CHAPTER IV
RESULTS AND DISCUSSION

4.1 Anaerobic Digestion of Cassava Wastewater without Microaeration

The cassava wastewater was digested in the anaerobic digestion under the CSTR system without oxygen supply. The COD loading rate was varied from 0.604 to 2.500 kg/m^3 d. For each COD loading rate, the gas production rate and gas composition were measured daily until the system reached steady state.

4.1.1 COD Removal and Gas Production Rate

The COD removal is defined as the relative change between the total feed COD and total effluent COD. Figure 4.1 shows that the COD removal is increased from 22.04 % to 34.53 % by increasing the COD loading rate from 0.604 to 1.710 kg/m^3 d. In addition, the COD removal is decreased from 34.53 % to 31.75 % with further increase in the COD loading rate from 1.710 to 2.500 kg/m^3 d. The maximum COD removal is 34.53 % at the COD loading rate of 1.710 kg/m^3 d. It may be explained that the increase in the COD loading rate results in the increase in the organic compounds available for microorganisms to degrade, which is consistence with the increase in the COD removal. On the other hand, when the COD loading rate is too high, like 2.500 kg/m^3 d, there is high volatile fatty acid accumulation, which unavoidably results in the system toxicity; hence, the decrease in the COD removal. The gas production rate shows the similar trend to the COD removal. That is the maximum gas production rate is 265.50 mL/d at the COD loading rate of 1.710 kg/m^3 d. In other words, the optimum COD loading rate of 1.710 kg/m^3 d results in the maximum COD removal and gas production rate.

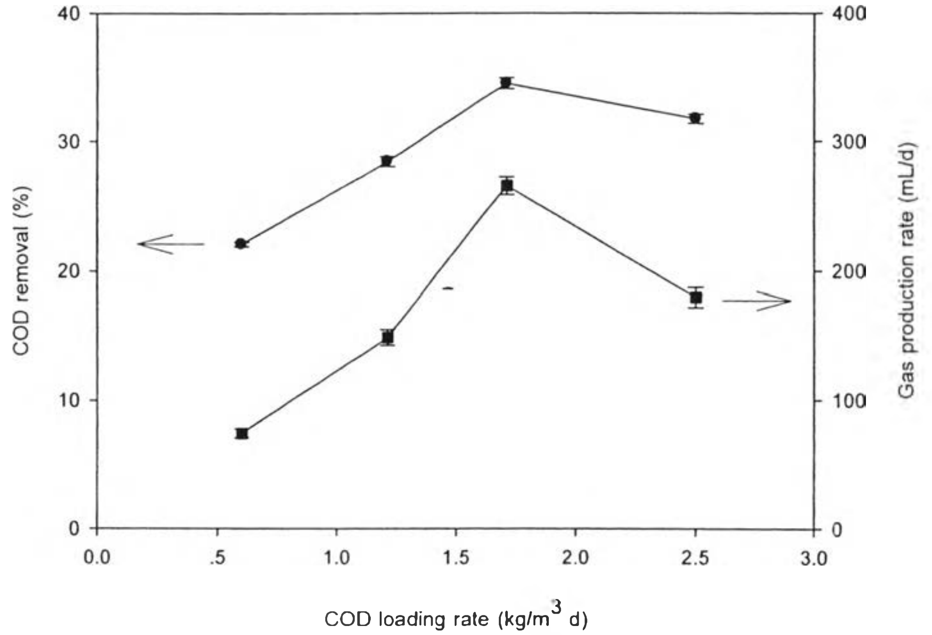

Figure 4.1 Effects of COD loading rate on COD removal and gas production rate.

4.1.2 Gas Composition and Methane Production Rate

Figure 4.2 shows the gas composition that is mainly methane and carbon dioxide. The methane composition and methane production rate are increased from 61.77 to 74.42 % and 45.87 to 197.61 mL/d, respectively, with the increase in the COD loading rate from 0.604 to 1.710 kg/m^3 d. However, when the COD loading rate is increased from 1.710 to 2.500 kg/m^3 d, the methane composition is decreased from 74.42 to 47.73 %, and the methane production rate is down from 197.61 to 85.76 mL/d, while the hydrogen composition is increased to 34.85 %. The results indicate that the lower COD loading rate is suitable for the methane production because the lower COD loading rate has lower volatile fatty acid accumulation than the higher COD loading rate. The lower volatile fatty acid accumulation can be clearly observed from the pH value. The pH value is in the range of 6.52 - 7.02 when the COD loading rate is in the range of 0.604 to 1.710 kg/m^3 d. The pH value is an important factor in the anaerobic digestion by most anaerobic microorganism including methane-forming microorganism, which performs well in the pH range of 6.8 - 7.2. The pH value lower than 6 is too toxic for the methanogens activities

(Chandra *et al.*, 2012). On the contrary, the hydrogen-forming microorganism performs well in the pH range of 4.5 - 5.5 (Yu *et al.*, 2002). The COD loading rate of 2.500 kg/m^3 d corresponding to the pH value of 5.26, and the rate of 1.710 kg/m^3 d has the pH value of 7.02. This explains the observed phenomena described above with the variuos COD loading rates. Both specific methane production rate and methane yield show similar trend (Figures 4.3 and 4.4). The maximum specific methane production rate of 49.40 mL CH_4/L d (or 4.90 mL CH_4/g MLVSS d) and the maximum methane yield of 44.13 mL CH_4/g COD removed (or 28.89 mL CH_4/g COD applied) is observed at the COD loading rate of 1.710 kg/m^3 d. In addition, this COD loading rate results in about 0.21 % hydrogen sulfide.

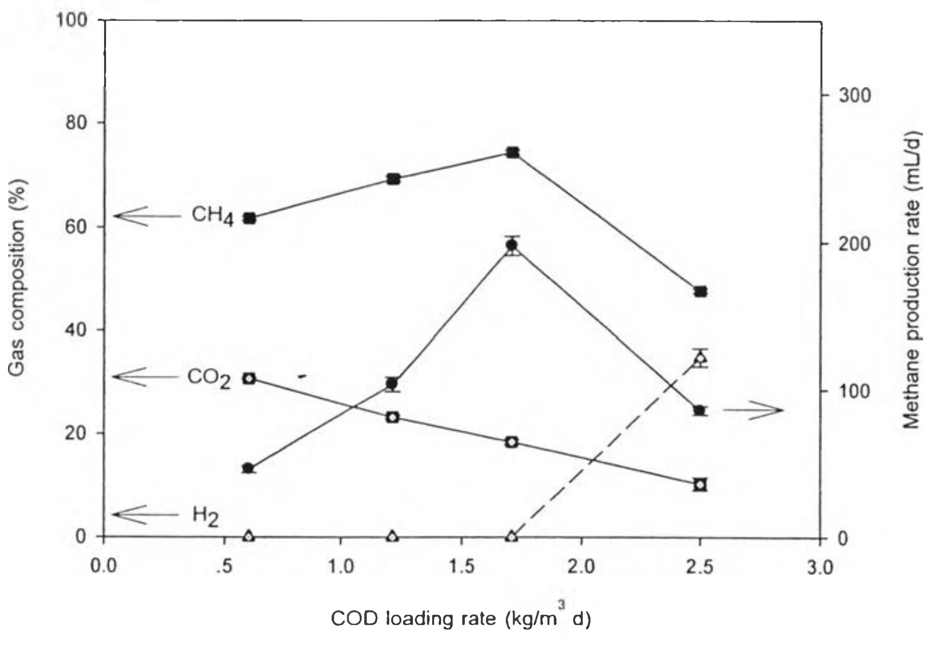

Figure 4.2 Effects of COD loading rate on gas composition and methane production rate.

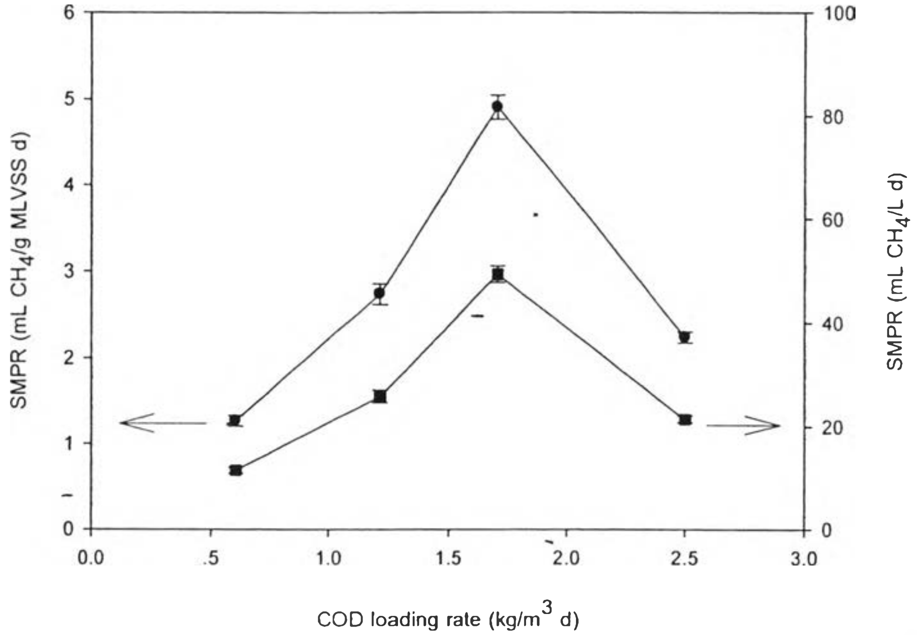

Figure 4.3 Effects of COD loading rate on SMPR (specific methane production rate).

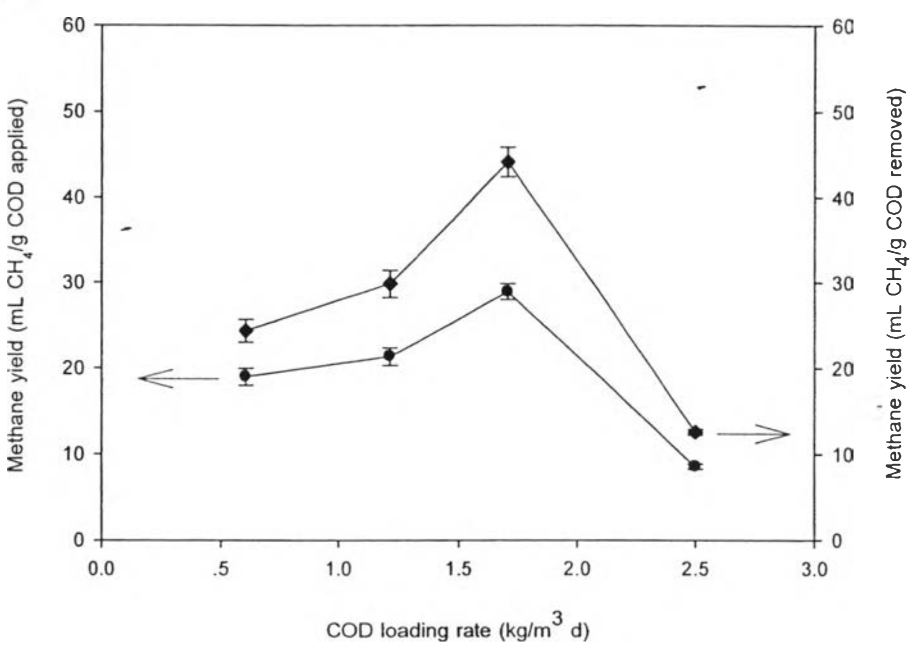

Figure 4.4 Effects of COD loading rate on methane yield.

4.1.3 Amount of Volatile Fatty Acid

Figure 4.5 shows the effects of COD loading rate on total VFA concentration (mg/L as acetic acid) and composition. The total VFA concentration increases with the increase in the COD loading rate and attains the maximum value of 1,087.13 mg/L as acetic acid at the COD loading rate of 2.500 kg/m^3 d (pH 5.26), whereas the methane production rate decreases with the increase in the COD loading rate (Figures 4.2 - 4.4). The results indicate that, when the organic compounds increase, they are converted to soluble organic acids, resulting in the decrease in the pH value from 7.02 to 5.26. The decrease in the pH value is toxic to the microorganisms, which is why lower efficiency of methane production is observed. The composition of total VFA (Figure 4.5) consists of acetic acid (HAc), propionic acid (HPr), butyric acid (HBu), and valeric acid (HVa). The concentration of VFA composition is highest at the COD loading rate of 2.500 kg/m^3 d. Under the optimum COD loading rate of 1.710 kg/m^3 d, the total VFA concentration is 818.89 mg/L as acetic acid, and the concentration of acetic acid is the highest (352.12 mg/L). These values indicate that both acidogenic and acetogenic bacteria with regard to acidogenesis and acetogenesis step perform well resulting in the high methane yield.

4.1.4 Microbial Concentration and Microbial Washout

Figure 4.6 shows the growth of microorganisms in the reactor (MLVSS) and the microorganism washout from the system (effluent VSS). The MLVSS increases with the increase in the COD loading rate and then decrease with further increase in the COD loading rate from 1.710 to 2.500 kg/m^3 d. For the effluent VSS, the opposite trend to that of the MLVSS is observed. The maximum MLVSS (10,075 mg/L) and minimum effluent VSS (2,064 mg/L) are obtained at the COD loading rate of 1.710 kg/m^3 d. The results indicate that when the COD loading rate is increased from 0.604 to 1.710 kg/m^3 d, the ability of the microorganisms to utilize the organic compounds increases. However, further increase in the COD loading rate from 1.710 to 2.500 kg/m^3 d results in the large amount of VFA resulting in the slow growth rate of microorganisms. The result is consistence with the high microorganism washout (effluent VSS) from the system.

