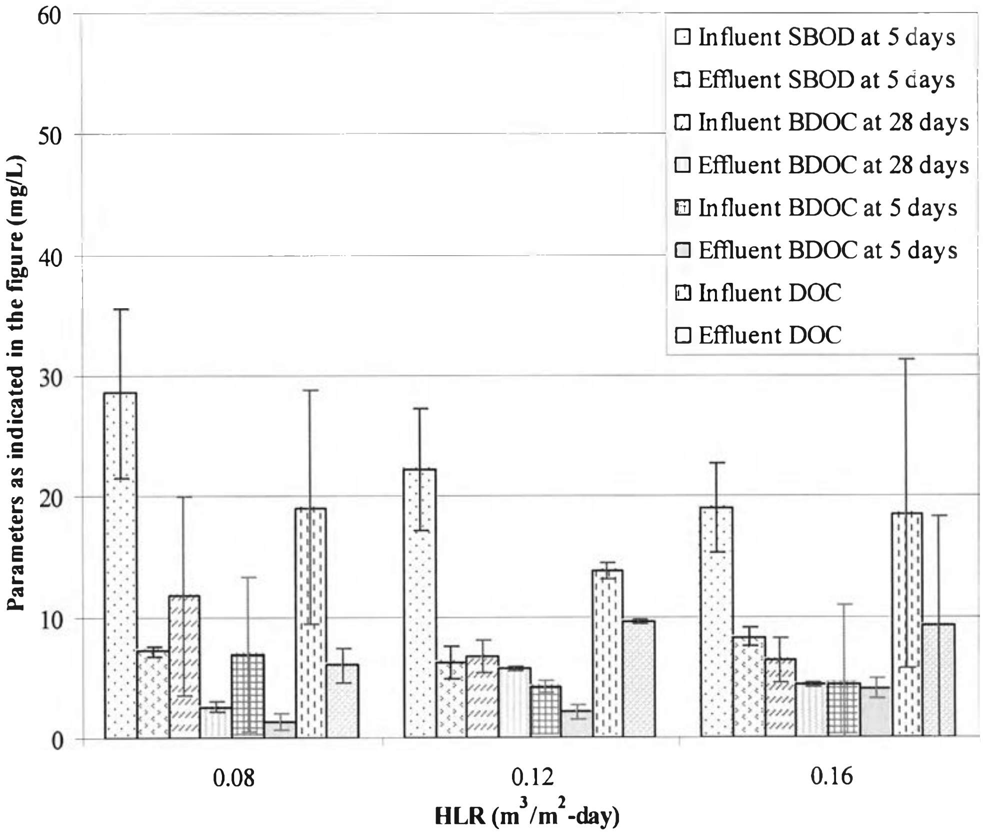

Figure 4.7 Influent and effluent $SBOD_5$, $BDOC_5$, $BDOC_{28}$ and DOC of RBC at different HLRs when using primary wastewater from the Si Phraya WWTP as influent.

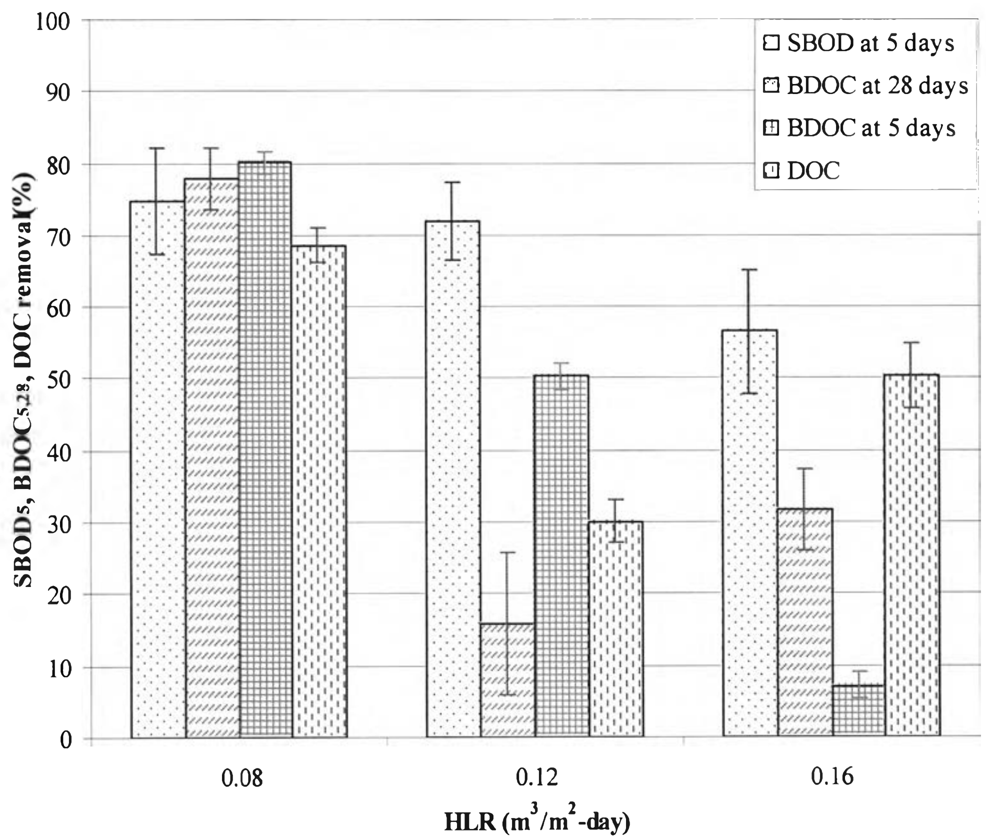

Figure 4.8 Relationships between $SBOD_5$, $BDOC_{28}$, $BDOC_5$ and DOC removal efficiencies of RBC system and HLRs when using primary wastewater from the Si Phraya WWTP as influent.

Figures 4.9 and 4.10 illustrate UV_{254} and SUVA profiles, respectively, of the influent and effluent at different HLRs. The same trends as those of the TF were obtained. They indicate that UV absorbing aromatic and unsaturated organics were barely or not removed in the RBC and are responsible for the SUVA increases after the process.

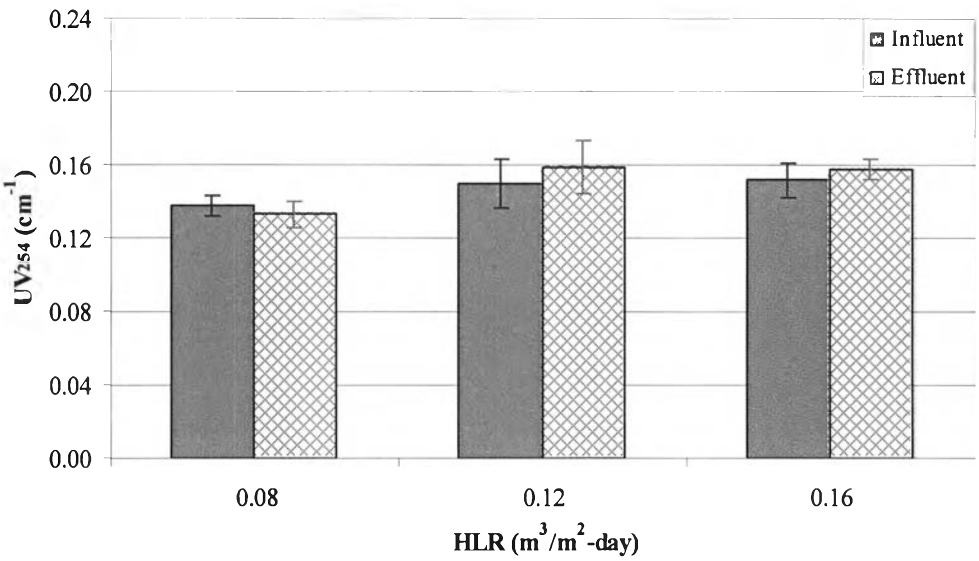

Figure 4.9 Influent and effluent UV_{254} of RBC at different HLRs when using primary wastewater from the Si Phraya WWTP as influent.

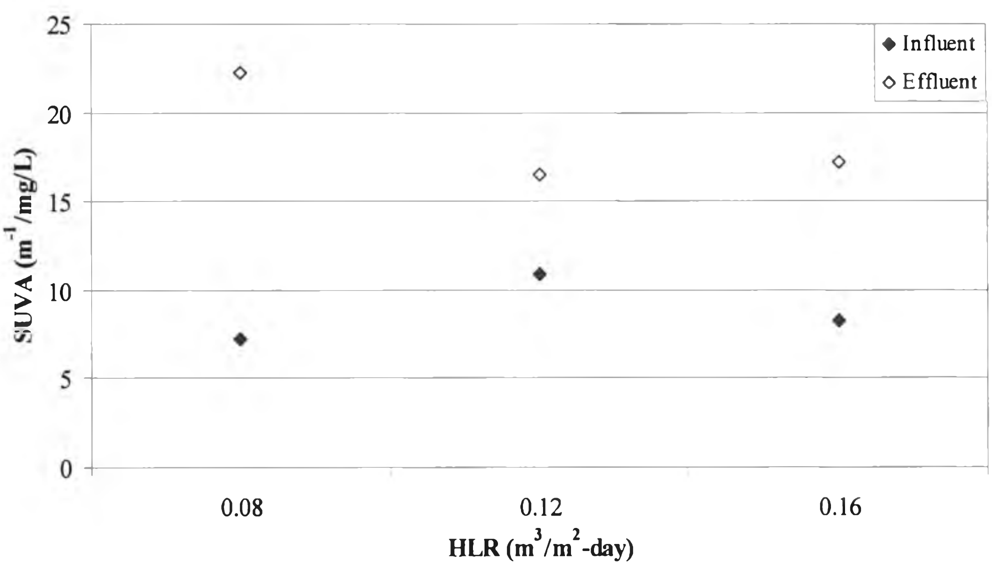

Figure 4.10 Influent and effluent SUVA of RBC at different HLRs when using primary wastewater from the Si Phraya WWTP as influent.

Initially, it was planned to use the primary wastewater from the Si Phraya WWTP for five different SRTs of AS, and for four different HLRs of TF and RBC. After operating the TF and RBC processes for three different HLRs, low $SBOD_5$, DOC and $BDOC_5$ of the wastewater, which might cause a difficulty in differentiating the removal efficiencies at different values of the control parameters, were observed. It was decided to change the primary wastewater to one with higher organic concentrations. This was how the primary wastewater of the MBK WWTP, which had higher $SBOD_5$, DOC_0 and $BDOC_5$ compared to those of Si Phraya WWTP, stepped in.

4.2 Effect of control parameters on the effluent concentrations and removal of the organic parameters when using primary wastewater from the MBK WWTP as influent for AS, TF, and RBC systems

4.2.1 Effect of SRT on the effluent concentrations and removal of SCOD, $SBOD_5$, $BDOC_5$, DOC, UV_{254}, and SUVA when using primary wastewater from the MBK WWTP as influent for AS system

Figure 4.11 illustrates MLSS at the five SRTs operated. The error bars represent the SD of 10 samples, which were collected at each SRT. The values of MLSS were between 916 and 1011 mg/L with the average value of 981 mg/L. Figure 4.12 shows the influent and effluent pH at different SRTs. pH of the influent and effluent were 6.53-6.79 and 7.31-7.98, respectively, which were in acceptable ranges for the unit operation condition (Metcalf & Eddy, Inc., 2003). Slight pH increases after the process might be because of the same reason as reported above for the TF process when using the primary wastewater of the Si Phraya WWTP as an influent.

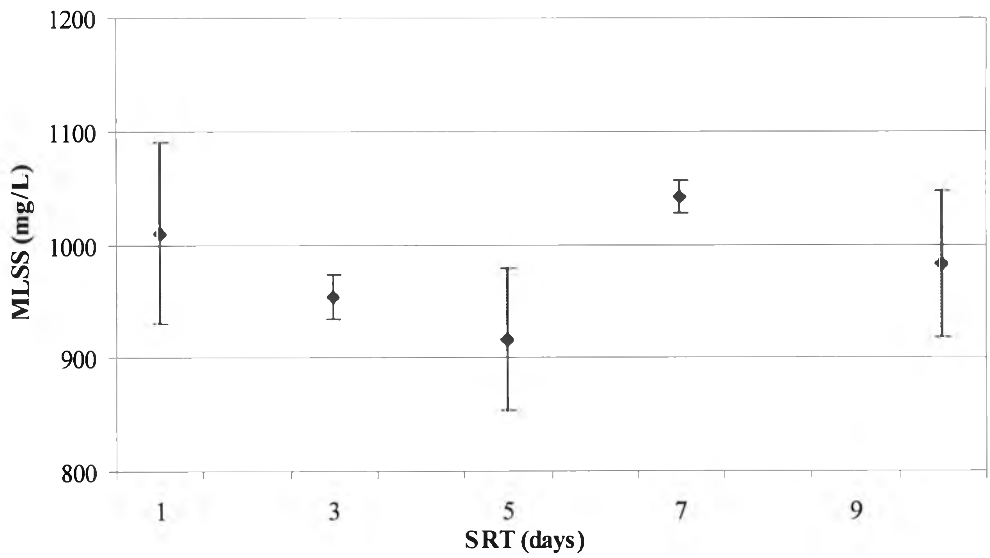

Figure 4.11 Relationship between MLSS and SRT of the AS unit operation.

