CHAPTER IV
RESULTS AND DISCUSSION

4.1 Anaerobic Digestion of Cassava Wastewater without Microaeration

4.1.1 Hydrogen Production

For the hydrogen production process, the cassava wastewater with vary of COD loading rate on hydrogen UASB unit. The hydrogen bioreactor was operated under mesophilic temperature (37°C) and a remain pH of 5.5.The system was operated at different COD loading rate of 12, 24, 36, 48 and 60 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ based on hydrogen UASB unit(2,4, 6, 8, 10 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ based on methane UASB unit, respectively).

4.1.1.1 Gas Production Rate and COD Removal

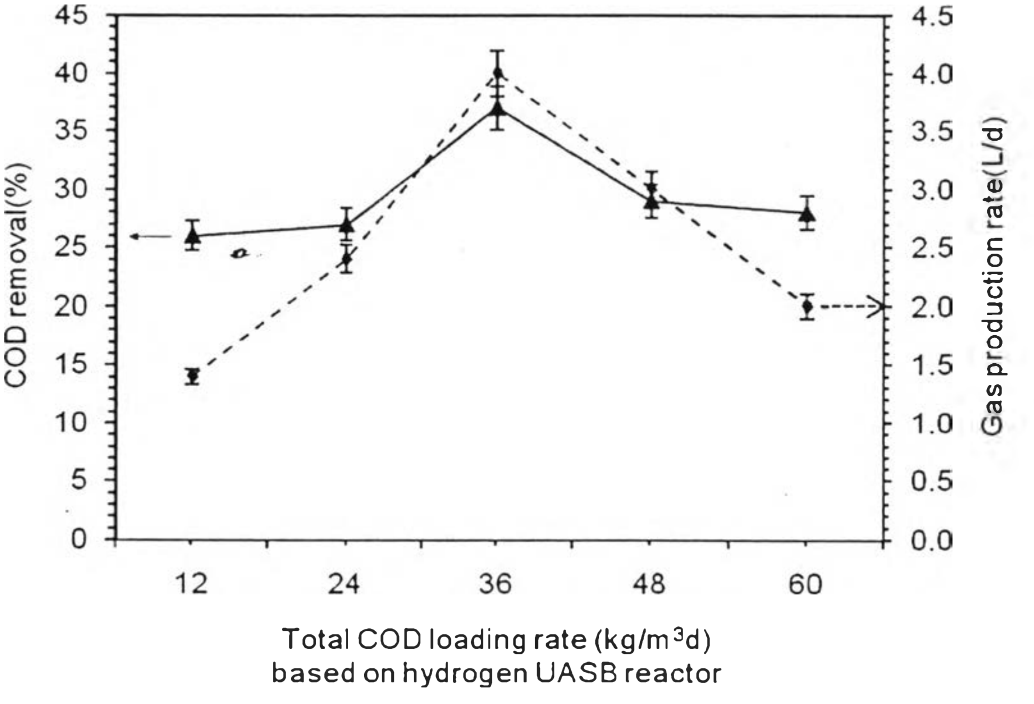

Figure 4.1 Effect of COD loading rate on COD removal and gas production rate on hydrogen UASB unit at 37°C and pH 5.5.

I 28368599

COD loading rates was further investigated to optimize the fermentation process. As shown in Fig 4.1 illustrates the gas production rate , it increased continuously from 1.4 $L{\cdot}d^{-1}$ to 4 $L{\cdot}d^{-1}$ with the increase of COD loading rate from 12 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ to 36 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ based on hydrogen UASB unit. Nevertheless the gas production rate decreased sharply when COD increased from 36 to 60 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ based on hydrogen UASB unit. This result demonstrated that gas production rate was positively related with COD loading rate. This was considering that more substrate in the reactor at a higher COD loading rate provided enough organic compounds for waste sludge . The COD removal efficiencies observes at different COD loading rate are plotted in Fig 4.1. As can be seen for COD loading rate between 12 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ to 36 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ based on hydrogen UASB unit, the COD removal efficiency increased from 26% to 37% .A slow decrease in COD removal efficiency from 37% to 28% was also observed when COD loading rate increased from 36 to 60 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ based on hydrogen UASB unit. For COD loading rate higher than 36 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ based on hydrogen UASB unit the performance of the gas production deteriorates sharply because of more toxic and difficult to degrade anaerobically (Borja *et al.*,1996), COD loading rate 36 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ based on hydrogen UASB unit was chosen as the optimal condition for gas production from cassava wastewater.