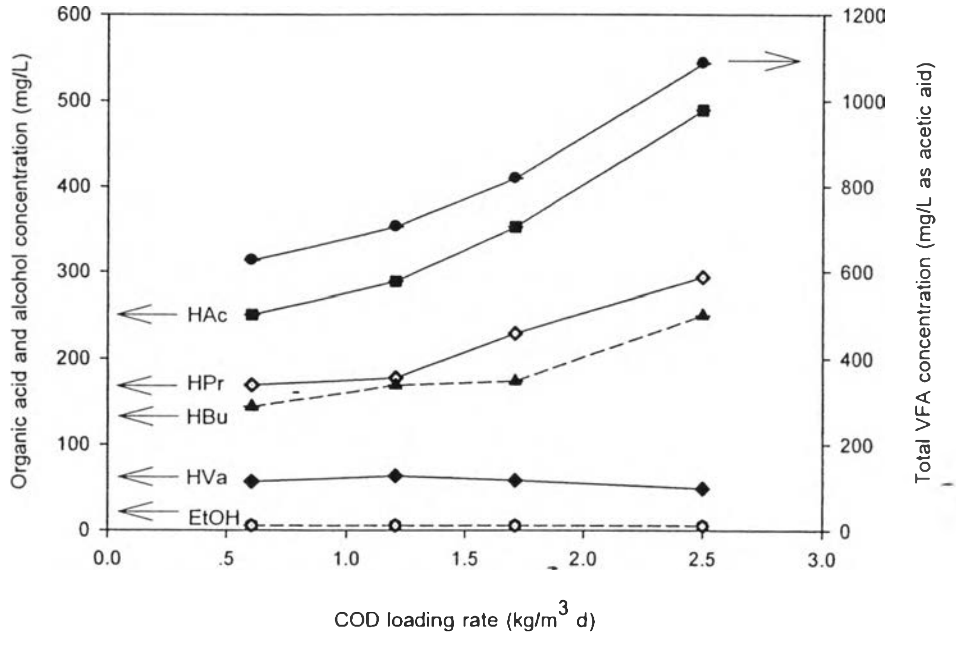

Figure 4.5 Effects of COD loading rate on total VFA, organic acid, and alcohol concentration.

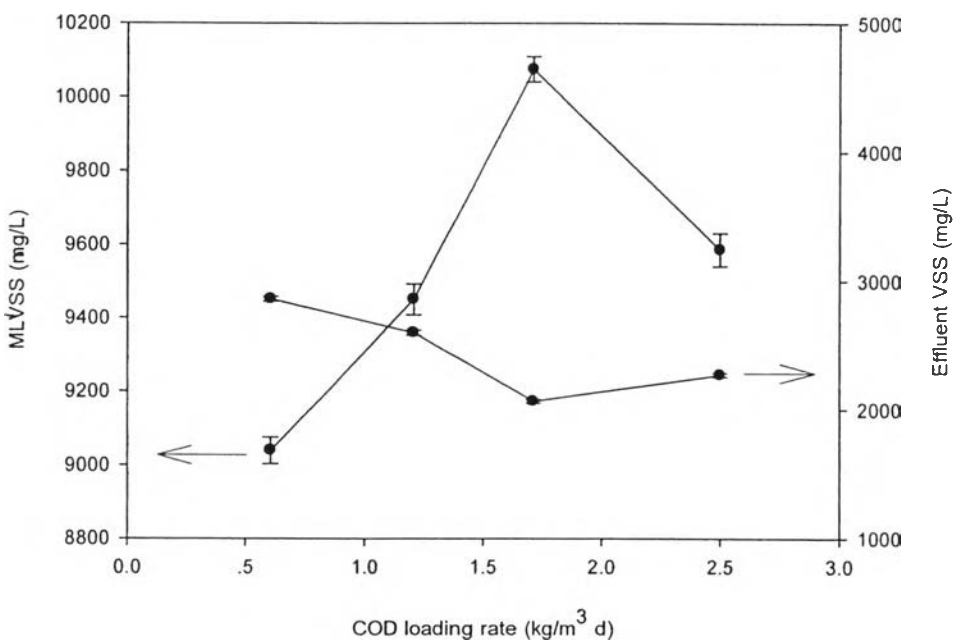

Figure 4.6 Effects of COD loading rate on MLVSS and effluent VSS.

4.1.5 Oxygen Content and Hydrolysis Efficiency

The hydrolysis efficiency is defined as the relative change between the inlet soluble COD and outlet soluble COD. The hydrolysis efficiency indicates the efficiency of conversion of complex organic matters to soluble organic molecules in anaerobic hydrolysis step by the facultative anaerobic bacteria. In the anaerobic hydrolysis step, the facultative anaerobic bacteria secrete the exoenzymes (hydrolase) in order to degrade the organic compounds in cassava wastewater to the soluble organic molecules that are the nutrients for the growth of anaerobic bacteria including acidogenic, acetogenic, and methanogenic bacteria. Besides the nutrients, the growth of anaerobic bacteria depends on the environmental parameters in the CSTR system. Especially, the oxygen content is an important parameter that affects the survival of the anaerobic bacteria cells. Figure 4.7 shows the oxygen content in terms of dissolved oxygen (in liquid phase) and oxygen gas composition (in gas phase). At any given COD loading rate, the dissolved oxygen content is 0.0 mg/L without oxygen gas composition confirming that the CSTR system is under the anaerobic operation. Under the optimum COD loading rate of 1.710 kg/m^3 d, the system provides the highest hydrolysis efficiency of 37.56 % and the highest gas production rate of 265.50 mL/d (Figure 4.8). At this anaerobic condition, the anaerobic bacteria can survive by consuming the produced soluble COD, which is produced from the anaerobic hydrolysis step resulting in more biogas produced (Todar, 2008).

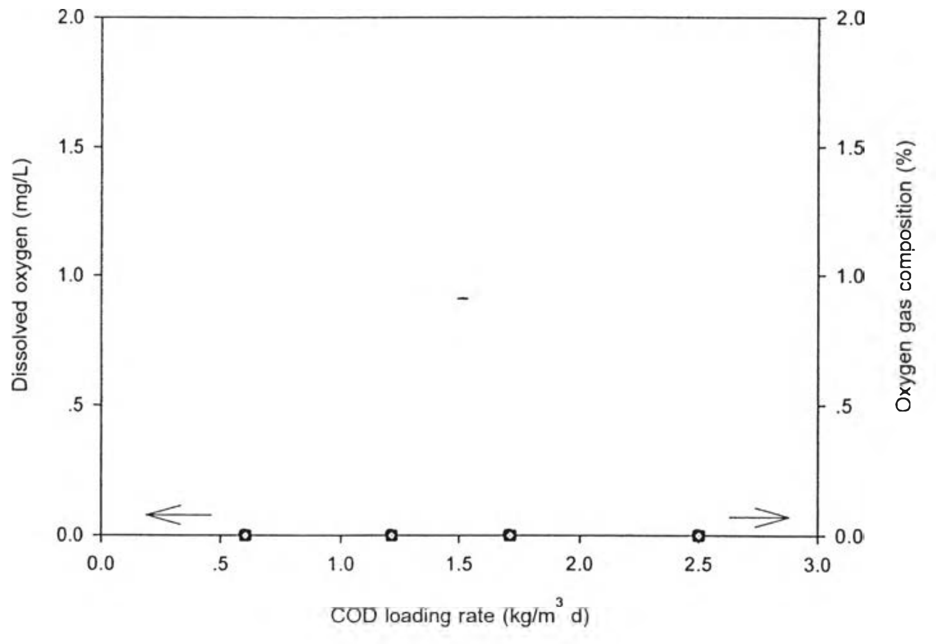

Figure 4.7 Effects of COD loading rate on dissolved oxygen and oxygen gas composition.

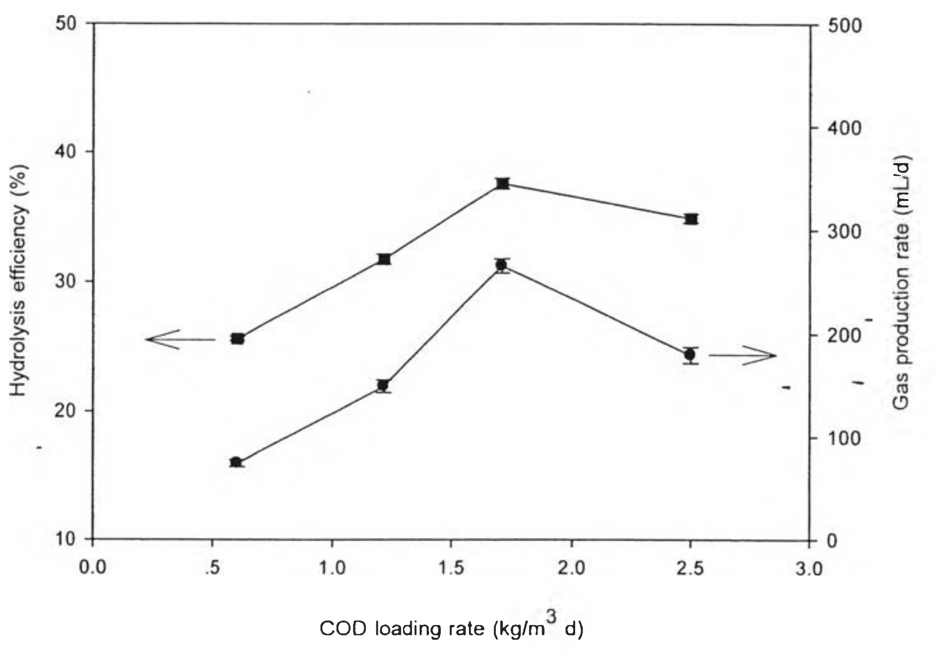

Figure 4.8 Effects of COD loading rate on hydrolysis efficiency and gas production rate.

4.2 Anaerobic Digestion of Cassava Wastewater with Cassava Residue without Microaeration

Contents of cassava residue were varied from 250 to 1,500 ppm and mixed with the cassava wastewater under the optimum COD loading rate of 1.710 kg/m^3 d without oxygen supply. The effects of cassava residue on the anaerobic digestion were investigated.

4.2.1 COD Removal and Gas Production Rate

The COD removal (Figure 4.9) is increased from 34.53 to 39.58 % by increasing the cassava residue concentration from 0 to 1,000 ppm. Then, the COD removal is decreased from 39.58 to 37.24 % with further increase in the cassava residue concentration from 1,000 to 1,500 ppm. The gas production rate shows the similar trend to the COD removal. The maximum COD removal is 39.58 % and the maximum gas production rate is 510.25 mL/d at the cassava residue concentration of 1,000 ppm. It may be explained that the increase in the cassava residue concentration results in the increase in the organic compounds available for microorganisms to degrade, which is consistence with increase the COD removal and gas production rate.

4.2.2 Gas Composition and Methane Production Rate

Both methane composition and methane production rate (Figure 4.10) are increased from 74.42 to 80.09 % and 197.61 to 408.68 mL/d, respectively, with the increase in the cassava residue concentration from 0 to 1,000 ppm. The maximum specific methane production rate is 102.17 mL CH_4/L d (or 9.22 mL CH_4/g MLVSS d) and the maximum methane yield is 89.75 mL CH_4/g COD removed (or 54.22 mL CH_4/g COD applied) (Figures 4.11 - 4.12). However, when the cassava residue concentration further increases from 1,000 to 1,500 ppm, methane production decreases with the hydrogen composition (11.34 %). The results indicate that the cassava residue concentration range of 250 to 1,000 ppm is suitable for methane production because of lower volatile fatty acid accumulation. However, at the highest cassava residue concentration (1,500 ppm), the methane production decreases due to the toxicity from the volatile fatty acid accumulation. In addition, under the optimum cassava residue concentration of 1,000 ppm, hydrogen sulfide gas composition is 0.28 %.

4.2.3 Amount of Volatile Fatty Acid

The total VFA concentration (mg/L as acetic acid) and composition are shown in Figure 4.13. The total VFA concentration increases with the increase in the cassava residue concentration and attains the maximum value of 1,271.81 mg/L as acetic acid at the highest cassava residue concentration of 1,500 ppm (pH 5.87), whereas the methane production decreases (Figures 4.10 - 4.12). When the cassava residue concentration is increased in the cassava wastewater, additional organic acid is produced resulting in the system acidity (pH 5.87). At the cassava residue concentration of 1,000 ppm, the system provides the highest methane production in terms of the highest methane yield and SMPR; hence, this cassava residue concentration is considered to be an optimum concentration to produce methane in the CSTR system without temperature and pH control. This condition corresponds to the maximum COD removal, optimum pH (6.83), total alkalinity (584.29 mg/l), and total acidity (918.42 mg/l) (Figure 4.14). Under the optimum cassava residue concentration of 1,000 ppm, the total VFA concentration is 1,107.43 mg/L as acetic acid, and the concentration of acetic acid is highest (482.84 mg/L). These values indicate that both acidogenic and acetogenic bacteria work under the operating condition.