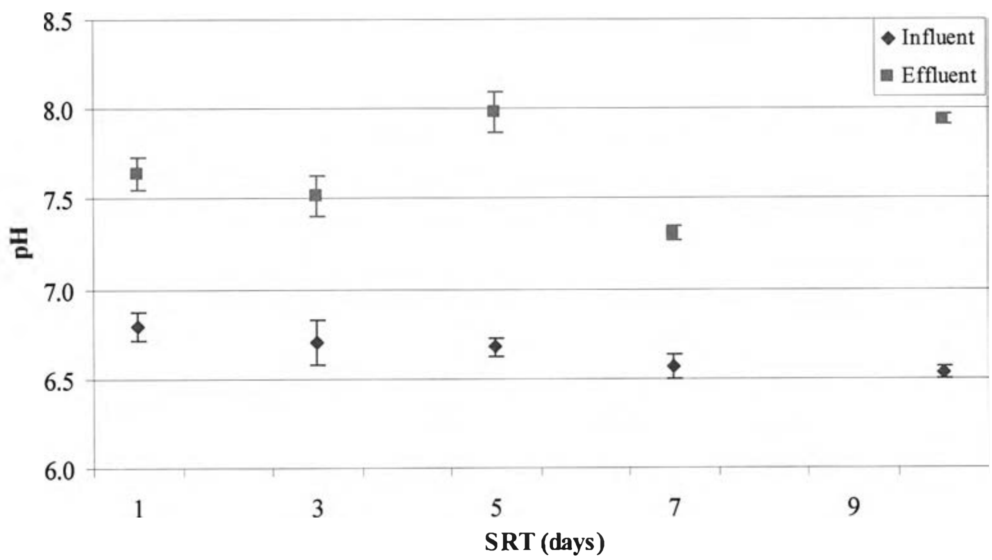

Figure 4.12 pH of influent and effluent at different SRTs.

Figure 4.13 shows that SCOD was not a precise wastewater quality parameter since the variation of the value of sample at the same SRT was very high. However, effluent SCOD tended to decline with increasing SRT as expected. As shown in Figure 4.14, no trend could be deduced from the relationship between SCOD removal and SRT. This was different from the results of Kim and Jeong (1997), and Seo *et al.* (1997) that reported increasing SCOD removal with increasing SRT, and might be caused from the errors of the SCOD method.

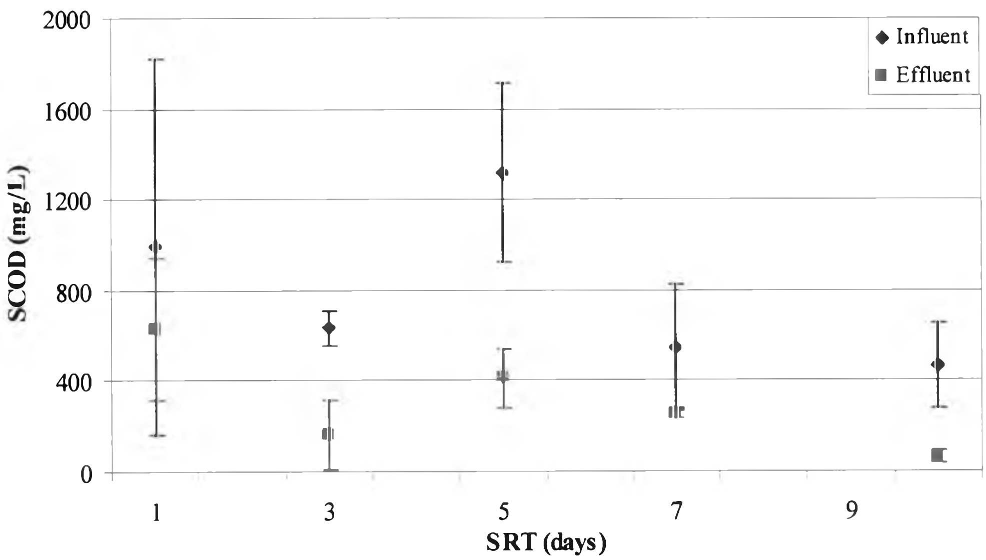

Figure 4.13 SCOD of influent and effluent at different SRTs of the AS system.

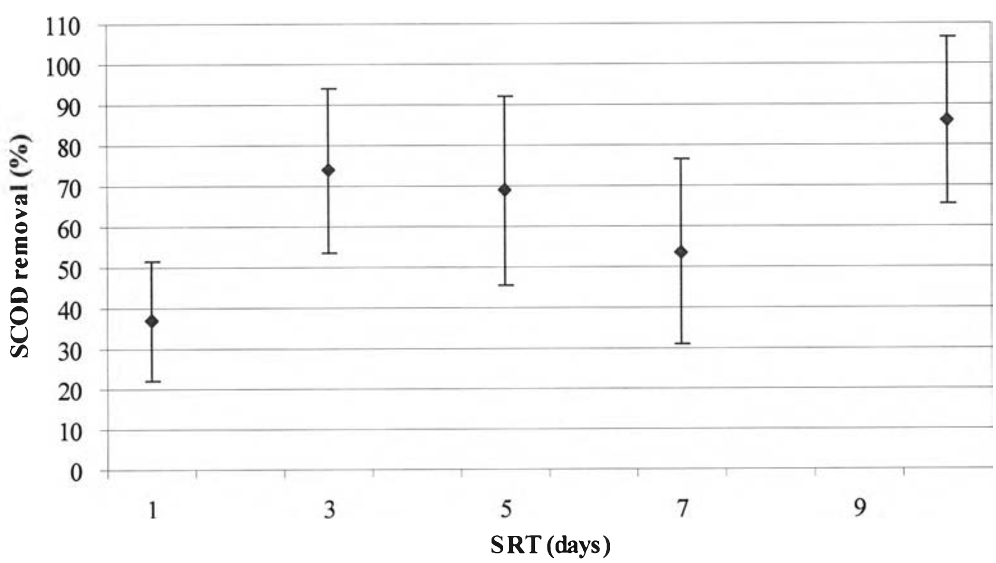

Figure 4.14 Relationship between SCOD removal and SRT of the AS system.

Figure 4.15 shows $SBOD_5$, $BDOC_5$ and DOC of the influent and effluent of the AS system at different SRTs. Influent $SBOD_5$ still fluctuated while less variation was observed with influent $BDOC_5$ and DOC at different SRTs. When influent $SBOD_5$ was high, effluent $SBOD_5$ tended to be high. The same effect was also applied to $BDOC_5$ and DOC. As a result, the effect of SRT on the effluent $SBOD_5$, $BDOC_5$ and DOC could not be inferred. Figure 4.16, which illustrates $SBOD_5$, $BDOC_5$ and DOC removal of the AS system versus SRT, confirmed the effect of influent organic concentrations on effluent organic concentrations. $SBOD_5$, $BDOC_5$ and DOC removal efficiencies across SRT were not much different, although they tend to be higher at higher SRTs (5-10 days). At each SRT, the removal efficiencies of the three parameters were comparable implying that one was as good as the other two in indicating the performance of the AS system.

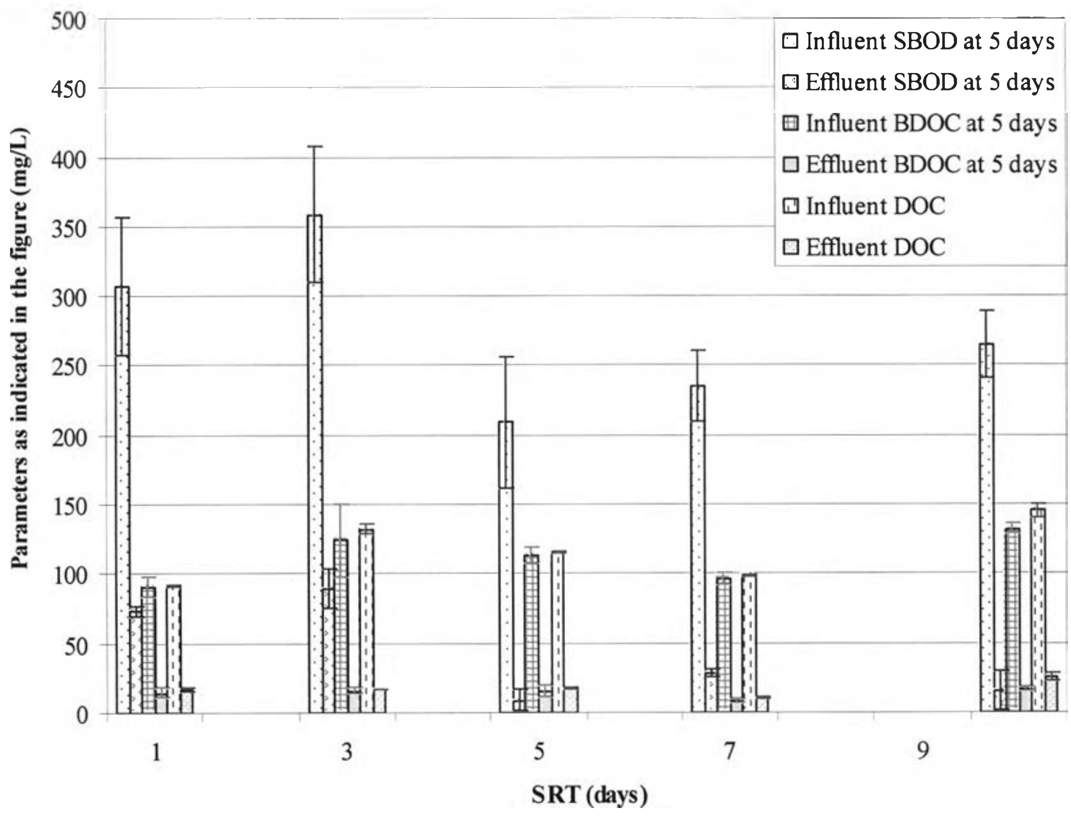

Figure 4.15 $SBOD_5$, $BDOC_5$ and DOC of influent and effluent of the AS system at different SRTs.

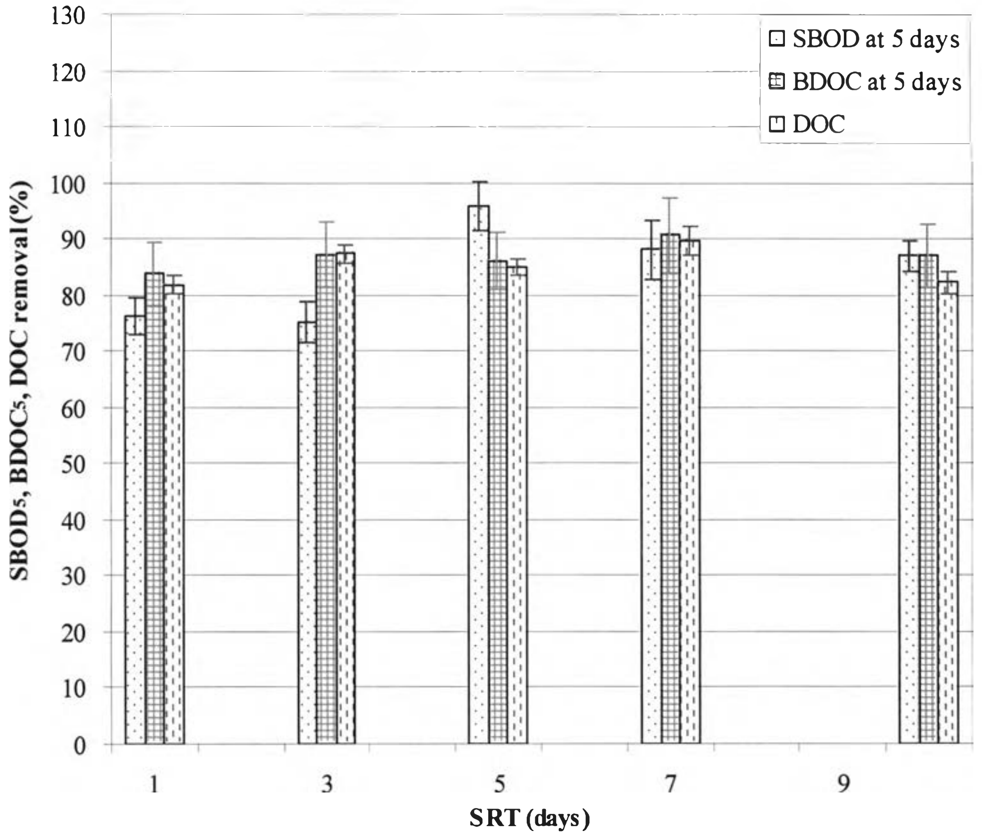

Figure 4.16 Relationship between $SBOD_5$, $BDOC_5$ and DOC removal and SRT of the AS system.