4.1.1.2 *Gas Composition and Hydrogen Production Rate*

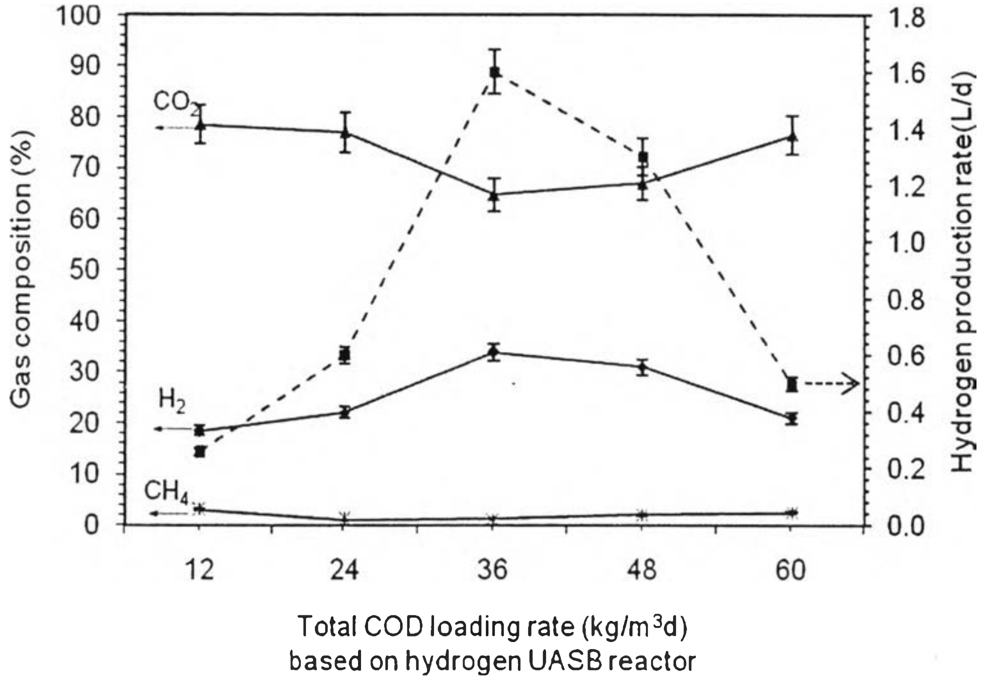

Figure 4.2 Effect of COD loading rate on gas composition and hydrogen production rate on hydrogen UASB unit at 37°C and pH 5.5.

Fermentative hydrogen production of five typical COD loading rate of 12, 24, 36, 48 and 60 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ based on hydrogen UASB unit, respectively. In this study, pH was adjusted to 5.5 in mesophilic temperature (37°C). Figure4.2 illustrates the variations of gas compositions and hydrogen production rate in the gas phase of the hydrogen reactors with different COD loading rate. The produced biogas contained hydrogen, carbon dioxide, slight methane. Initially, Both almost all of gas compositions and hydrogen production rate rapidly up warded with COD loading rate (HRT decreased) which reach a highest composition at about 34%H_2, 65%CO_2 1%CH_4 at 36 $KgCOD{\cdot}m^{-3}{\cdot}d^{-1}$ based on hydrogen UASB unit and highest hydrogen production rate of 1.6 $L{\cdot}d^{-1}$at the same COD loading rate when further increased COD loading rate from 36 to 60 $Kg{\cdot}m^{-3}{\cdot}d^{-1}$ based on hydrogen UASB unit because of toxicity from organic acid accumulation. It is obvious that an increase on COD loading rate has resulted in hydraulic retention (HRT) is directly related to up-flow velocity of influent in a UASB reactor. Hence, an adequate an flow velocity and accordingly HRT provide sufficient contact between sludge and wastewater, reduces the formation of gas pockets (Magnusson *et al.*, 2008).

4.1.1.3 Hydrogen Yield and Specific Hydrogen Production Rate

Figures 4.3-4.4 illustrated the process performance of the mesophilic UASB unit during the start-up. COD loading rate was increased stepwise from 12 to 36 KgCOD·m^{-3}·d^{-1} based on hydrogen UASB unit and there was an increase in and hydrogen yield and the specific hydrogen production rate(SHPR). The highest hydrogen yield(54 mLH_2·g^{-1} COD removed or 17 mLH_2·g^{-1}MLVSS·d^{-1}) and the highest specific hydrogen production rate(267 mLH_2·L^{-1}·d^{-1} or 47 mLH_2·g^{-1} MLVSS· d^{-1}) were shown at 36 KgCOD·m^{-3}·d^{-1} based on hydrogen UASB unit. However, with COD loading rate increased extremely from 36 KgCOD·m^{-3}·d^{-1} to 60 KgCOD·m^{-3}·d^{-1}, a steep drop occurred in both term, which also resulted in the accumulation of VFA in the effluent. It can be confirmed that at 36 KgCOD·m^{-3}·d^{-1} based on hydrogen UASB unit is optimal condition for hydrogen production under the two stage UASB system at a mesophilic temperature(37°C) and remained pH 5.5.