4.2.4 Microbial Concentration and Microbial Washout

The growth of microbes with the accumulated cassava residue in the reactor (MLVSS), the total solids in the reactor (MLSS), the microbial and cassava residue washout (effluent VSS) and the total solids washout (effluent TSS) from the system are shown in Figure 4.15. The MLVSS and MLSS increase with the increase in the cassava residue concentration and then decrease with further increase in the cassava residue concentration from 1,000 to 1,500 ppm. The effluent VSS and TSS show the opposite trend. The maximum MLVSS (11,080 mg/L) and minimum effluent VSS (4,504 mg/L) are obtained at the cassava residue concentration of

1,000 ppm. The maximum bacteria concentration in CSTR and minimum bacteria concentration washout are 3,643.5 mg/L and 564.7 mg/L, respectively (Figure 4.16). The results indicate that, when the cassava residue concentration increases in the cassava wastewater, the population of methane-producing bacteria increases, and only the inactive bacteria are washout from the CSTR.

4.2.5 Oxygen Content, Hydrolysis Efficiency, and Degradation

The oxygen content in terms of dissolved oxygen (in liquid phase) and oxygen gas composition (in gas phase) directly affect the methane production (Figures 4.17 - 4.18). At any given cassava residue concentration, the dissolved oxygen content is 0.0 mg/L without oxygen gas composition, confirming the anaerobic operation. Under the optimum cassava residue concentration of 1,000 ppm, the system provides the highest hydrolysis efficiency of 41.79 % and the highest gas production rate of 510.25 mL/d (Figure 4.18). The results show that under the optimum cassava residue concentration, the CSTR system is still under anaerobic condition because the dissolved oxygen (in liquid phase) is zero and no excess oxygen gas composition (in gas phase) which does not affect the growth of the anaerobic bacteria including the strict anaerobic bacteria. Note that the anaerobic bacteria are sensitive to oxygen or aerobic condition, oxygen form which is a toxic substance for the bacteria growth (Todar, 2008).

The degradation of cassava residue and the bacteria concentration in the CSTR are shown in Figure 4.19. Under the optimum condition, after hydrolysis, 38.84 % of cellulose, 23.09 % of hemicellulose, and 27.25 % of starch were degraded but not lignin. The highest degradation of cassava residue is at this optimum condition, which is consistent with the maximum hydrolysis efficiency.

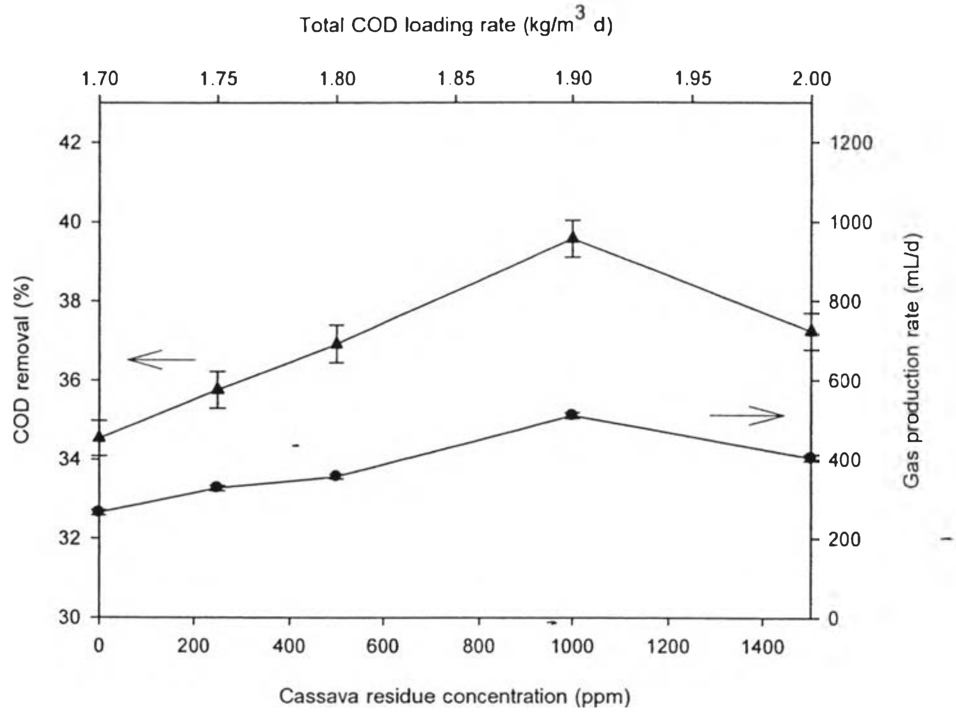

Figure 4.9 Effects of cassava residue concentration on COD removal and gas production rate.

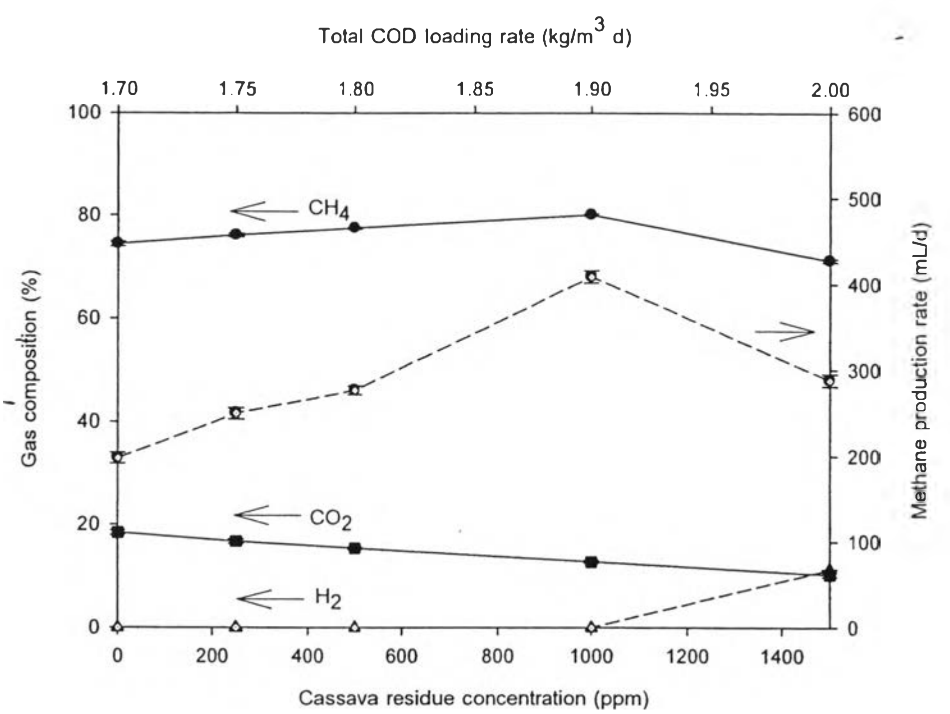

Figure 4.10 Effects of cassava residue concentration on gas composition and methane production rate.

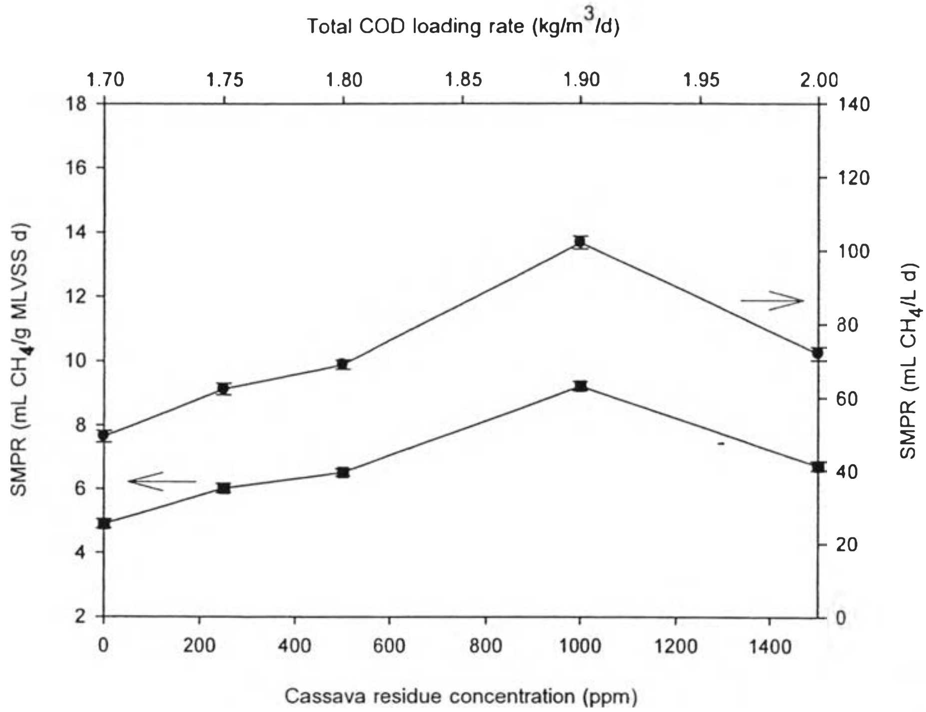

Figure 4.11 Effects of cassava residue concentration on SMPR (specific methane production rate).

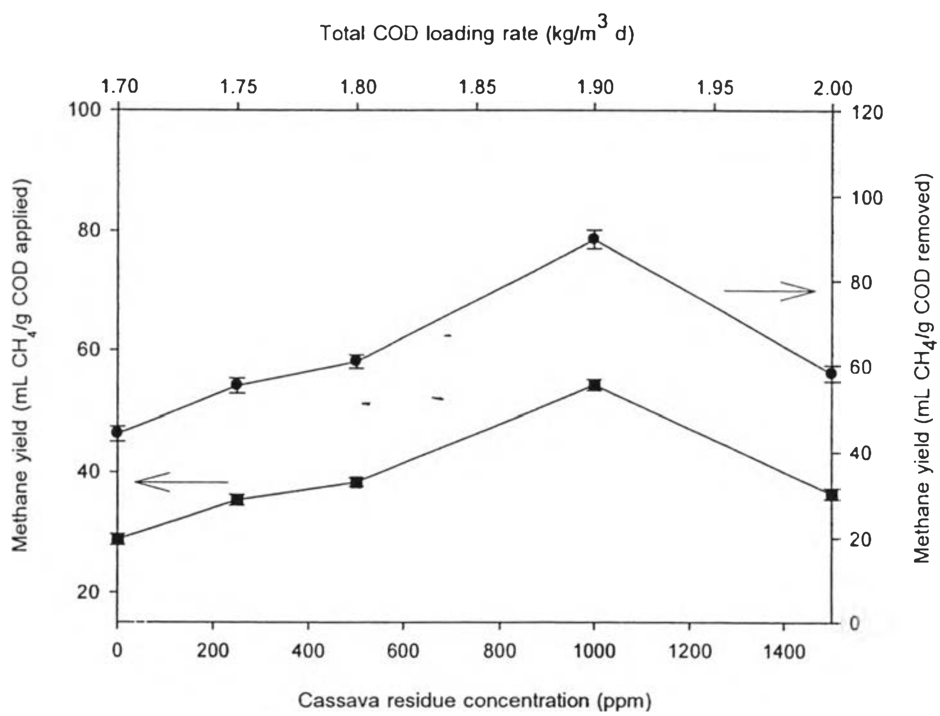

Figure 4.12 Effects of cassava residue concentration on methane yield.

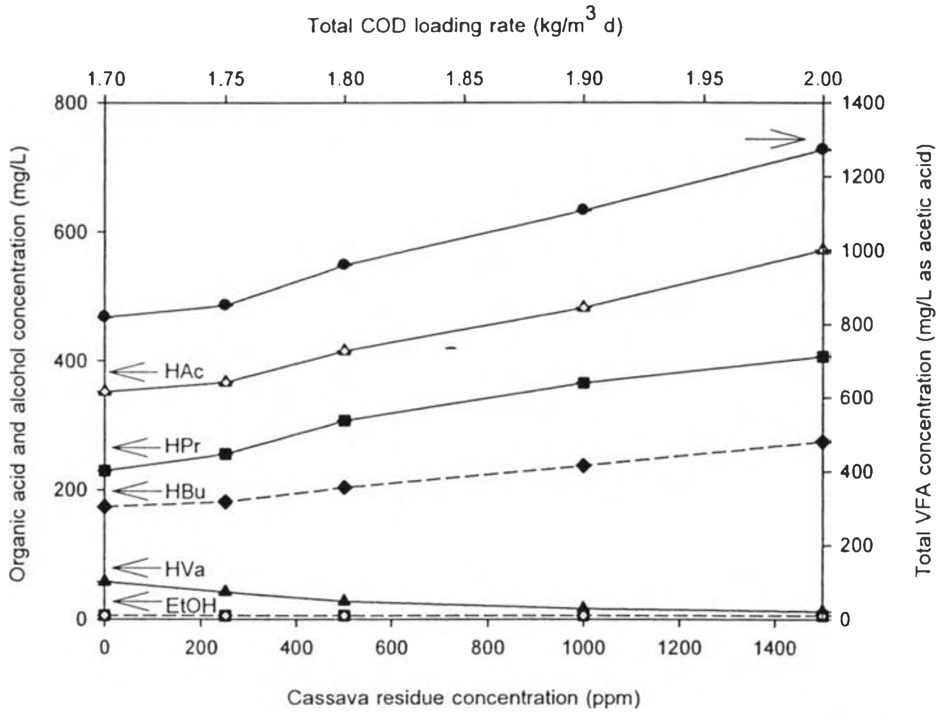

Figure 4.13 Effects of cassava residue concentration on total VFA, organic acid, and alcohol concentration.