UV_{254} of the influent and effluent and removal of the AS system at different SRTs are presented in Figures 4.17 and 4.18, respectively. The UV_{254} ranges of the influent and effluent were 0.411-0.482 cm^{-1} and 0.220-0.263 cm^{-1}, respectively. The influent UV_{254} of the MBK primary wastewater was two to three times higher than that of the Si Phraya primary wastewater. UV_{254} of the influent and effluent and removal were consistent through all the SRT tested. Not only the biodegradable and total organics but also UV absorbing unsaturated and aromatic organics of the MBK primary wastewater were higher than those of the Si Phraya primary wastewater. SRT did not affect the ability of the system to remove UV absorbing constituents; about 40% to 50% of them were removed as a whole. As presented in Figure 4.19, SUVA increased after the treatment as seen with the cases for the TF and RBC when using the Si Phraya primary wastewater as influent. Unusually high SUVA in the effluent at 7 day SRT was due to low effluent DOC resulting from low influent DOC.

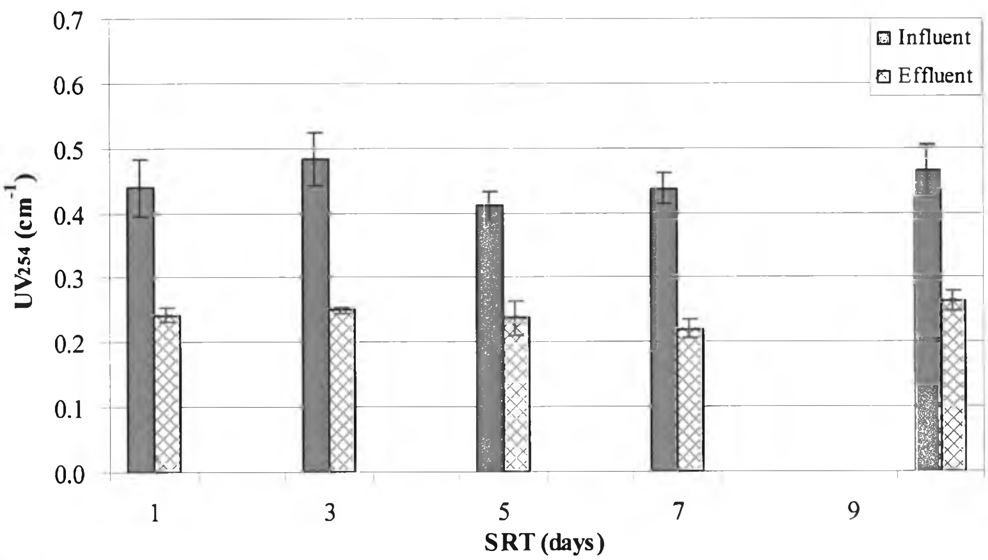

Figure 4.17 Influent and effluent UV_{254} of AS system at different SRTs.

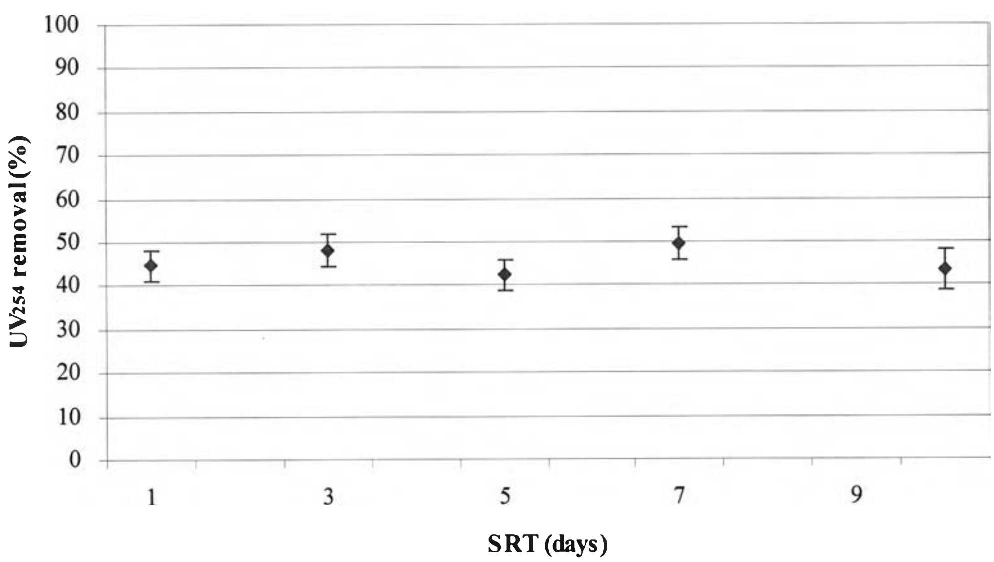

Figure 4.18 UV_{254} removal efficiency of the AS system at different SRTs.

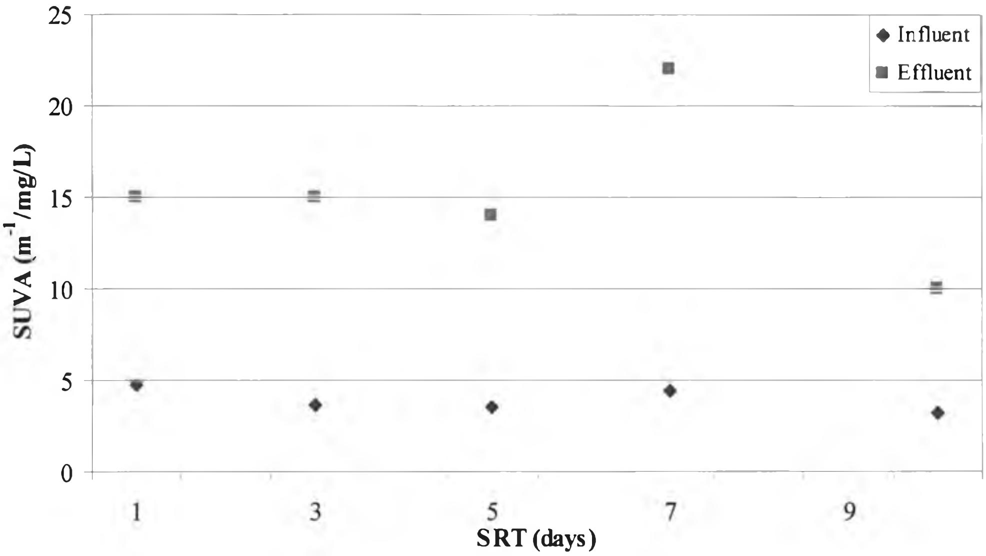

Figure 4.19 Influent and effluent SUVA of AS system at different SRTs.

4.2.2 Effect of HLR on the effluent concentrations and removal of SCOD, $SBOD_5$, $BDOC_5$, DOC, UV_{254}, and SUVA when using primary wastewater from the MBK WWTP as influent for TF system

Figures 4.20, 4.21, and 4.22 present influent and effluent pH, influent and effluent SCOD, and SCOD removal efficiency of TF system at different HLRs, respectively. Similar to all of the pH results presented above, minor increases of pH were obtained after the TF process. In spite of the high variability of influent SCOD at each HLR and across the HLRs tested, the SCOD removal efficiency was lower when HLR was higher, except for the value at HLR of 3 m^3/m^2-day. The deviation from the known trend that the performance should decrease with increasing HLR, at HLR of 3 m^3/m^2-day could not be easily explained but may be attributed to the precision of the SCOD measurement.

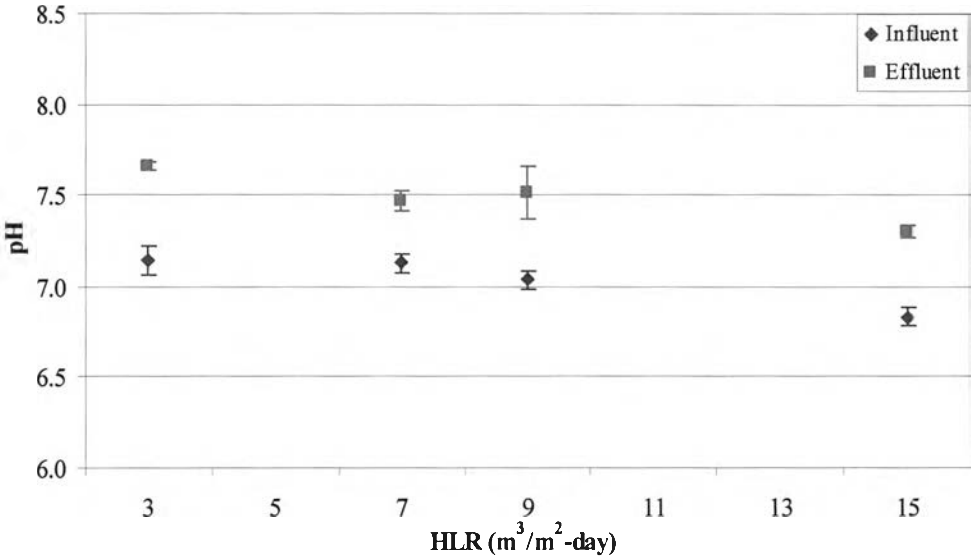

Figure 4.20 pH of influent and effluent when using primary wastewater from the MBK WWTP as influent for TF system at different HLRs.

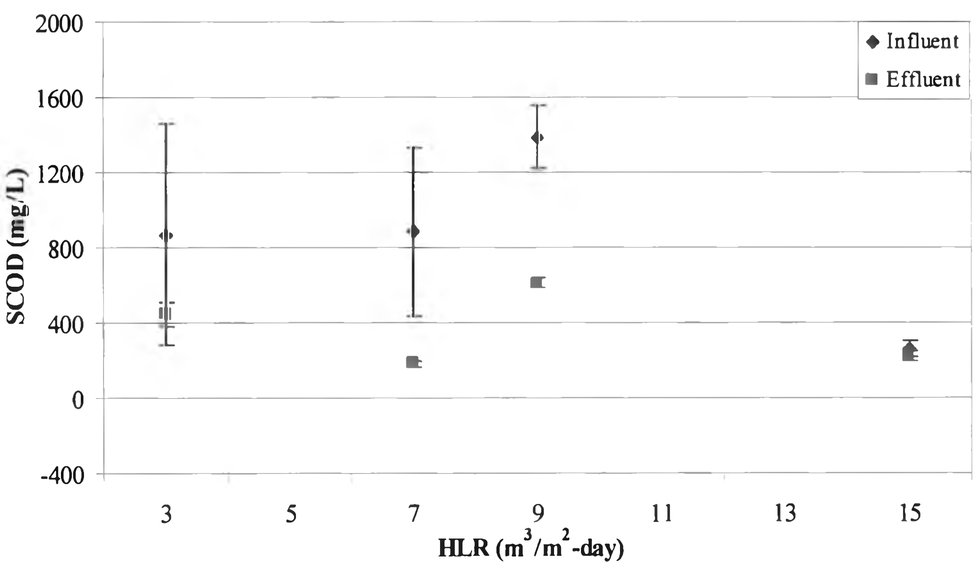

Figure 4.21 Influent and effluent SCOD of TF system at different HLRs when using primary wastewater from the MBK WWTP as influent.

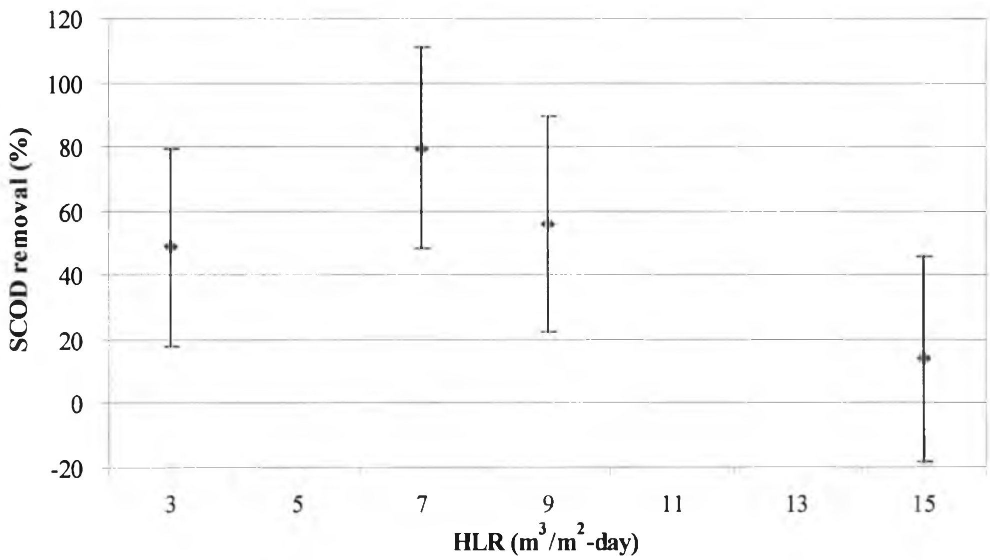

Figure 4.22 Relationship between SCOD removal efficiencies of TF system and HLRs when using primary wastewater from the MBK WWTP as influent.

Plots between HLR and $SBOD_5$, $BDOC_5$ and DOC of influent and effluent and their removal efficiencies of the TF system are shown in Figures 4.23 and 4.24, respectively. Although not strictly, higher effluent $BDOC_5$ and DOC were obtained at higher HLRs, due to the inconsistency of the influent quality, especially $SBOD_5$, it was very difficult to conclusively elucidate the effect of HLR on the effluent quality. The relationships between $SBOD_5$, $BDOC_5$ and DOC removal and HLR tended to be as expected. The deviations from the known trend at some HLRs are not explainable.