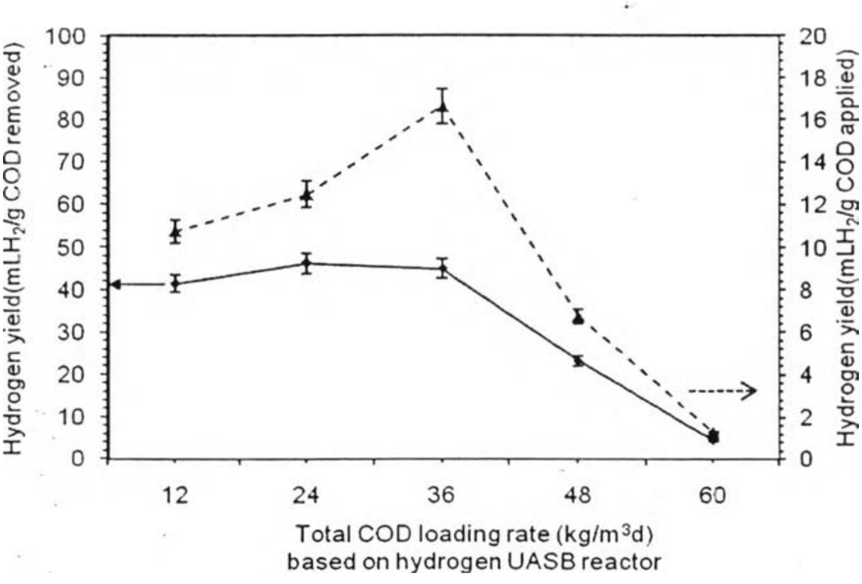

Figure 4.3 Effect of COD loading rate on hydrogen yield on hydrogen UASB unit at 37°C and pH 5.5.

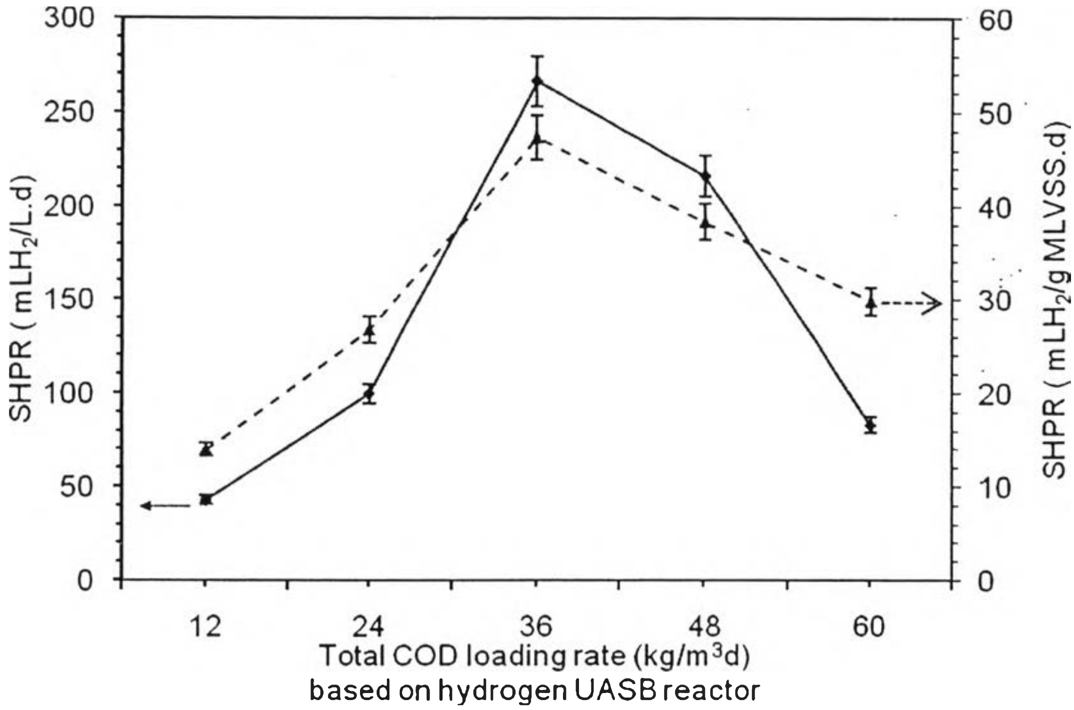

Figure 4.4 Effect of COD loading rate on Specific hydrogen production rate (SPHR) on hydrogen UASB unit at 37°C and pH 5.5.