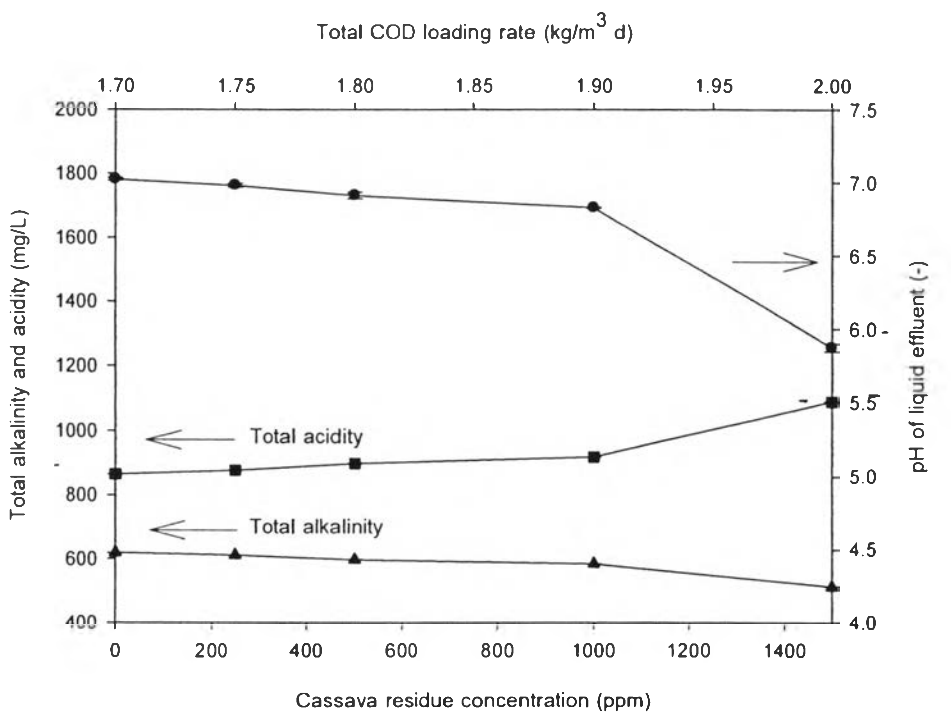

Figure 4.14 Effects of cassava residue concentration on total alkalinity, total acidity, and pH of liquid effluent.

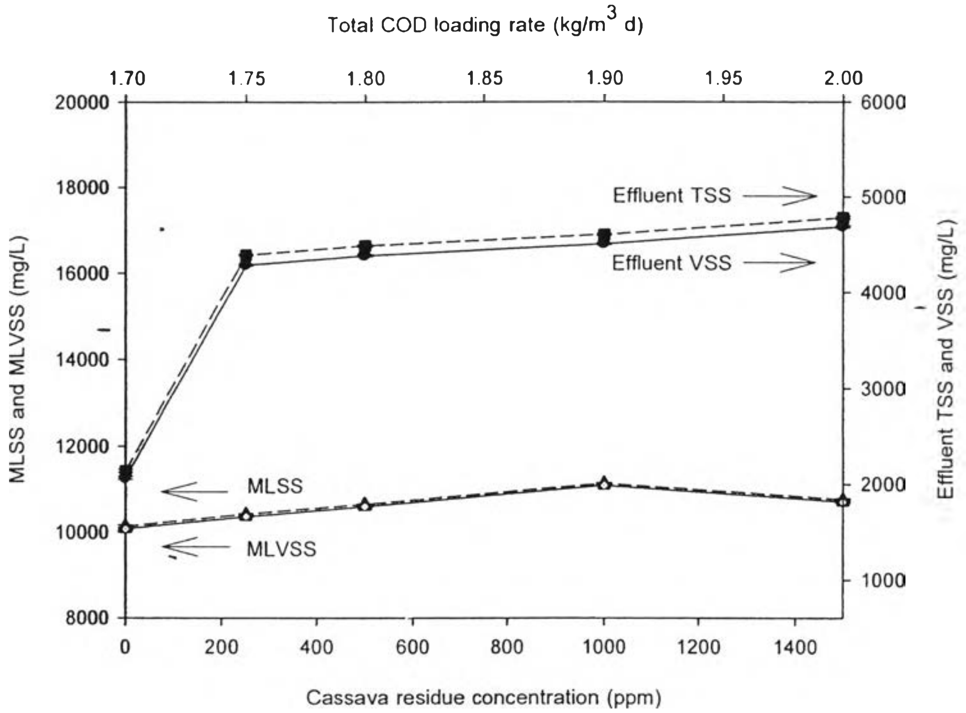

Figure 4.15 Effects of cassava residue concentration on MLSS, MLVSS, effluent TSS, and effluent VSS.

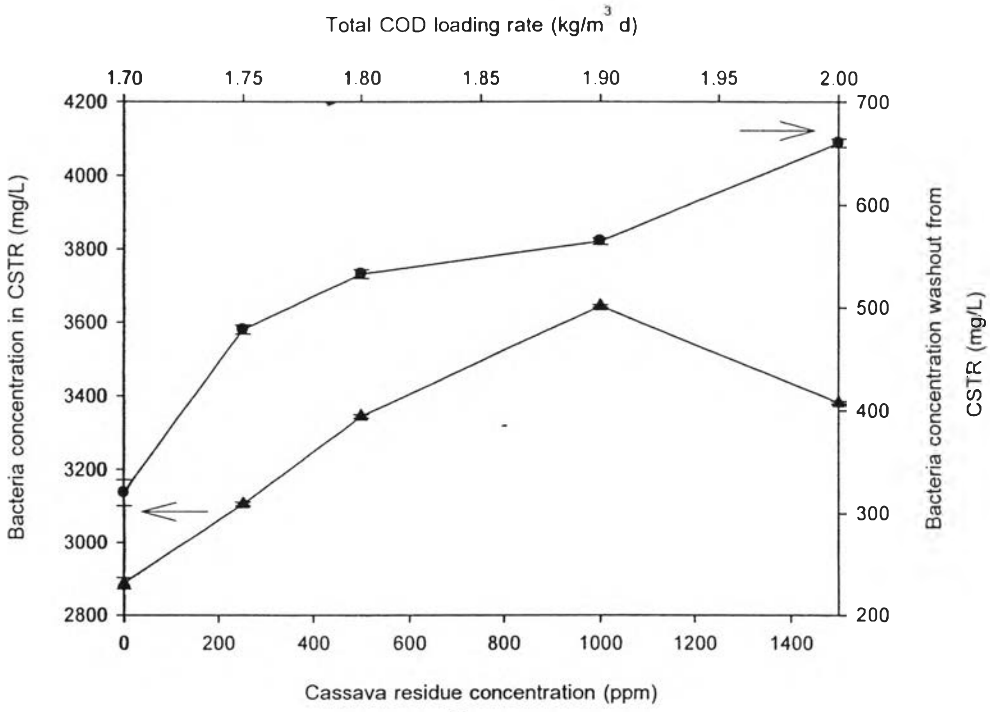

Figure 4.16 Effects of cassava residue concentration on bacteria concentration in CSTR and bacteria concentration washout from the CSTR.

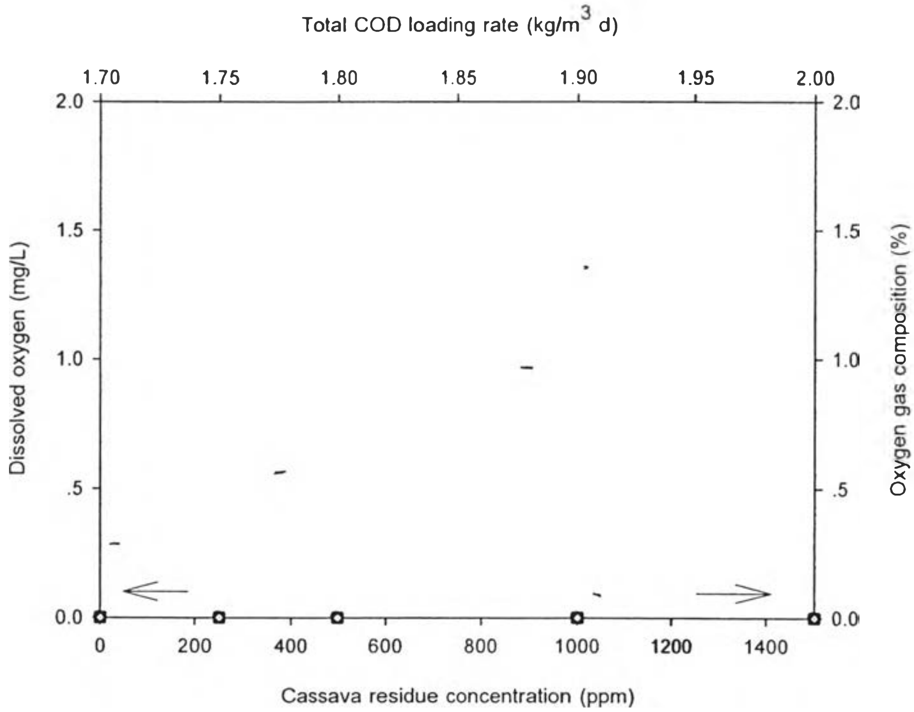

Figure 4.17 Effects of cassava residue concentration on dissolved oxygen and oxygen gas composition.

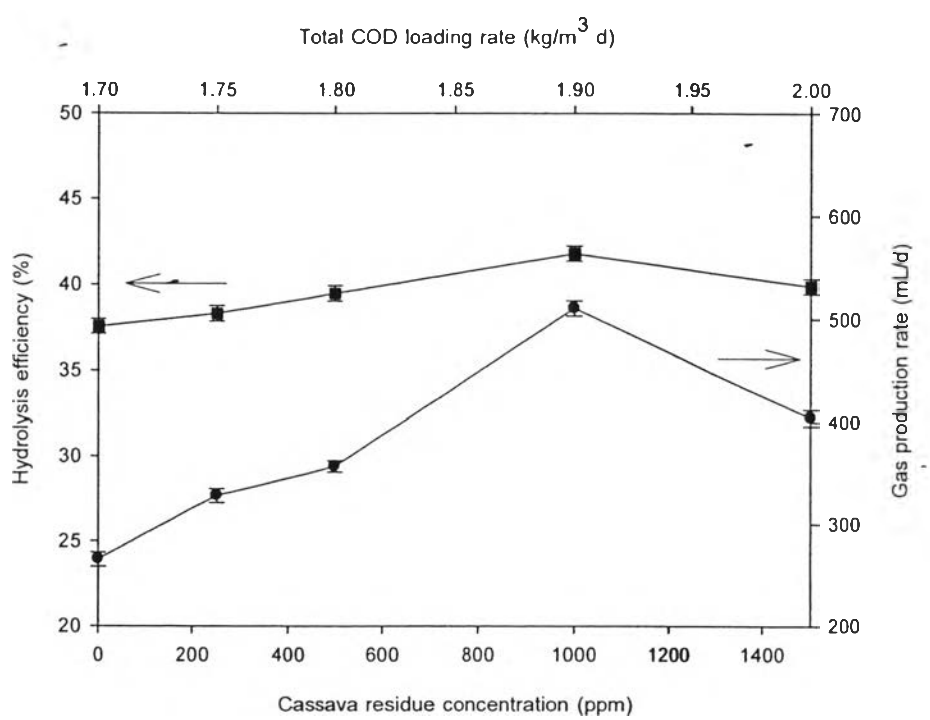

Figure 4.18 Effects of cassava residue concentration on hydrolysis efficiency and gas production rate.