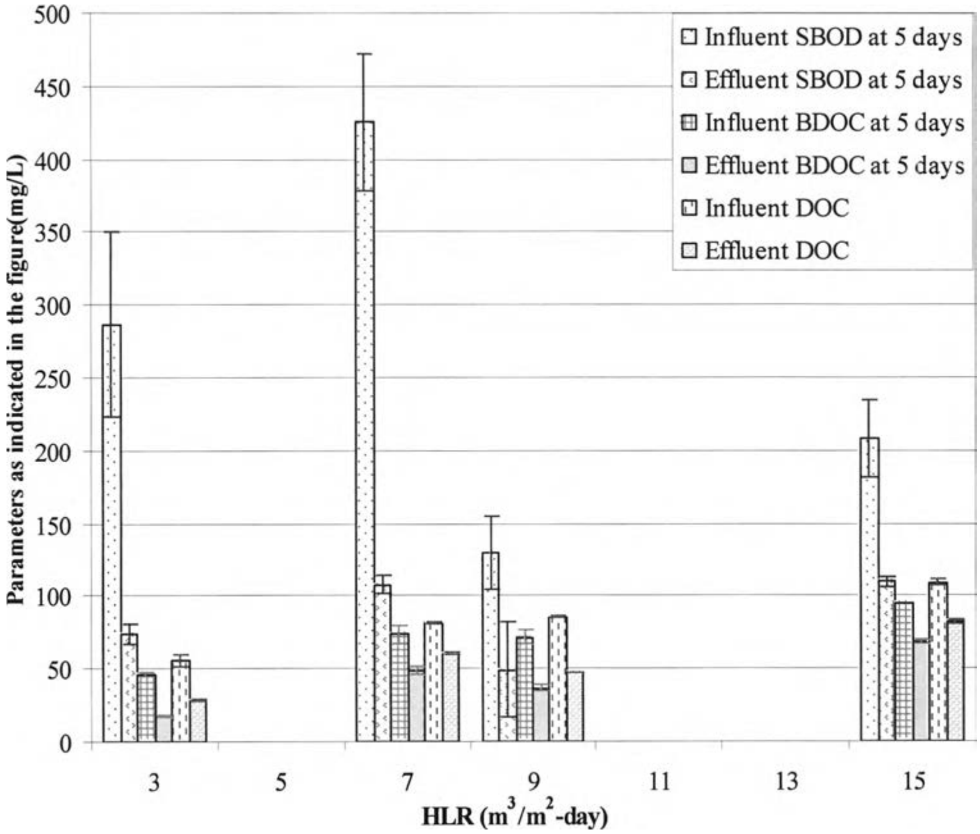

Figure 4.23 Influent and effluent $SBOD_5$, $BDOC_5$, and DOC of TF system at different HLRs when using primary wastewater from the MBK WWTP as influent.

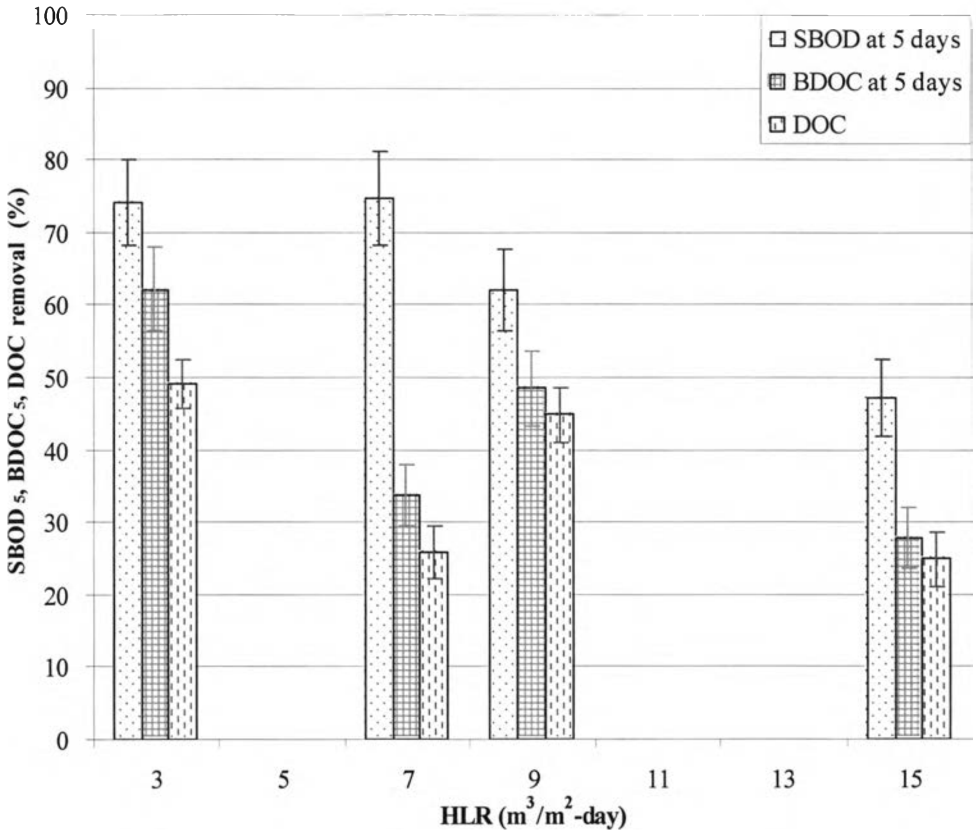

Figure 4.24 Relationships between $SBOD_5$, $BDOC_5$ and DOC removal efficiencies of TF system and HLRs when using primary wastewater from the MBK WWTP as influent.

Figures 4.25 and 4.26 show the influent and effluent UV_{254} and influent and effluent SUVA of the TF system at different HLRs, respectively. UV_{254} was hardly removed and it is not necessary to show the removal efficiency. The maximum removal of 5% occurred at HLR of 15 m^3/m^2-day. The TF system barely removed UV_{254} absorbing unsaturated or aromatic organics. The results complied with the UV_{254} results of the TF system feeding with the Si Phraya primary wastewater. Effluent SUVA was higher than influent SUVA but the differences were less than the differences provided by the AS system and tended to decrease with increasing HLR. The AS system was more efficient in removing organics than the TF system as shown in Figures 4.16 and 4.24. Although UV_{254} absorbing constituents were removed more through the AS, effluent DOC of the AS system was much lower than that of the TF system while the influent SUVA was not much different for the two systems. This caused the effluent SUVA of the AS system to be higher than of the TF system. The decrease in the effluent SUVA with increasing HLR, that made the gap between the influent and effluent SUVA closer, was due to higher effluent DOC at higher HLRs while the effluent UV_{254} remained relatively constant.

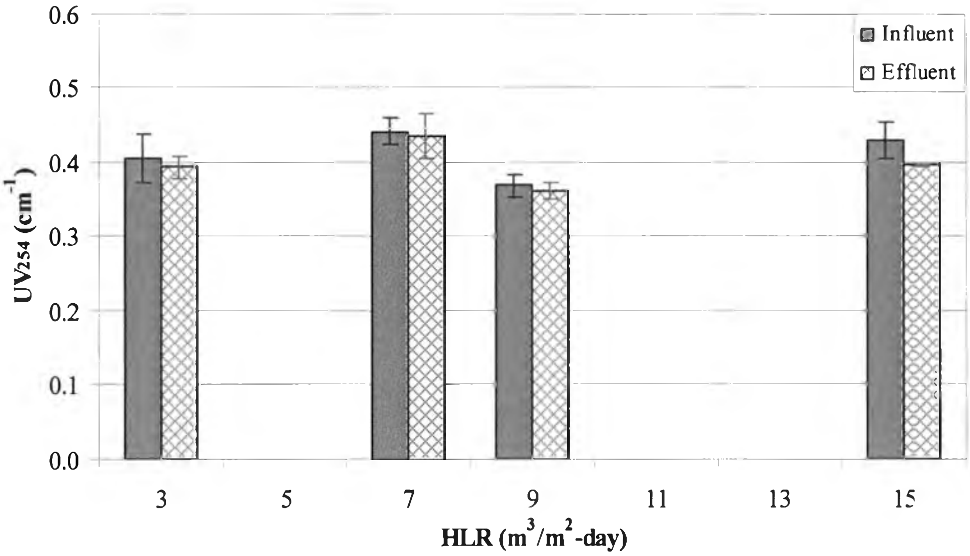

Figure 4.25 Influent and effluent UV_{254} of TF system at different HLRs when using primary wastewater from the MBK WWTP as influent.

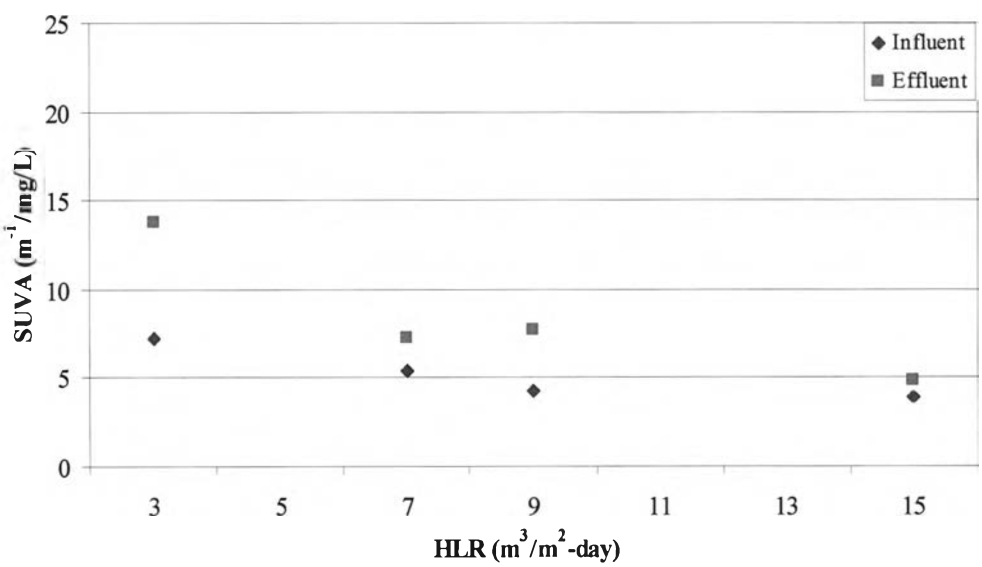

Figure 4.26 Influent and effluent SUVA of TF system at different HLRs when using primary wastewater from the MBK WWTP as influent.

4.2.3 Effect of HLR on the effluent concentrations and removal of SCOD, SBOD$_5$, BDOC$_5$, DOC, UV$_{254}$, and SUVA when using primary wastewater from the MBK WWTP as influent for RBC system

Influent and effluent pH, influent and effluent SCOD, and SCOD removal efficiency of the RBC system at different HLRs are shown in Figures 4.27, 4.28, and 4.29, respectively. The results were somewhat similar to those of the TF system using the same wastewater as a feed. The lowest HLR again provided poorer COD removal performance than some of the higher HLRs. However, no trend could be established between COD removal and HLR.

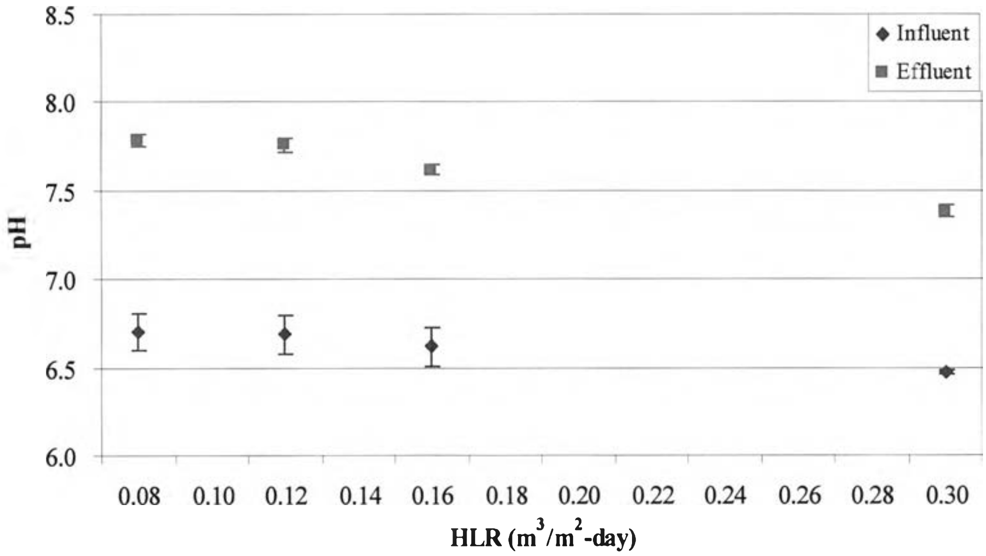

Figure 4.27 pH of influent and effluent when using primary wastewater from the MBK WWTP as influent for RBC system at different HLRs.

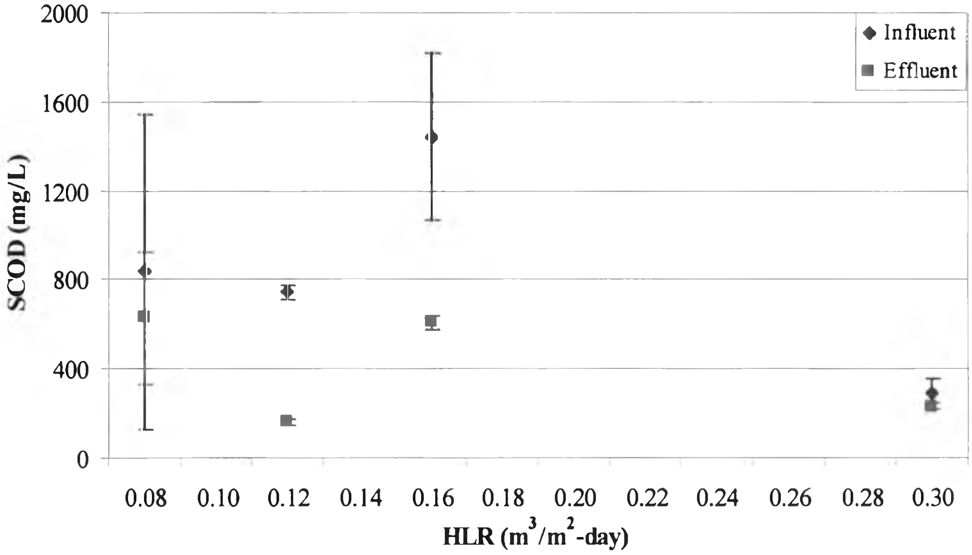

Figure 4.28 Influent and effluent SCOD of RBC system at different HLRs when using primary wastewater from the MBK WWTP as influent.

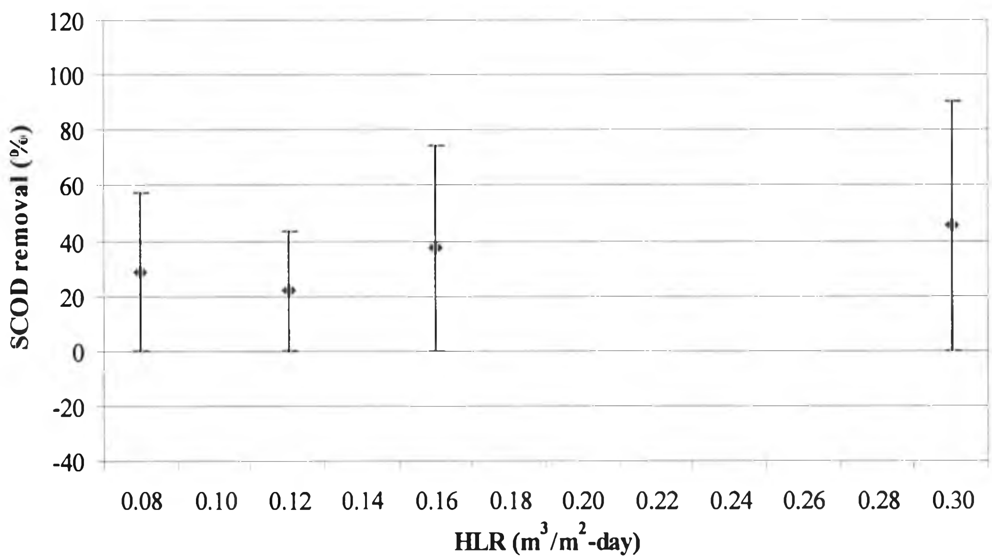

Figure 4.29 Relationship between SCOD removal efficiencies of RBC system and HLRs when using primary wastewater from the MBK WWTP as influent.

Figures 4.30 and 4.31 show the plots of $SBOD_5$, $BDOC_5$ and DOC of the influent and effluent of the RBC system and their removal efficiencies against HLRs, respectively. Similar to the results of the TF system fed with the MBK primary wastewater, not always but in general, a decrease in organic removal and increases in effluent organic concentrations were observed with increasing HLR. The results in Figures 4.30 and 4.31 and similar figures for the AS and TF systems confirm the utility of $BDOC_5$ in characterizing the effluent quality and performance of the three commonly used biological wastewater treatment processes. In addition, the magnitudes of $BDOC_5$ and DOC decreases at all SRTs tested for the AS system and all HLRs experimented for the TF and RBC systems were comparable suggesting that organics removed were mostly readily biodegradable constituents.

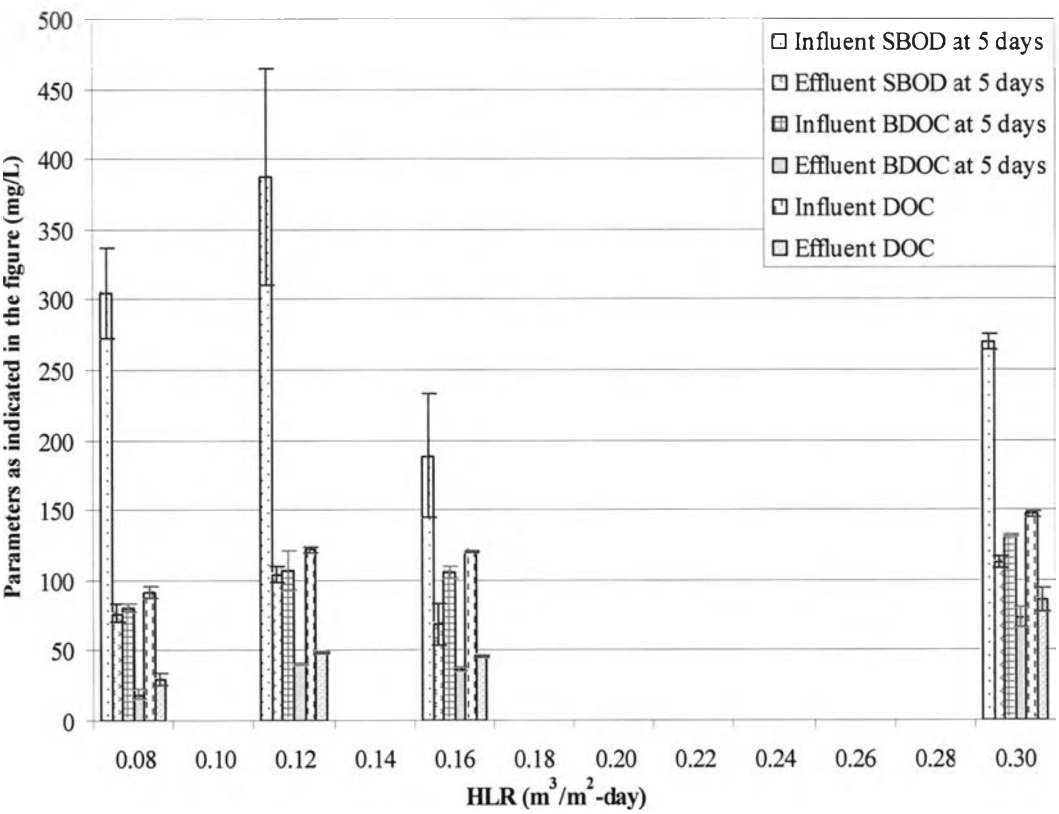

Figure 4.30 Influent and effluent $SBOD_5$, $BDOC_5$, and DOC of RBC system at different HLRs when using primary wastewater from the MBK WWTP as influent.

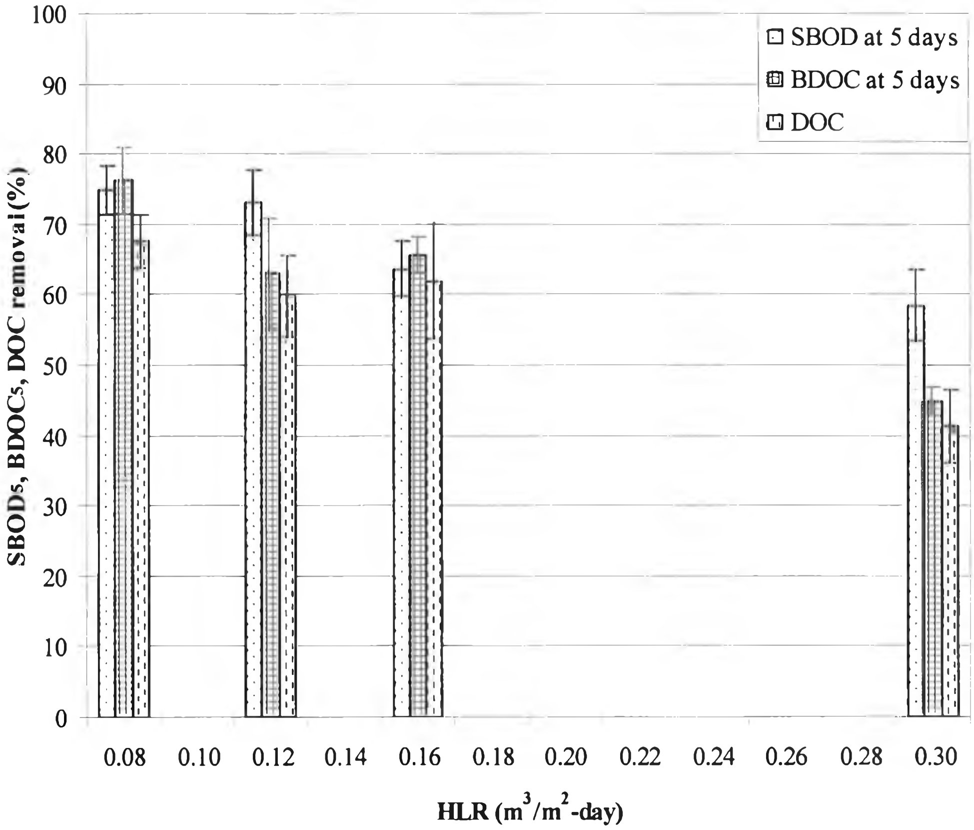

Figure 4.31 Relationships between $SBOD_5$, $BDOC_5$ and DOC removal efficiencies of RBC system and HLRs when using primary wastewater from the MBK WWTP as influent.

Influent and effluent UV_{254}, UV_{254} removal, and influent and effluent SUVA of the RBC system are shown in Figures 4.32, 4.33, and 4.34. The removal of UV_{254} absorbing constituents was in between those of the AS and TF systems. This agrees with the known fact that the performance of the three widely used biological wastewater treatment processes is in the following order: AS > RBC > TF. Attached cells might not be effective in degrading UV_{254} absorbing unsaturated and aromatic organics as suspended cells. This explains why the RBC system, which typically has fair amounts of suspended cells in the process, was more and less efficient than the TF and AS systems, respectively, in UV_{254} reduction. The SUVA results followed the same trend as seen with the TF system but the increase of the closeness between the influent and effluent SUVA with increasing HLR was more evident.

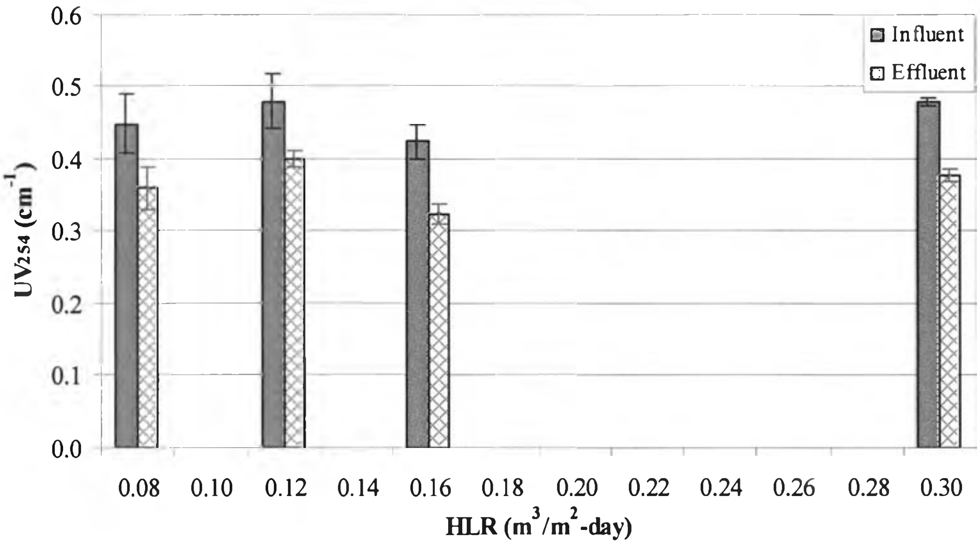

Figure 4.32 Influent and effluent UV_{254} of RBC system at different HLRs when using primary wastewater from the MBK WWTP as influent.