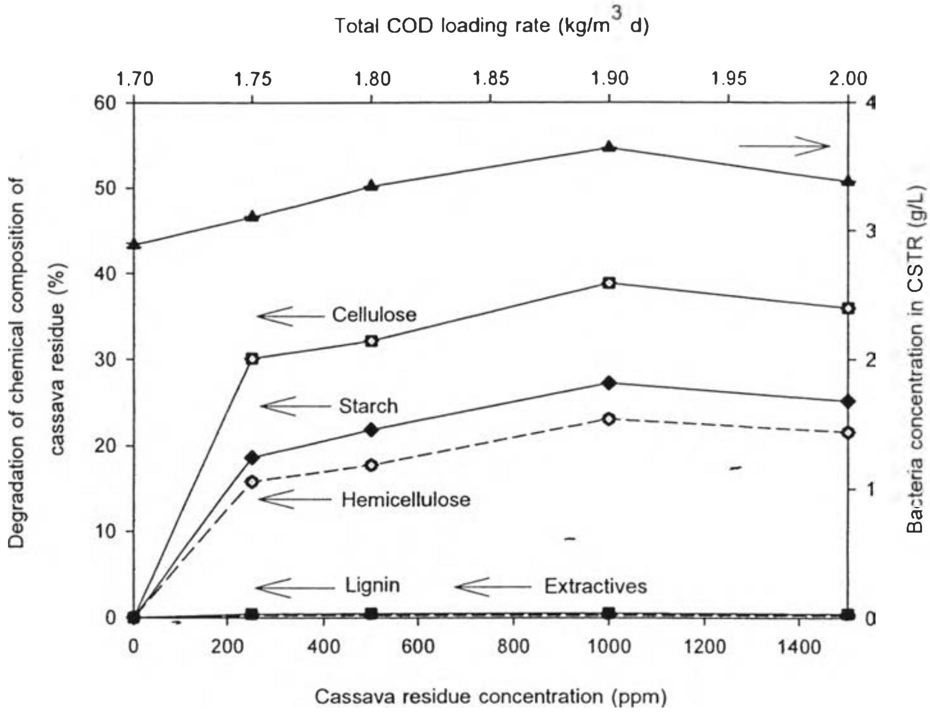

Figure 4.19 Effects of cassava residue concentration on degradation of cassava residue and bacteria concentration in CSTR.

4.3 Anaerobic Digestion of Cassava Wastewater with Microaeration

The enhancement of anaerobic digestion of the cassava wastewater was investigated by supplying oxygen from 1.5 to 6.0 mL O_2/L_R d under the optimum COD loading rate of 1.710 kg/m^3 d.

4.3.1 <u>COD Removal and Gas Production Rate</u>

The COD removal (Figure 4.20) is increased from 34.53 to 72.34 % by increasing the oxygen supply rate from 0.0 to 3.0 mL O_2/L_R d. In addition, the COD removal is decreased to 12.73 % with further increase in the oxygen supply rate from 3.0 to 6.0 mL O_2/L_R d. For the gas production, it has the similar trend to the COD removal. The maximum COD removal of 72.34 % and the maximum gas production rate of 897.25 mL/d are obtained at the oxygen supply rate of 3.0 mL O_2/L_R d. The increase in the oxygen supply results in the increase in the facultative anaerobic bacteria activity and biogas (Botheju and Bakke, 2011). However, with the higher oxygen supply rate (6.0 mL O_2/L_R d), the oxygen content is higher resulting in the toxic environment on the activity of the strict anaerobic bacteria.

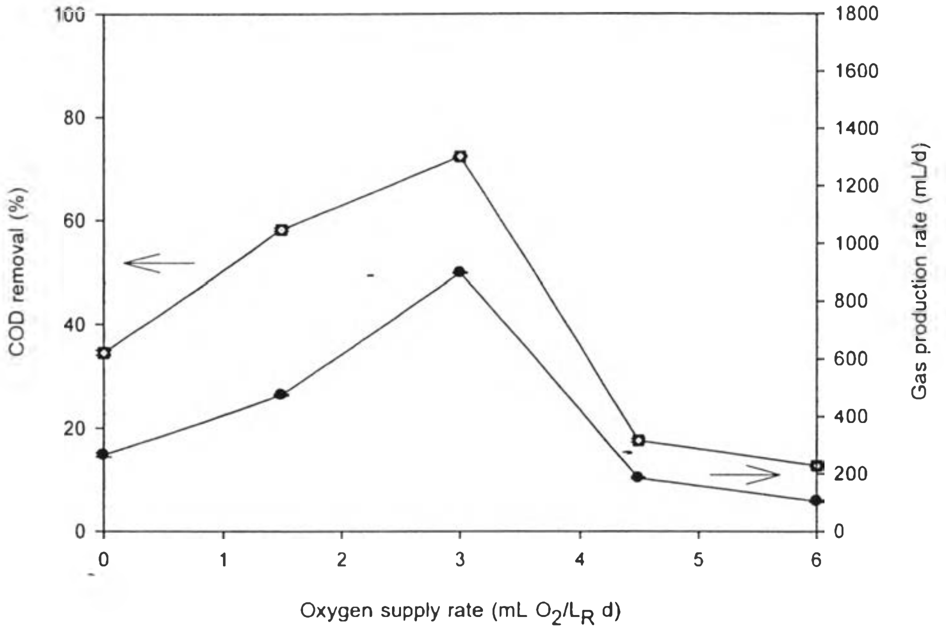

Figure 4.20 Effects of oxygen supply rate on COD removal and gas production rate.

4.3.2 Gas Composition and Methane Production Rate

The methane composition and methane production rate (Figure 4.21) are increased from 74.42 to 77.12 % and 197.61 to 691.92 mL/d, respectively, with the increase in the oxygen supply rate from 0.0 to 3.0 mL O_2/L_R d. However, when the oxygen supply rate is increased from 3.0 to 6.0 mL O_2/L_R d, the methane composition and methane production rate is decreased to 1.08 % and 1.15 mL/d, respectively, while a large amount of carbon dioxide (69.90 %) and oxygen (22.13 %) can be observed at the oxygen supply rate of 6.0 mL O_2/L_R d. The results indicate that according to the aerobic respiration (or aerobic type of metabolism) of facultative anaerobic bacteria, carbon dioxide is the main produced gas in this microaeration system.

The specific methane production rate and methane yield show the similar trend (Figures 4.22 and 4.23) to the methane production rate. The maximum specific methane production rate of 172.98 mL CH_4/L d (or 10.90 mL CH_4/g

MLVSS d) and the maximum methane yield of 365.70 mL CH_4/g COD removed (or 101.15 mL CH_4/g COD applied) is obtained with the oxygen supply rate of 3.0 mL O_2/L_R d. Therefore, the oxygen supply rate of 3.0 mL O_2/L_R d is the optimum oxygen content for methane production. In addition, the system contained cassava wastewater with microaeration eliminates the hydrogen sulfide gas from 0.21 % without microaeration to 0.00 % with microaeration due to the microaeration condition stimulates the H_2S-consumming bacteria to consume dissolved H_2S that further converted to elemental sulfur (S^0) and the new cells of H_2S-consumming bacteria are produced in the CSTR system (Equation 4.1).

$$H_2S\text{-consumming bacteria} + H_2S + \text{Organic substrate} + O_2 \rightarrow S^0 + \text{New cells} \qquad (4.1)$$

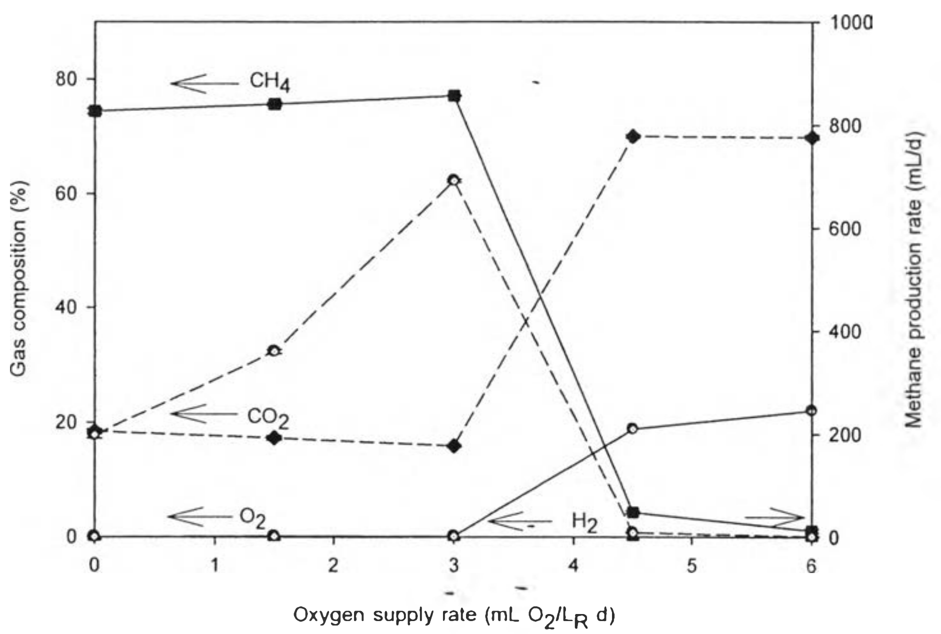

Figure 4.21 Effects of oxygen supply rate on gas composition and methane production rate.

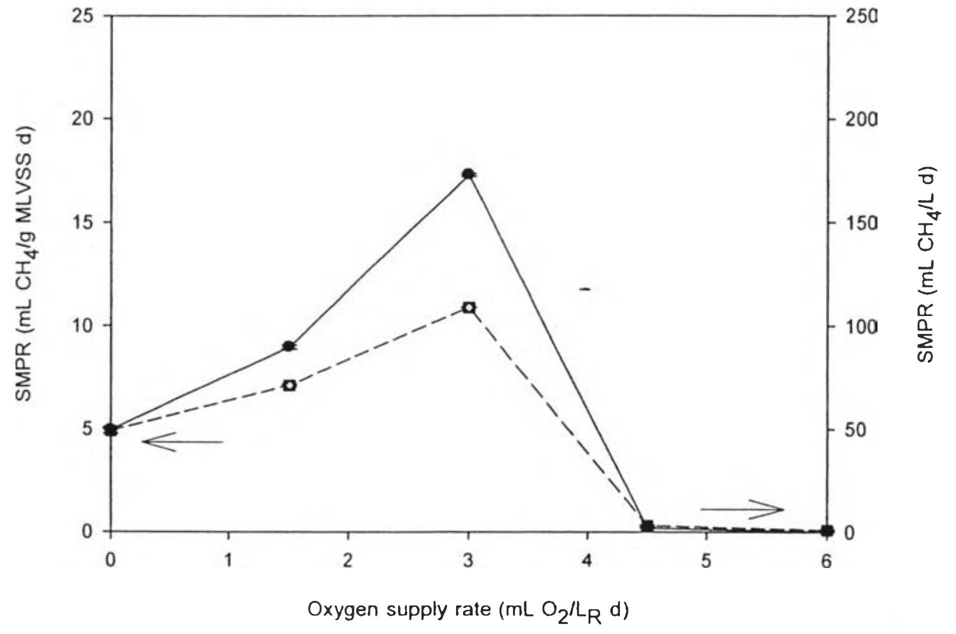

Figure 4.22 Effects of oxygen supply rate on SMPR (specific methane production rate).

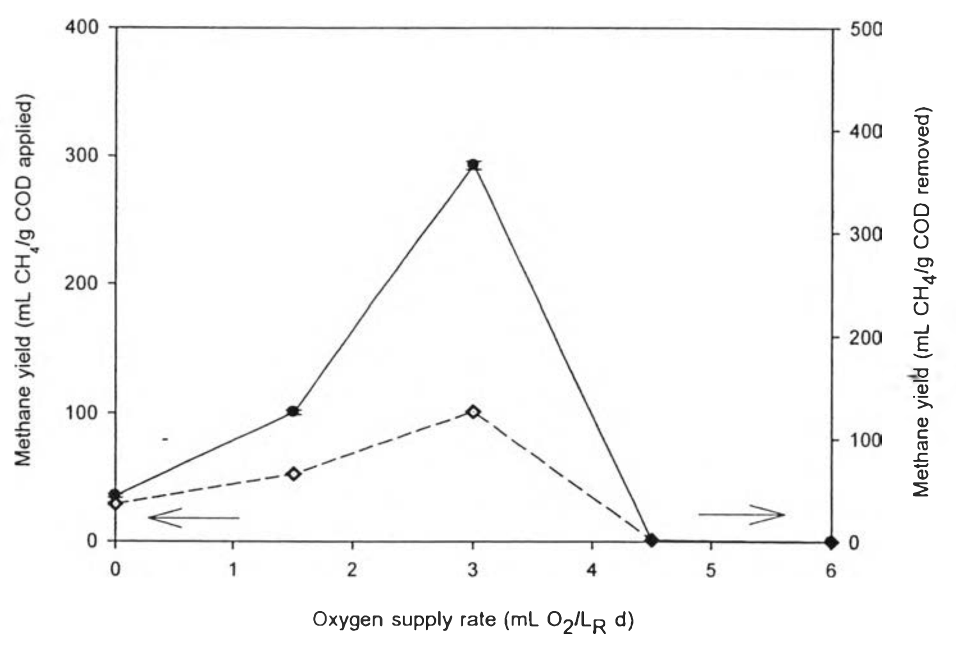

Figure 4.23 Effects of oxygen supply rate on methane yield.

4.3.3 Amount of Volatile Fatty Acid

The total VFA concentration increases with the increase in the oxygen supply rate and attains the maximum value of 937.13 mg/L as acetic acid at the oxygen supply rate of 3.0 mL O_2/L_R d (Figures 4.24), whereas the methane production rate decreases with the increase in the oxygen supply rate from 3.0 to 6.0 mL O_2/L_R d (Figures 4.21). The results indicate that, under the oxygen supply rate from 0.0 to 3.0 mL O_2/L_R d, both acidogenic and acetogenic bacteria perform well. For the composition of the total VFA, acetic acid concentration is highest because this condition is suitable for the growth of acetogenic bacteria that are microorganisms converting VFA into acetic acid.