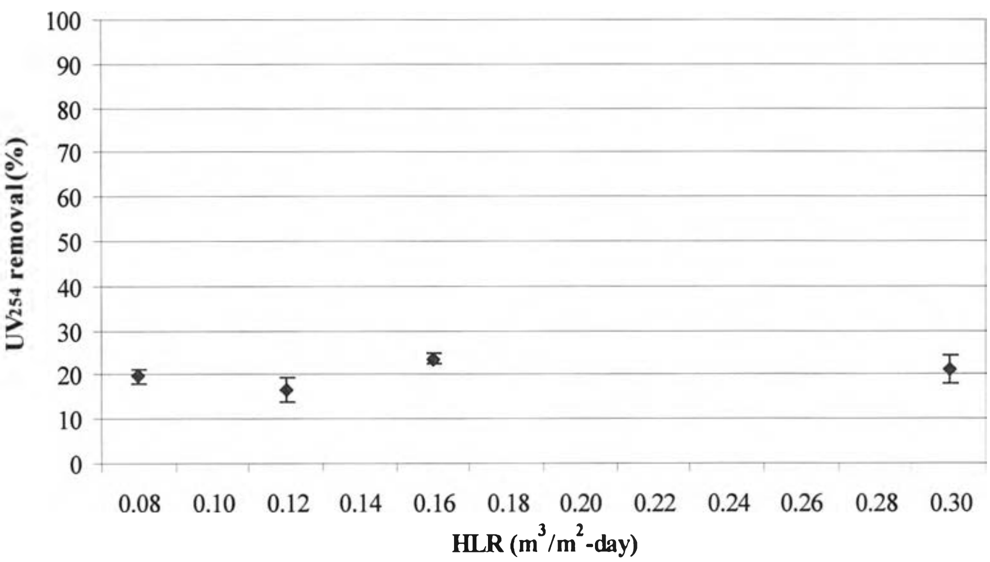

Figure 4.33 UV_{254} removal efficiency of RBC system at different SRTs when using primary wastewater from the MBK WWTP as influent.

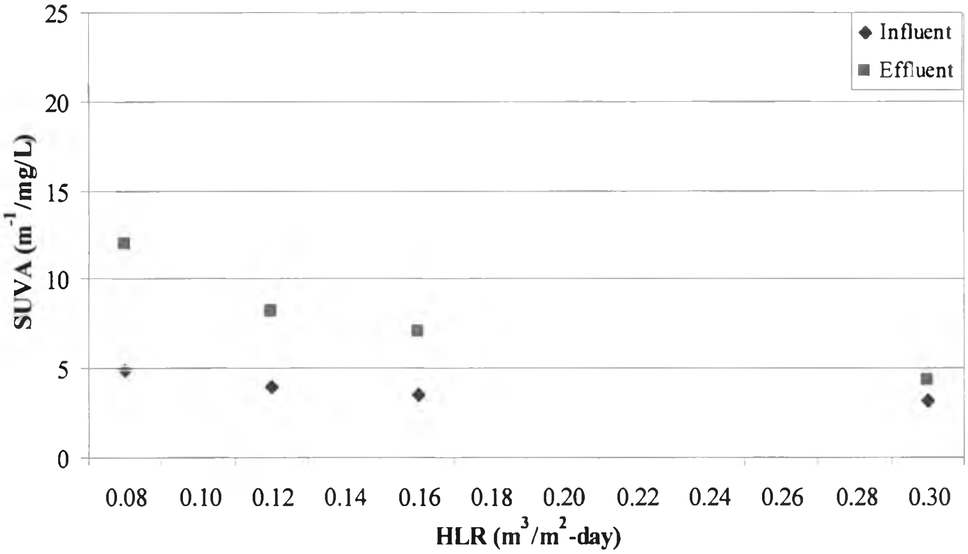

Figure 4.34 Influent and effluent SUVA of RBC system at different HLRs when using primary wastewater from the MBK WWTP as influent.

4.3 Relationships among $BDOC_5$, UV_{254}, DOC, SCOD and $SBOD_5$.

Relationships among $BDOC_5$, UV_{254}, DOC, SCOD and $SBOD_5$ were investigated separately for influent and effluent of the three biological wastewater treatment systems receiving primary wastewater from the MBK WWTP. A linear regression was performed on the relationships and the regression equation and coefficient of correlation (r) obtained are presented.

Poor negative correlations between $SBOD_5$ and SCOD were observed as shown in Figure 4.35. The relationships do not agree with a known trend that the concentration of $SBOD_5$ increases as that of SCOD increases (Babcock *et al.*, 2001). This deviation occurred because of the low precision of both methods. Similar observations were found when plotting SCOD against DOC, $BDOC_5$, and UV_{254} as shown in Figures 4.36, 4.37, and 4.38, respectively, confirming the poor precision of the COD method.

The fairly strong linear relationship between $SBOD_5$ and $BDOC_5$ of the effluent shown in Figure 4.39 is in agreement with the results of Servais *et al.* (1999). The poor relationship for the influent was due to low precision of the $SBOD_5$ method especially with wastewater with high levels of organics. Moreover, the trends and slopes of influent and effluent relationships suggested that $BDOC_5$ can be used for characterizing primary and secondary treated wastewater qualities, since influent and effluent $BDOC_5$ illustrated the differentiation of each sample, while influent $SBOD_5$ were about the same at different samples. A positively very strong relationship between DOC and $BDOC_5$, as illustrated in Figure 4.40, were expected for the influent. $BDOC_5$ is a portion of DOC and for municipal wastewater, of which the chemical characteristic does not usually fluctuate, such as the one used in this study, a strong relationship between the two parameters should be observed. A slightly higher slope of the relationship for the effluent suggested that the three processes were slightly more efficient on $BDOC_5$ removal than DOC removal ($BDOC_5$ removed/influent BDOC > DOC removed/influent DOC). Furthermore, it was learned the three processes provided effluent with consistent organic characteristics (biodegradability or $BDOC_5$/DOC). The strong relationships also confirmed the high precision of both methods compared with $SBOD_5$ and SCOD. Strong relationships between DOC and BDOC were also reported by Khan *et al.* (1998b), Servais *et al.* (1999) and Wanaratna (2002). The plots between $SBOD_5$ and DOC in Figure 4.41 had the same trends as those of $SBOD_5$ and $BDOC_5$ in Figure 4.39 as anticipated since DOC strongly related to $BDOC_5$.

Figures 4.42, 4.43, and 4.44 show that UV_{254} correlated fairly well with DOC, $BDOC_5$, and $SBOD_5$, respectively. A strong relationship between UV_{254} and DOC was reported. UV_{254} represents the amount of unsaturated double bonds and aromatic organics that are a major composition NOM as well as DOC in water. Edzwald *et al.* (1985) indicated that UV_{254} can be used a surrogate parameter for organic carbon. Since $BDOC_5$ and $SBOD_5$ are positively and linearly related to DOC, the correlations shown in Figures 4.43 and 4.44 are reasonable. They also agree well with previous studies. Wanaratna (2002) suggested that the relationship between $BDOC_5$ and UV_{254} of wastewater exists. Reynolds and Ahmad (1997) presented a strong relationship between UV_{254} and $SBOD_5$. The higher slopes of the relationships for the effluent samples agree with the fact the biological processes removed relatively much less UV_{254} absorbing constituents than biodegradable organics.

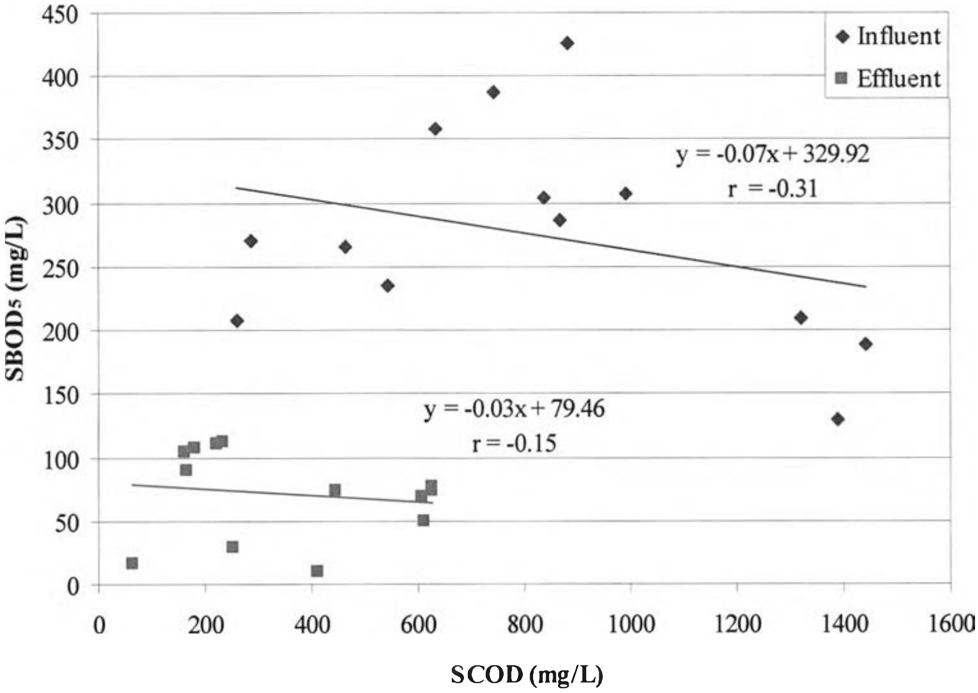

Figure 4.35 Correlations of $SBOD_5$ and SCOD.

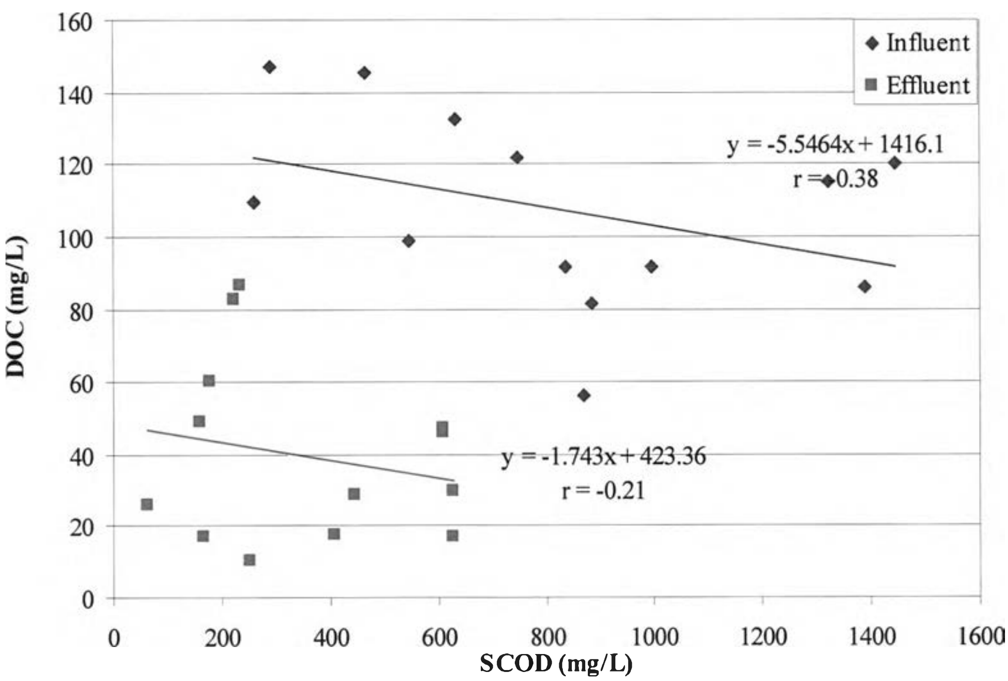

Figure 4.36 Correlations of DOC and SCOD.

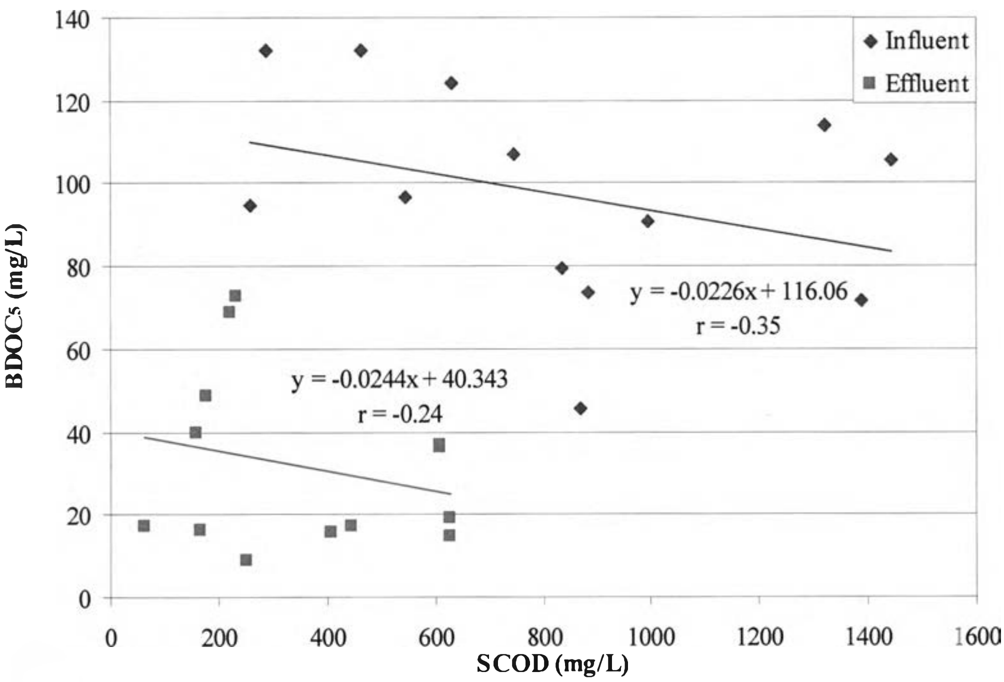

Figure 4.37 Correlations of $BDOC_5$ and SCOD.