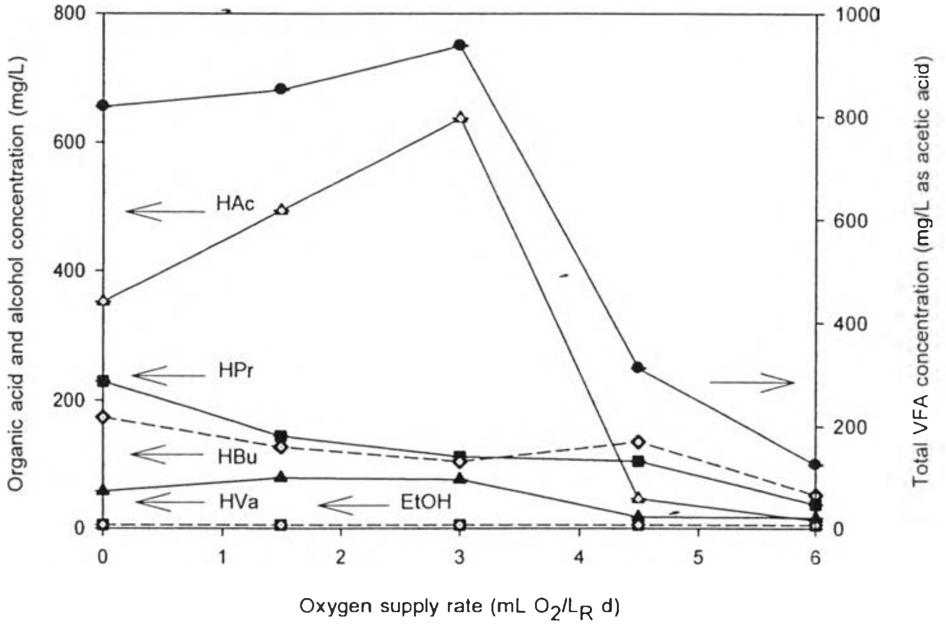

Figure 4.24 Effects of oxygen supply rate on total VFA, organic acid, and alcohol concentration.

4.3.4 Microbial Concentration and Microbial Washout

Figure 4.25 shows the growth of microbes in the reactor (MLVSS) and the microbes washout from the system (effluent VSS). The MLVSS increases with the increase in the oxygen supply rate from 0.0 to 3.0 mL O_2/L_R d and then decreases with further increase in the oxygen supply rate from 3.0 to 6.0 mL O_2/L_R d. For the effluent VSS, it has the opposite trend to that of the MLVSS. The maximum

MLVSS (15,865 mg/L) and minimum effluent VSS (1,344 mg/L) are obtained at the oxygen supply rate of 3.0 mL O_2/L_R d. The results indicate that, at the oxygen supply rate 0.0 to 3.0 mL O_2/L_R d, the anaerobic bacteria in CSTR perform well. In contrast, beyond the oxygen supply rate of 3.0 mL O_2/L_R d, inactive anaerobic bacteria were washed out at a greater extend from the CSTR system.

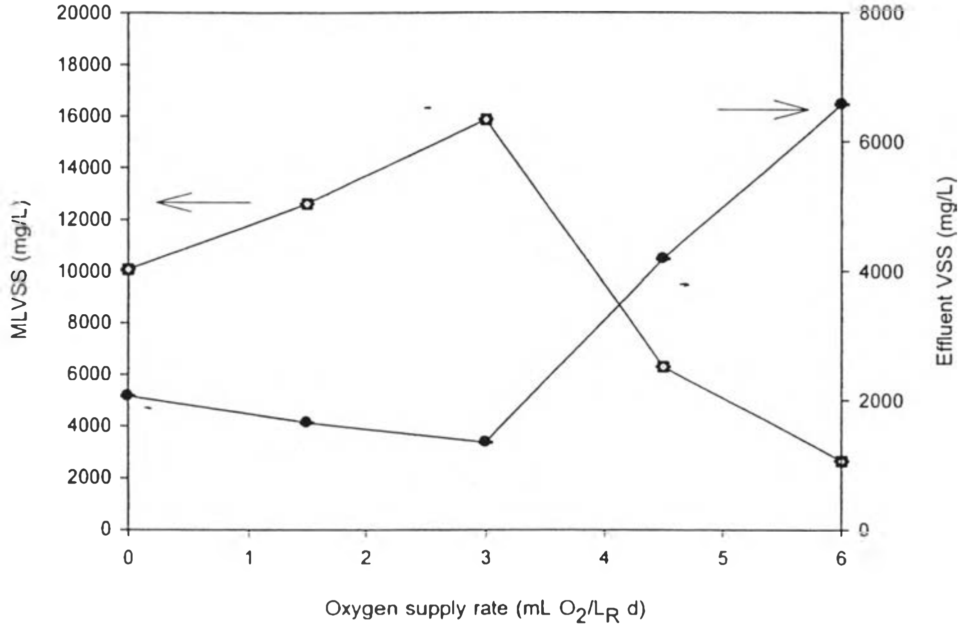

Figure 4.25 Effects of oxygen supply rate on MLVSS and effluent VSS.

4.3.5 Oxygen Content and Hydrolysis Efficiency

The oxygen content in terms of dissolved oxygen and oxygen gas composition directly affects the methane production (Figures 4.21 – 4.23). At the oxygen supply rate from 0.0 to 3.0 mL O_2/L_R d, the dissolved oxygen contents (Figure 4.26) are 0.0 mg/L with a small amount of oxygen gas composition (0.08 - 0.11 %). In other words, beyond the oxygen supply rate of 3.0 mL O_2/L_R d, the high amount of dissolved oxygen contents, 13.9 and 19.6 mg/L, can be observed with a large amount of oxygen gas composition (18.85 - 22.13 %). It can be explained that the system adjusts itself to the microaerobic condition when the oxygen supply rate is increased from 1.5 to 3.0 mL O_2/L_R d, whereas the system condition moves towards aerobic when the oxygen supply rate is increased from 4.5 to 6.0 mL O_2/L_R d.

Under the microaerobic condition, facultative anaerobic bacteria can switch to aerobic types of metabolism or aerobic respiration, which promptly consume the total supplied oxygen in the CSTR resulting in no excess oxygen in the system and do not affect to strict anaerobic bacteria (such as aectogenic and methanogenic bacteria). Besides, the facultative anaerobic bacteria contain superoxide dismutase and catalase enzymes that detoxify oxygen radicals in the CSTR system. Under the aerobic condition, facultative anaerobic bacteria can switch to aerobic respiration but they may not promptly consume the total supplied oxygen in the CSTR due to the large amount of oxygen resulting in oxygen excess in the system and result in strict anaerobic bacteria (such as aectogenic and methanogenic bacteria) that are either killed or their growth is inhibited (Botheju and Bakke, 2011).

Therefore, under the optimum oxygen supply rate of 3.0 mL O_2/L_R d, the oxygen gas composition is 0.08 % providing the highest hydrolysis efficiency of 73.87 % and the highest gas production rate of 897.25 mL/d (Figure 4.27).

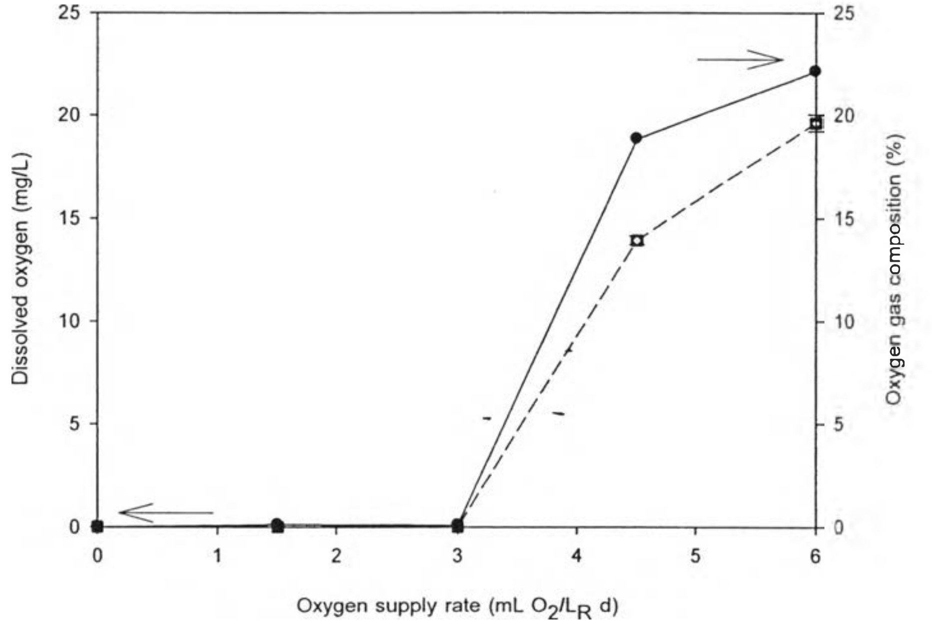

Figure 4.26 Effects of oxygen supply rate on dissolved oxygen and oxygen gas composition.

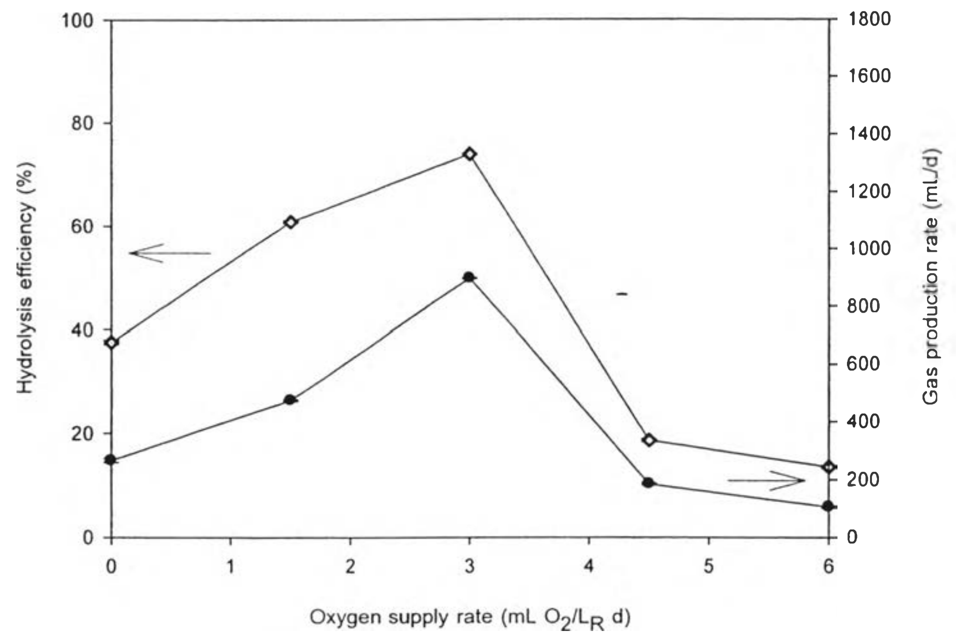

Figure 4.27 Effects of oxygen supply rate on hydrolysis efficiency and gas production rate.

4.4 Anaerobic Digestion of Cassava Wastewater with Cassava Residue with Microaeration

The enhancement of anaerobic digestion of added cassava residue in the cassava wastewater was investigated by supplying oxygen from 1.5 to 6.0 mL O_2/L_R d under the total optimum COD loading rate of 1.884 kg/m^3 d.

4.4.1 COD Removal and Gas Production Rate

The COD removal (Figure 4.28) is increased from 39.58 to 79.24 % by increasing the oxygen supply rate from 0.0 to 3.0 mL O_2/L_R d. In addition, the COD removal is decreased to 15.46 % with further increase in the oxygen supply rate from 3.0 to 6.0 mL O_2/L_R d. For the gas production, it had a similar trend to COD removal. The maximum COD removal of 79.24 % and the maximum gas production rate of 1,188.50 mL/d are obtained at the oxygen supply rate from 3.0 mL O_2/L_R d. The increase in the oxygen supply results in the increase in the facultative anaerobic bacteria activity and biogas (Botheju and Bakke, 2011). However, with the oxygen supply rate of 6.0 mL O_2/L_R d, there is a high oxygen content resulting in the system toxicity and the activity of the strict anaerobic bacteria.

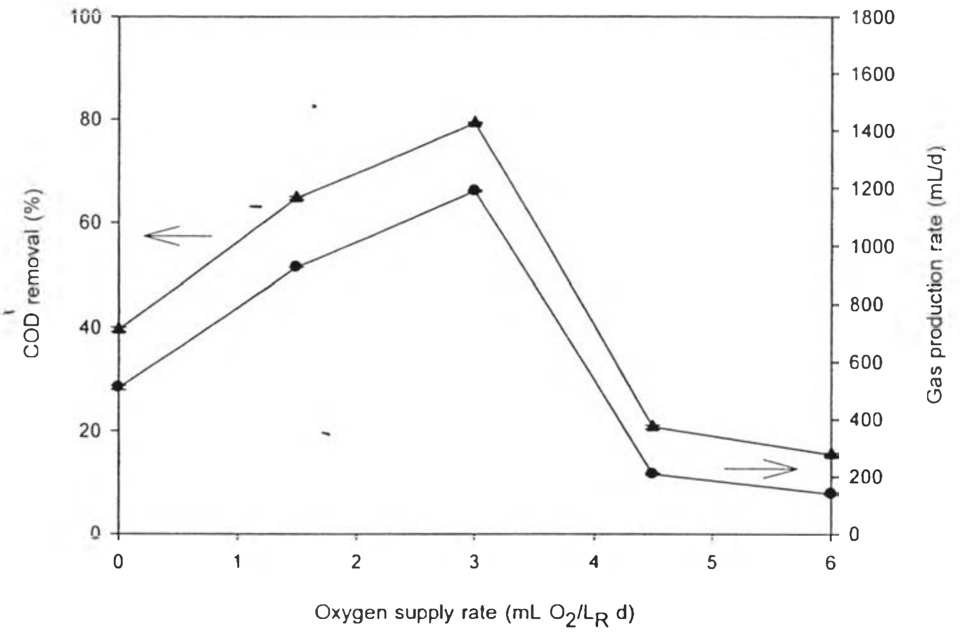

Figure 4.28 Effects of oxygen supply rate on COD removal and gas production rate.