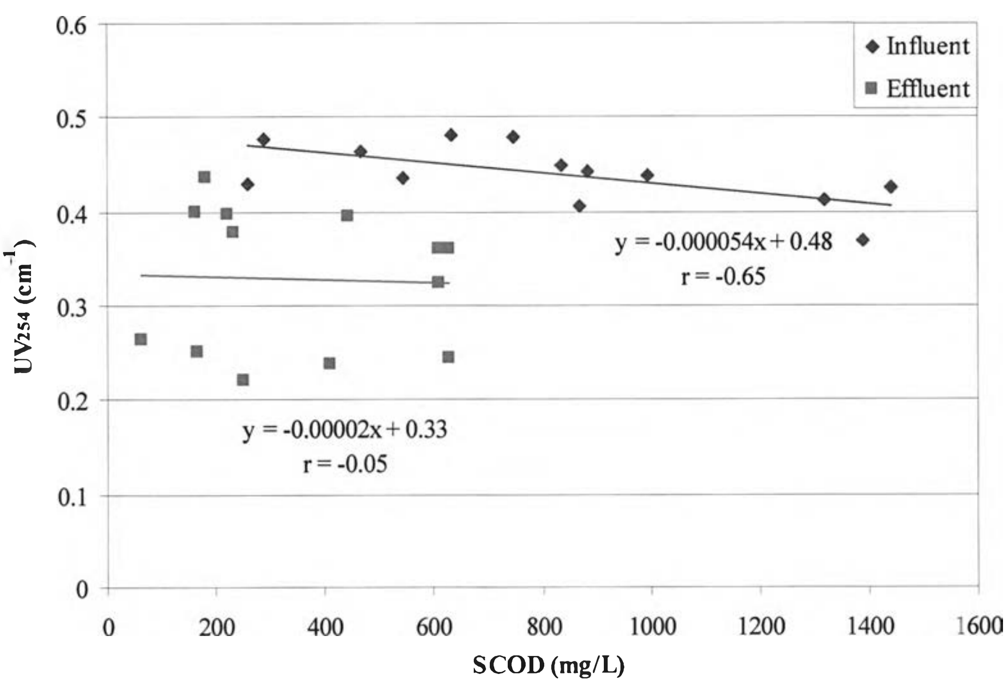

Figure 4.38 Correlations of UV_{254} and SCOD.

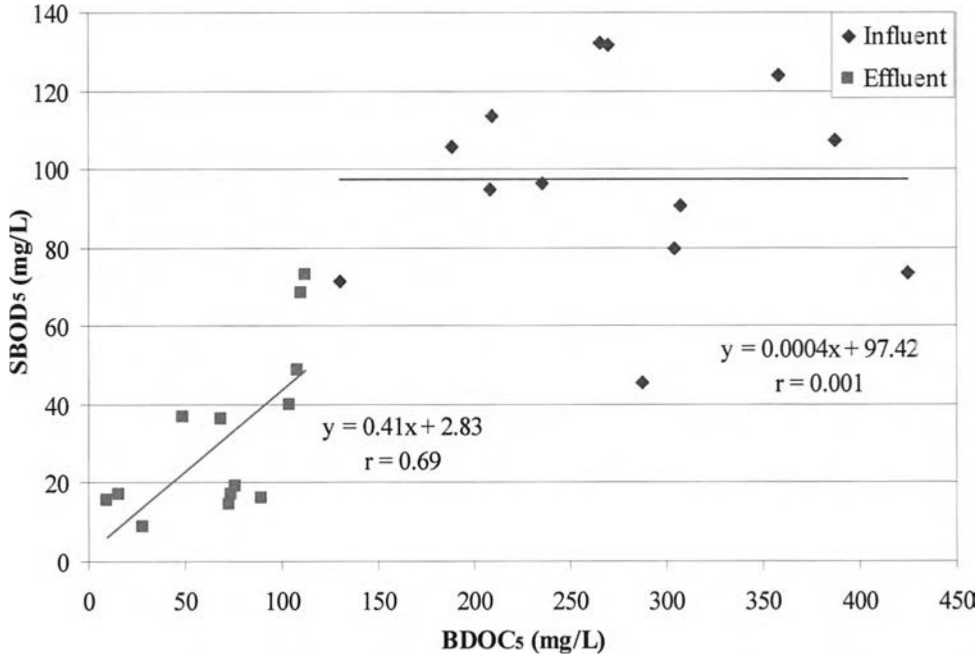

Figure 4.39 Correlations of $SBOD_5$ and $BDOC_5$.

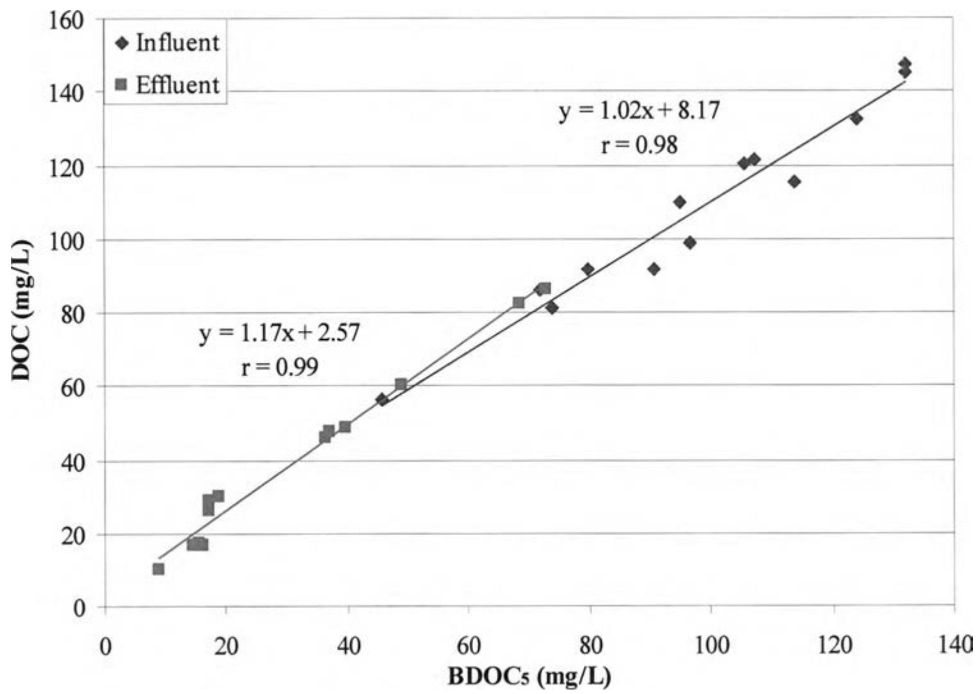

Figure 4.40 Correlations of DOC and $BDOC_5$.

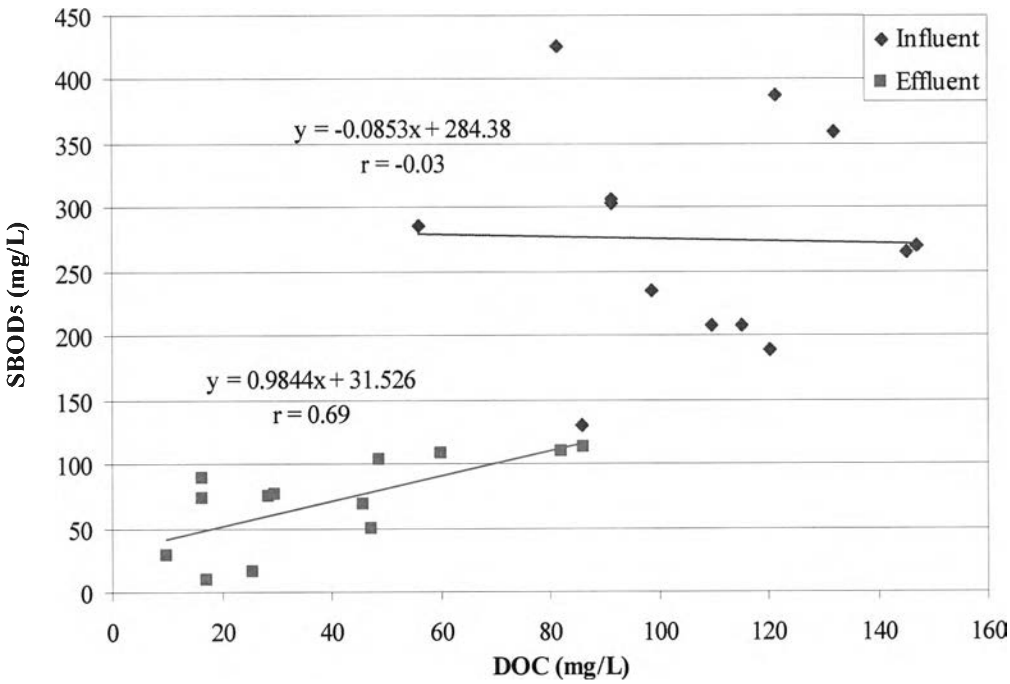

Figure 4.41 Correlations of DOC and $SBOD_5$.

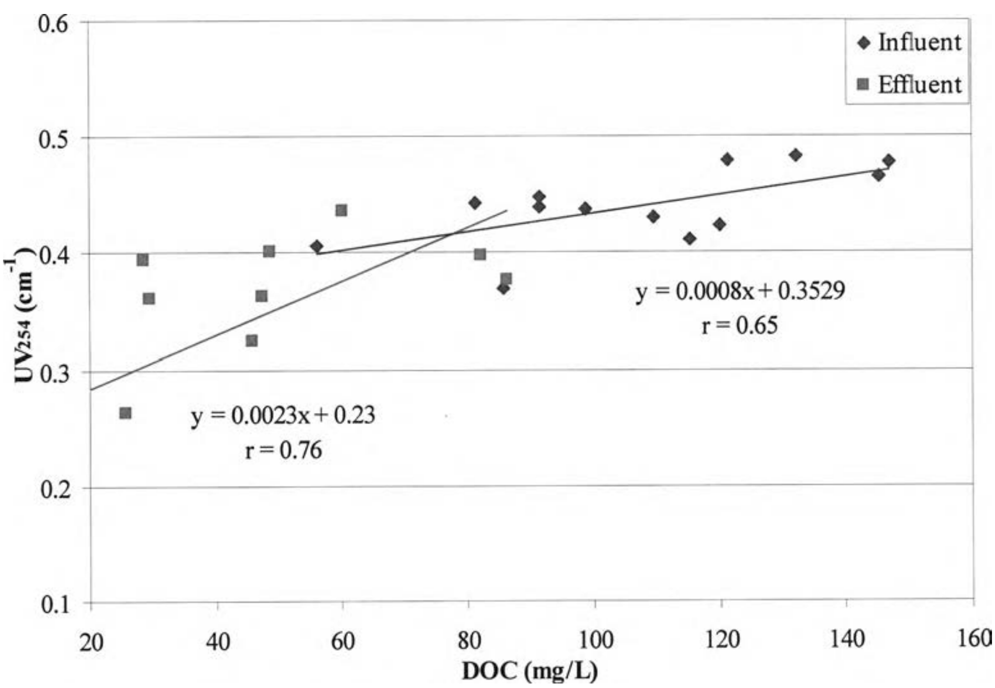

Figure 4.42 Correlations of UV_{254} and DOC.

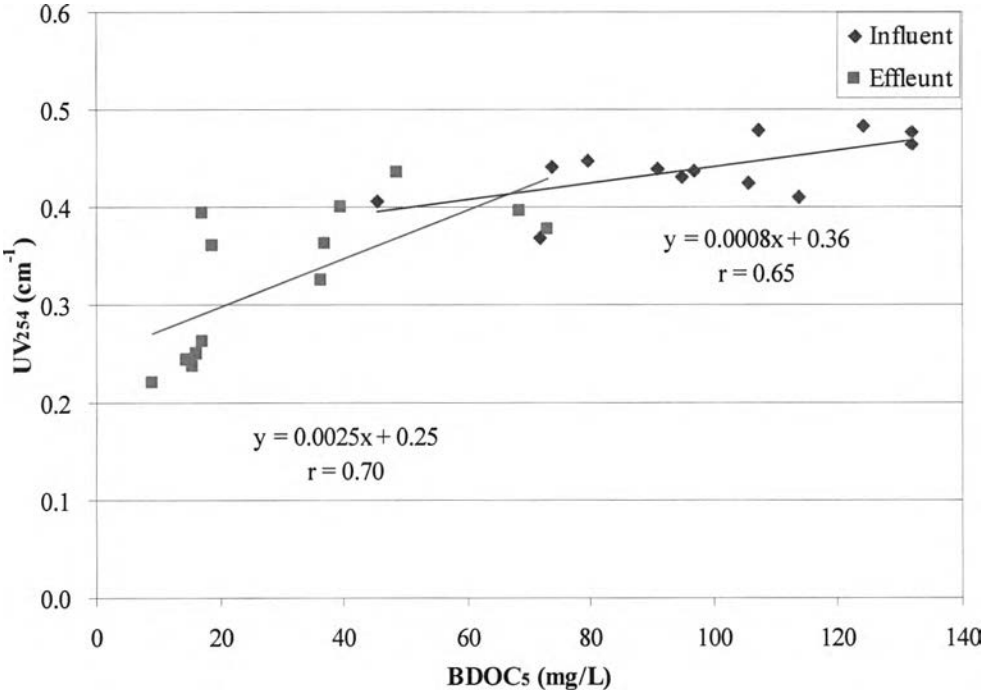

Figure 4.43 Correlations of UV_{254} and $BDOC_5$.

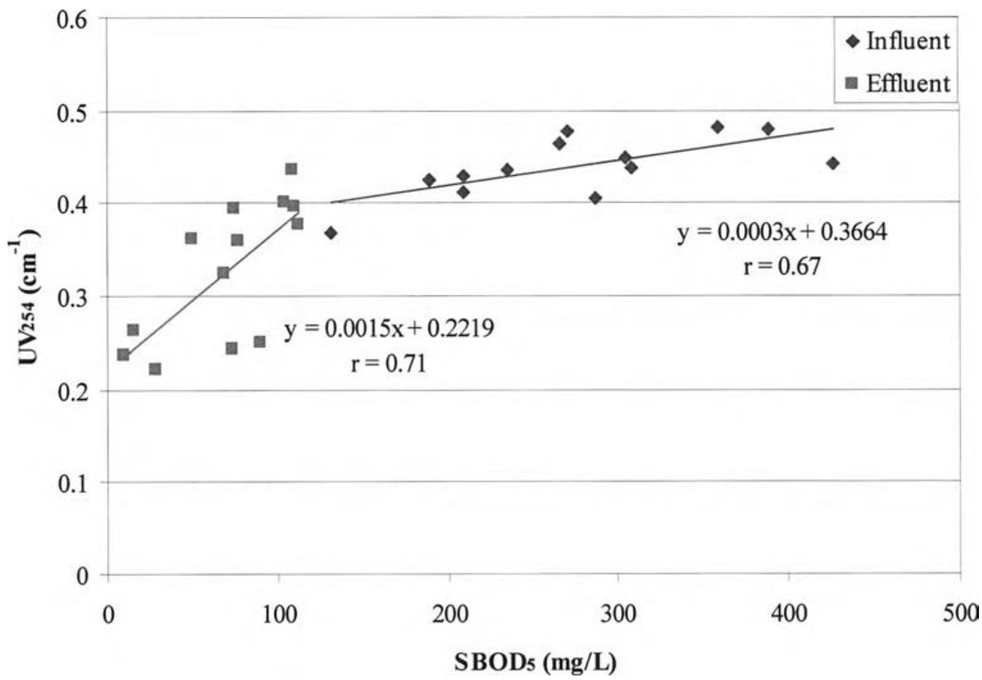

Figure 4.44 Correlations of UV_{254} and $SBOD_5$.

As shown in Figures 4.45 and 4.46, SUVA has weak relationships with SCOD and $SBOD_5$, respectively, except for the case between effluent SUVA and $SBOD_5$, which has a fair relationship. This is again attributed to poor precision of SCOD and $SBOD_5$, especially at high organic concentrations. Figures 4.47 and 4.48 illustrate relatively strong negative relationships between SUVA and $BDOC_5$, and DOC, respectively. The trend lines indicate increasing $BDOC_5$ and DOC with decreasing SUVA. SUVA indicates the relative amount of aquatic humics (less biodegradable organics) in water. Thus, the samples with more $BDOC_5$ should be less in SUVA. Since $BDOC_5$ and DOC correlate strongly, they have similar relationships with UV_{254}. After the biological treatment processes, the biodegradable portion was removed and therefore the proportion of less biodegradable organics was higher. As a result, effluent SUVA tended to be higher than influent SUVA. The relationship between effluent SUVA and $BDOC_5$, and DOC are affected by the degree of treatment. This explains why relative SUVA increase per unit of $BDOC_5$ and DOC decrease (slope of the regression lines) were higher for the effluent.

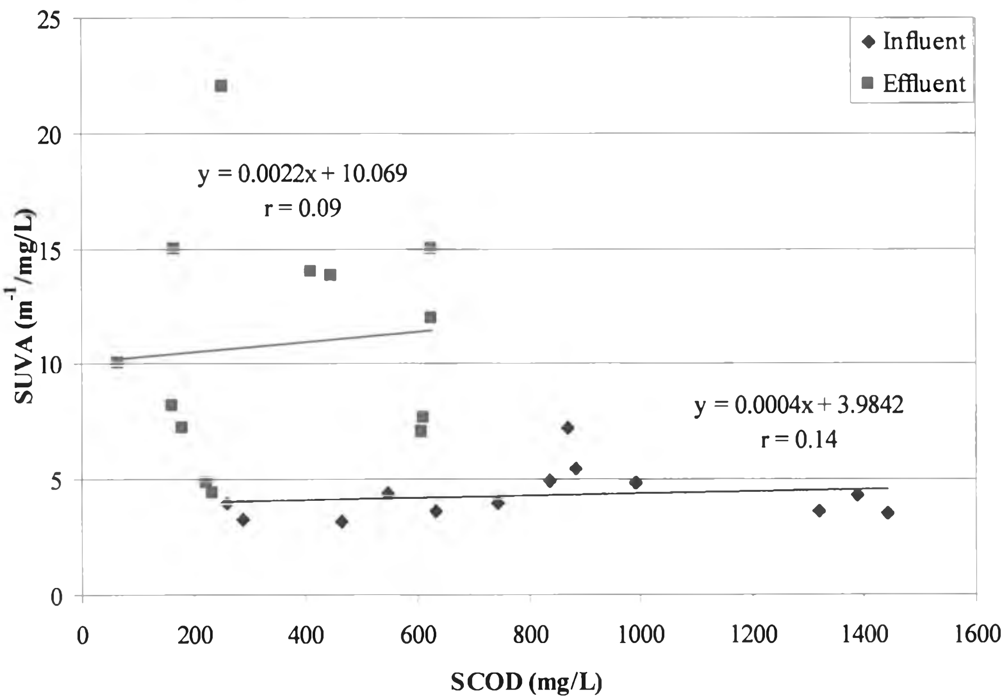

Figure 4.45 Correlations of SUVA and SCOD.

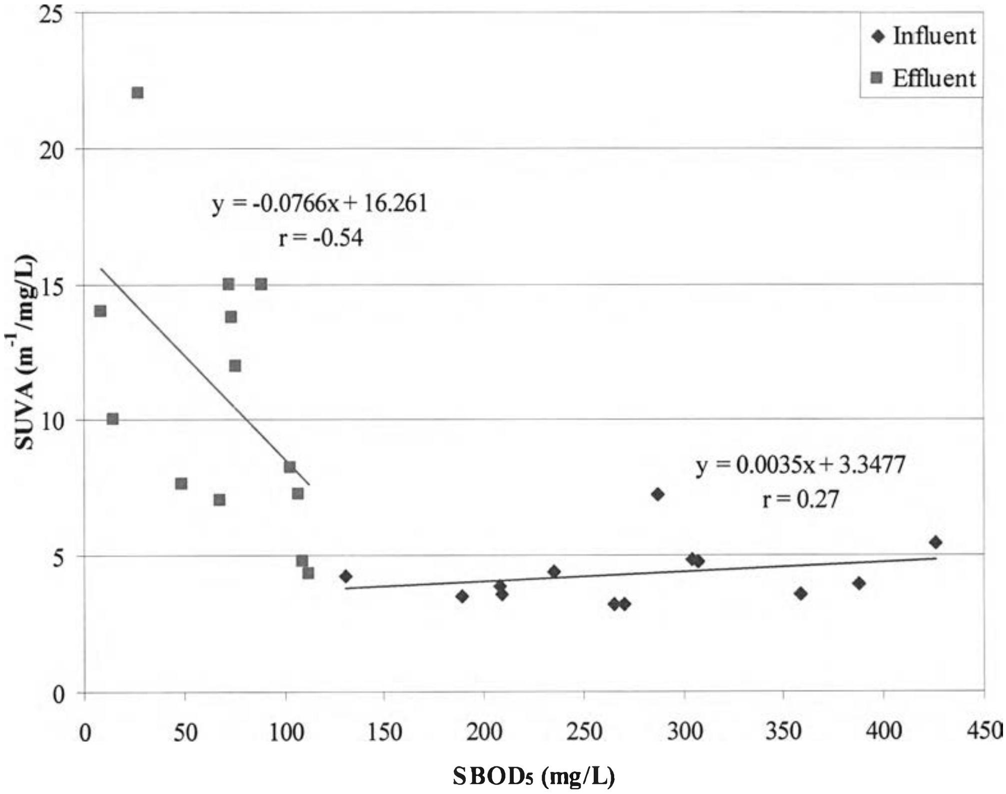

Figure 4.46 Correlations of SUVA and $SBOD_5$.

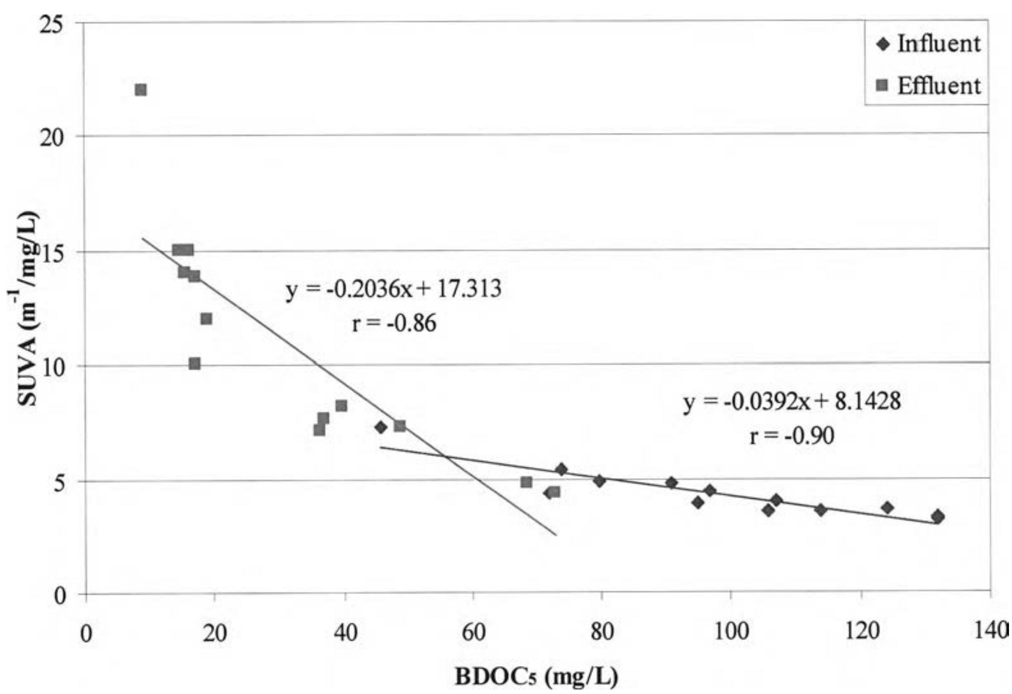

Figure 4.47 Correlations of SUVA and $BDOC_5$.

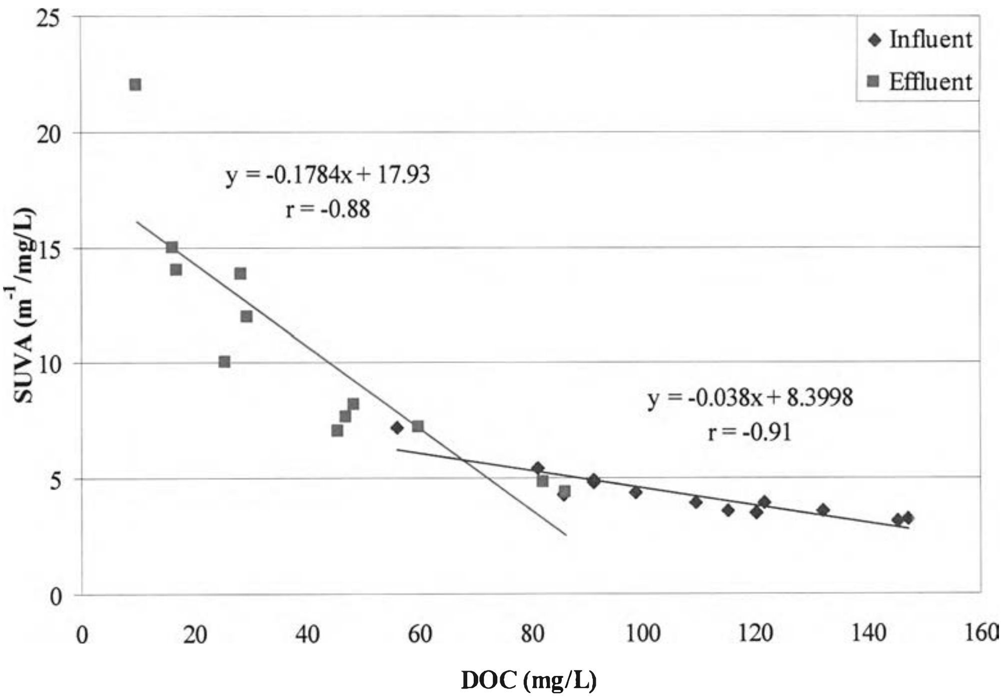

Figure 4.48 Correlations of SUVA and DOC.