4.4.2 Gas Composition and Methane Production Rate

The methane composition and methane production rate (Figure 4.29) are increased from 80.09 to 82.25 % and 408.68 to 977.52 mL/d, respectively, with the increase in the oxygen supply rate from 0.0 to 3.0 mL O_2/L_R d. However, when the oxygen supply rate is increased from 3.0 to 6.0 mL O_2/L_R d, the methane composition and methane production rate is decreased to 1.14 % and 1.61 mL/d, respectively while a large amount of carbon dioxide (73.74 %) and oxygen (18.33 %) were observed at this the highest oxygen supply rate of 6.0 mL O_2/L_R d. The results indicate that according to the aerobic respiration of facultative anaerobic bacteria, carbon dioxide is the main produced gas in this microaeration system.

The specific methane production rate and methane yield show the similar trend (Figures 4.30 and 4.31) to the methane production rate. The maximum specific methane production rate of 244.38 mL CH_4/L d (or 13.79 mL CH_4/g MLVSS d) and the maximum methane yield of 624.79 mL CH_4/g COD removed (or 129.69 mL CH_4/g COD applied) is obtained at the oxygen supply rate of 3.0 mL

O_2/L_R d. Therefore, the oxygen supply rate of 3.0 mL O_2/L_R d is the optimum oxygen content for methane production. In addition, the addition of cassava residue and oxygen result in no hydrogen sulfide gas.

4.4.3 Amount of Volatile Fatty Acid

The total VFA concentration increases with the increase in the oxygen supply rate and attains the maximum value of 1,254.31 mg/L as acetic acid at the oxygen supply rate of 3.0 mL O_2/L_R d (Figures 4.32), whereas the methane production rate decreases with the increase in the oxygen supply rate from 3.0 to 6.0 mL O_2/L_R d (Figure 4.29). The results indicate that, under the oxygen supply rate from 0.0 to 3.0 mL O_2/L_R d, both acidogenic and acetogenic bacteria could perform well including the highest activity especially at optimum condition. For the composition of the total VFA, acetic acid concentration is highest corresponding to optimum pH (6.81), total alkalinity (580.59 mg/l), and total acidity (938.43 mg/l) (Figure 4.33).

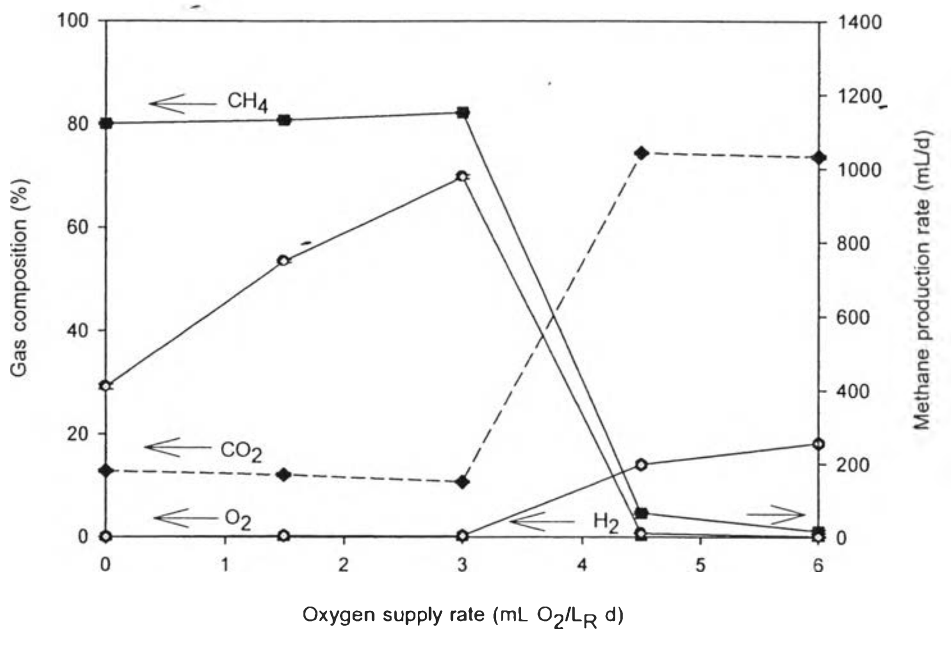

Figure 4.29 Effects of oxygen supply rate on gas composition and methane production rate.

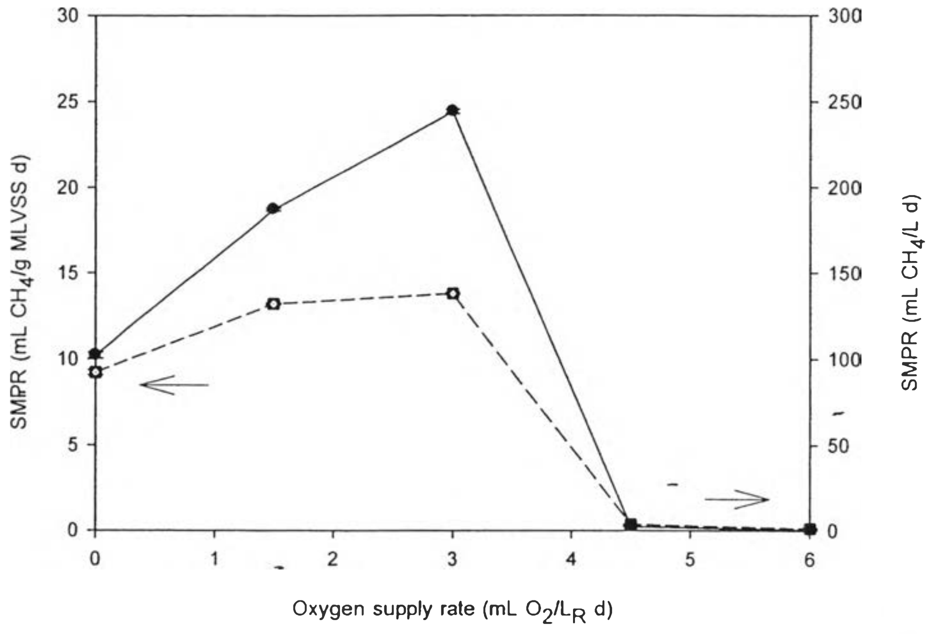

Figure 4.30 Effects of oxygen supply rate on SMPR (specific methane production rate).

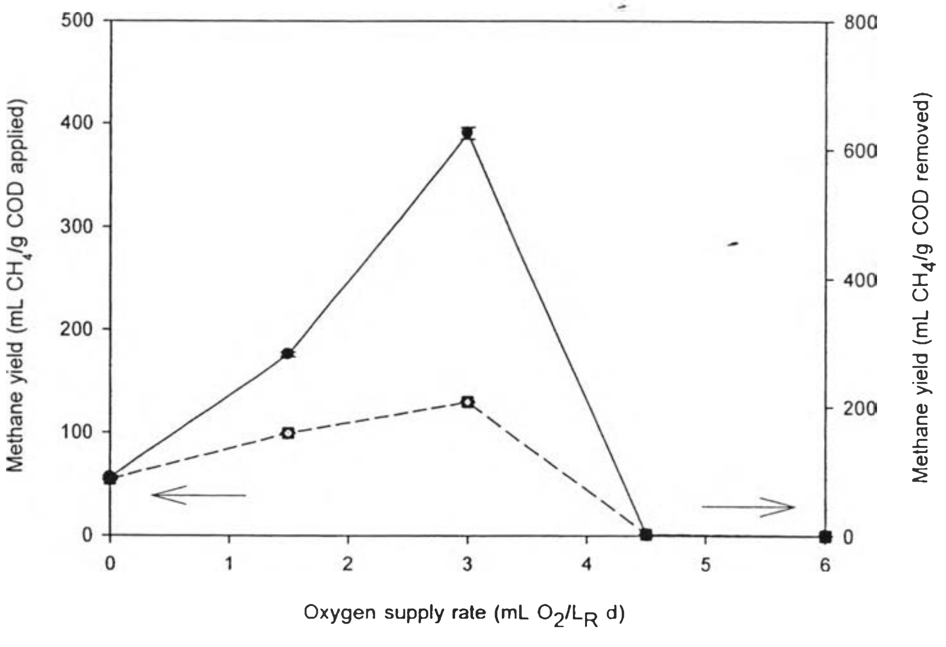

Figure 4.31 Effects of oxygen supply rate on methane yield.

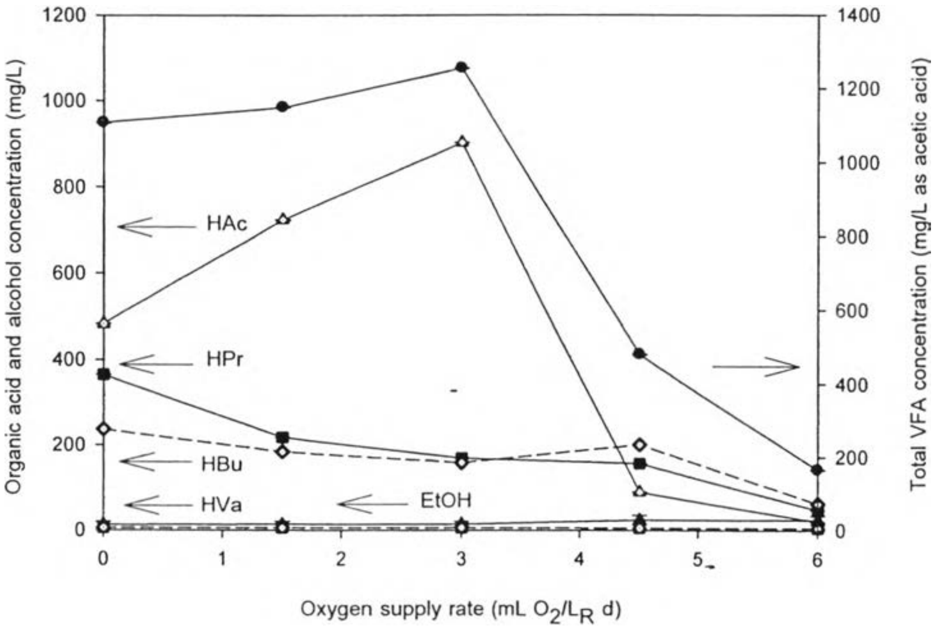

Figure 4.32 Effects of oxygen supply rate on total VFA, organic acid, and alcohol concentration.

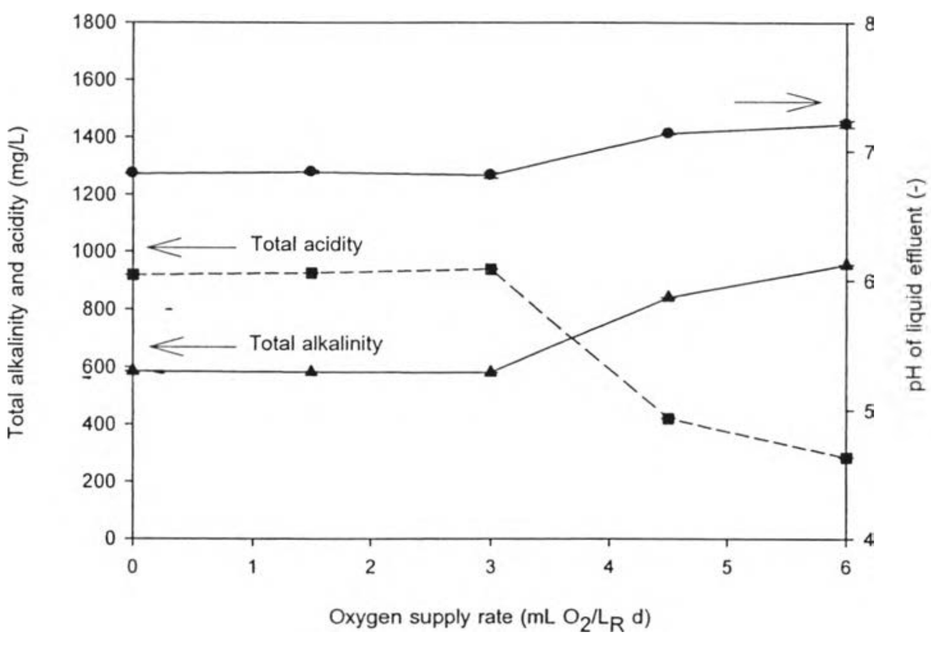

Figure 4.33 Effects of oxygen supply rate on total alkalinity, total acidity, and pH of liquid effluent.

4.4.4 Microbial Concentration and Microbial Washout

The growth of microbes with the accumulated cassava residue in the reactor (MLVSS), the total solids in the reactor (MLSS), the microbial and cassava residue washout (effluent VSS) and the total solids washout (effluent TSS) from the system are shown in Figure 4.34. The MLVSS and MLSS increase with the increase in the oxygen supply rate and then decrease with further increase in the oxygen supply rate from 3.0 to 6.0 mL O_2/L_R d. The effluent VSS and TSS show the opposite trend. The maximum MLVSS (17,716 mg/L) and minimum effluent VSS (1,160 mg/L) are obtained at the oxygen supply rate of 3.0 mL O_2/L_R d consistent with the maximum bacteria concentration in CSTR (5,039.1 mg/L) and minimum bacteria concentration washout from the CSTR (205.0 mg/L) (Figure 4.35). The results indicate that, when the oxygen supply rate increases, the population of anaerobic bacteria is increased and only the inactive bacteria are washout from the CSTR. Under the oxygen supply rate 0.0 to 3.0 mL O_2/L_R d, the anaerobic bacteria in the CSTR could perform well. In contrast, beyond the oxygen supply rate of 3.0 mL O_2/L_R d, more inactive anaerobic bacteria are washed out from the CSTR system.

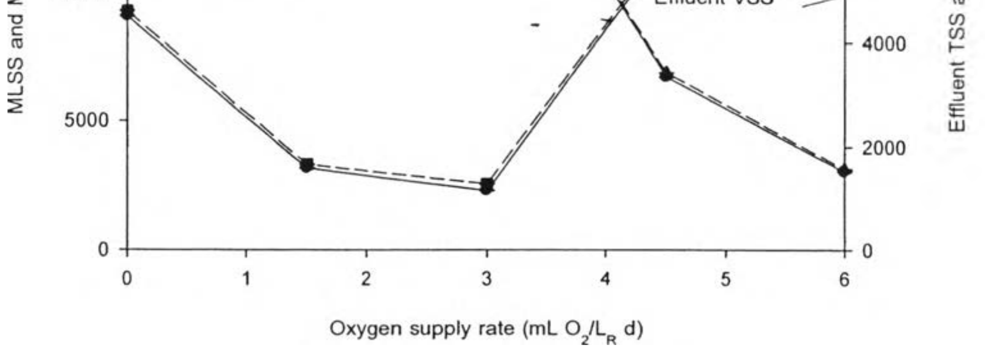

Figure 4.34 Effects of oxygen supply rate on MLSS, MLVSS, effluent TSS, and effluent VSS.

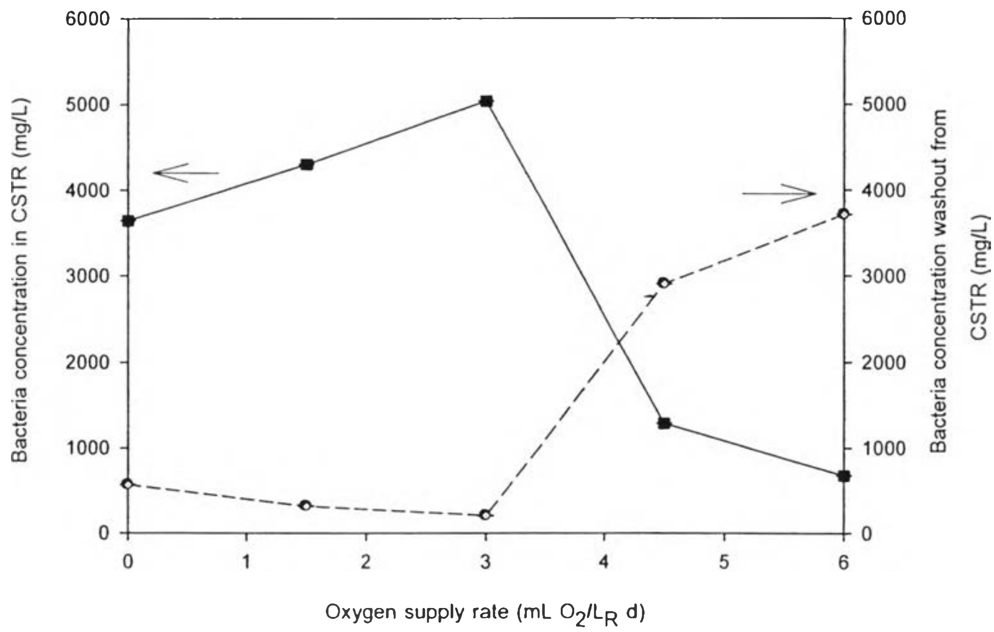

Figure 4.35 Effects of oxygen supply rate on bacteria concentration in the CSTR and bacteria concentration washout from the CSTR.

4.4.5 Oxygen Content, Hydrolysis Efficiency, and Degradation

The oxygen content in terms of dissolved oxygen and oxygen gas composition directly affects the methane production (Figures 4.29 – 4.31). At the oxygen supply rate from 0.0 to 3.0 mL O_2/L_R d, the dissolved oxygen contents (Figure 4.36) are 0.0 mg/L with a small amount of oxygen gas composition (0.25 - 0.27 %). In other words, beyond the oxygen supply rate of 3.0 mL O_2/L_R d, the high amount of dissolved oxygen contents 7.8 and 12.3 mg/L is observed with a large amount of oxygen gas composition (14.14 - 18.33 %). It can be explained that the system is under the microaerobic condition when the oxygen supply rate is increased from 1.5 to 3.0 mL O_2/L_R d, whereas the system is subject to the aerobic condition when the oxygen supply rate is from 4.5 to 6.0 mL O_2/L_R d.

Under the microaerobic condition, facultative anaerobic bacteria can switch to aerobic types of metabolism or aerobic respiration, which promptly consume the total supplied oxygen in the CSTR resulting in no excess oxygen in the system and do not affect the strict anaerobic bacteria (such as aectogenic and methanogenic bacteria). Besides, the facultative anaerobic bacteria contain superoxide dismutase and catalase enzymes that detoxify oxygen radicals in the CSTR system. Under the aerobic condition, facultative anaerobic bacteria can switch to aerobic respiration but they may not promptly consume the total supplied oxygen in the CSTR due to the large amount of supplied oxygen resulting in excess oxygen in the system and affect the strict anaerobic bacteria (such as aectogenic and methanogenic bacteria) that these bacteria are either killed or their growth is inhibited (Botheju and Bakke, 2011).

Therefore, under the optimum oxygen supply rate of 3.0 mL O_2/L_R d, the oxygen gas composition is 0.25 % providing the highest hydrolysis efficiency of 78.45 % and the highest gas production rate of 1,188.50 mL/d (Figure 4.37). In addition, the degradation of cassava residue and the bacteria concentration in the CSTR are shown in Figure 4.38. Under the optimum condition, after hydrolysis, 62.57 % of cellulose, 37.24 % of hemicellulose, and 44.85 % of starch were degraded but not lignin. The highest degradation of cassava residue is found at this optimum condition consistent with the maximum hydrolysis efficiency.

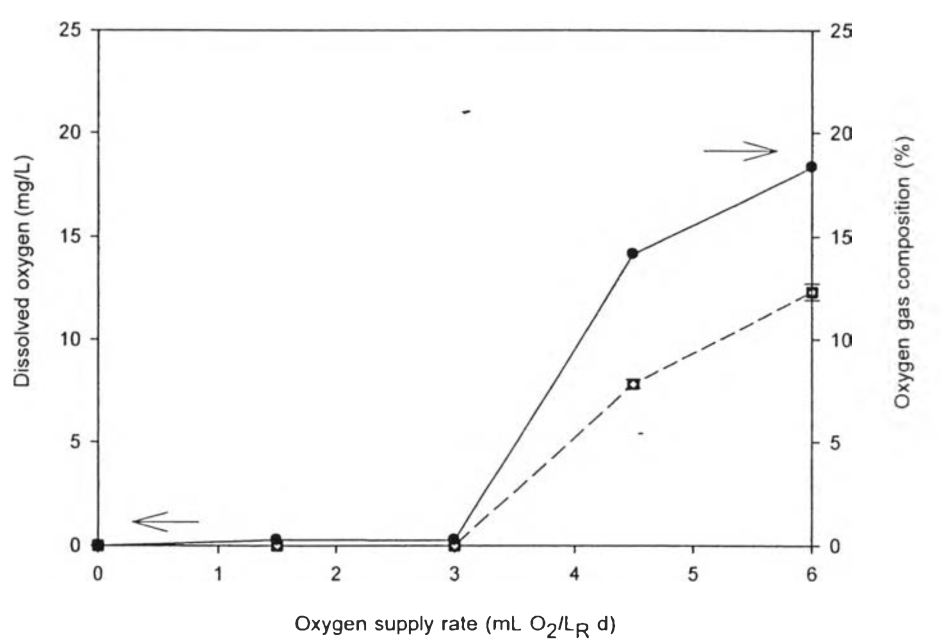

Figure 4.36 Effects of oxygen supply rate on dissolved oxygen and oxygen gas composition.

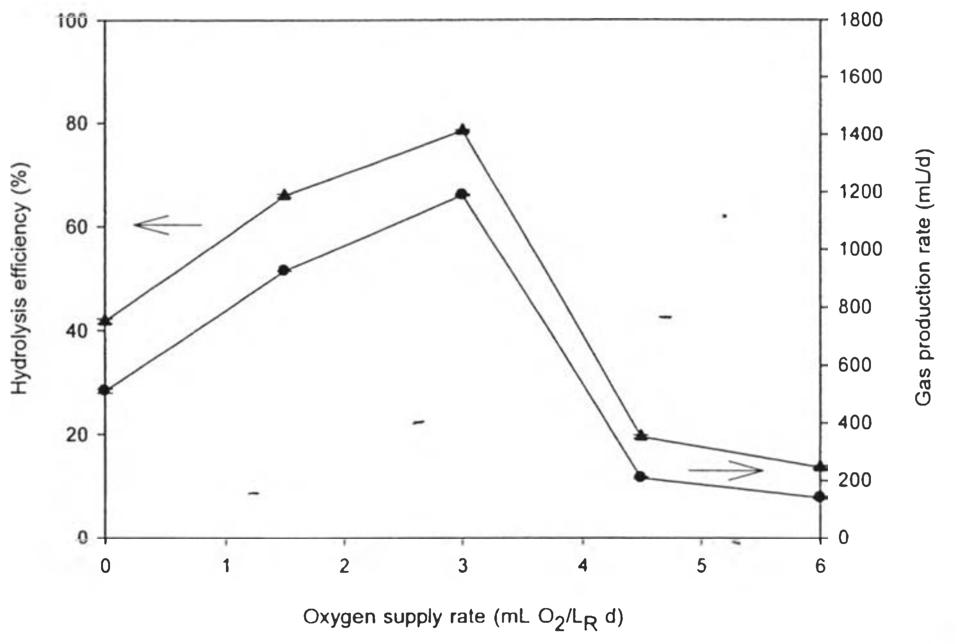

Figure 4.37 Effects of oxygen supply rate on hydrolysis efficiency and gas production rate.

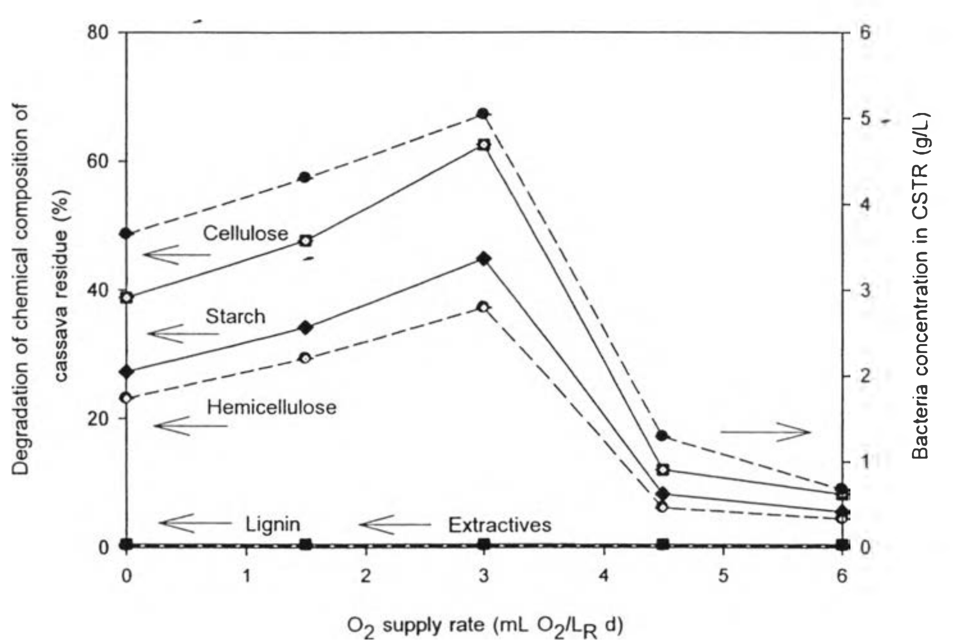

Figure 4.38 Effects of oxygen supply rate on degradation of cassava residue and bacteria concentration in the CSTR.