4.1.1.4 The Amount of Organic Acid and Ethanol Concentration and Total Volatile Acid (VFA) Concentration.

The trend was different with that of hydrogen production. The organic acid and ethanol production increased with increase of COD loading rate while hydrogen production reach a peak at 36 KgCOD·m^{-3}·d^{-1} based on hydrogen UASB unit. The phenomenon was different from reports on fermentative hydrogen production from substrates of cassava wastewater(Luo *et al.*, 2011). As can be seen from Figure4.5, the variation of the amount of organic acid, ethanol and the total VFA concentration in hydrogen UASB unit with different COD loading rate under mesophilic condition contained with acetic acid, propionic acid, butyric acid, valeric acid and ethanol are the main aqueous products(Hwang *et al.*,2004).

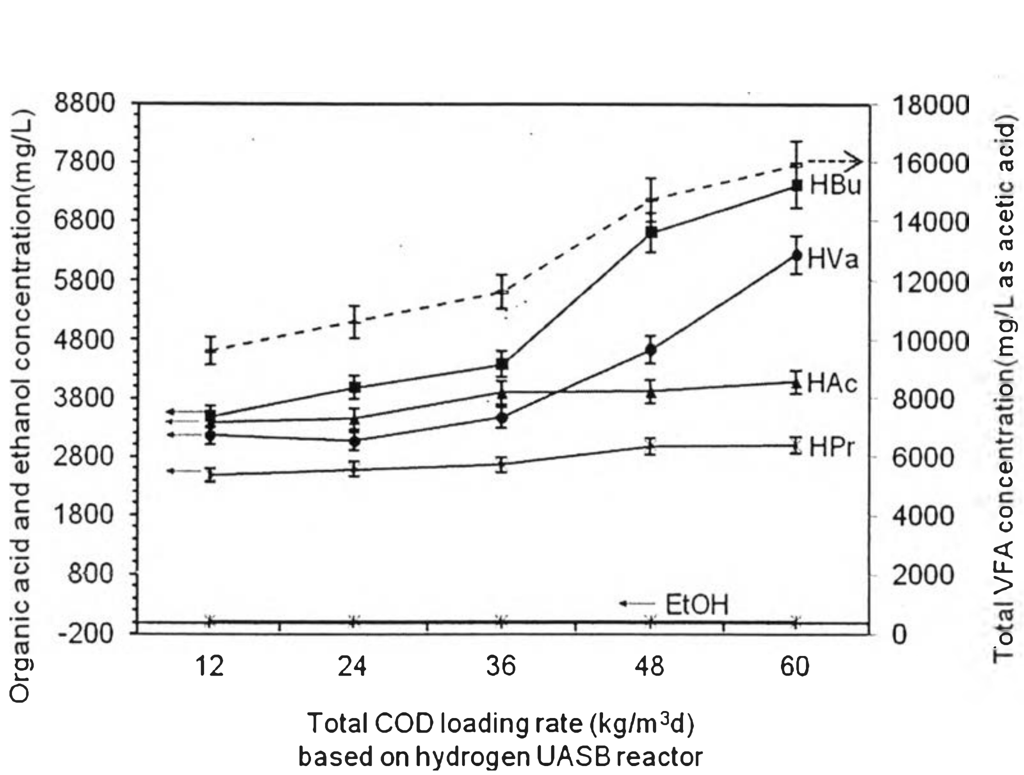

Figure 4.5 Effect of COD loading rate on total VFA, organic acid and alcohol concentration on hydrogen UASB unit at 37°C and pH 5.5.

In this experiment, the total VFA concentration gradually risen with increasing COD loading rate and reaching a maximum value of 15,941 mg·L^{-1} as acetic acid at the highest COD loading rate of 60 KgCOD·m^{-3}·d^{-1} based on hydrogen UASB unit when COD loading rate further increased from 36 to 60 KgCOD·m^{-3}·d^{-1} based on hydrogen UASB unit, it vitally affected to the drop in performance of hydrogen production due to the accumulation of organic acid resulting in the decrease in microbial activity(Fan *et al.*, 2006), Moreover, butyric acid was followed by valeric acid at approximately 34%. The other acids measured propionic acid and acetic acid with concentrations lower than 15% of the final acid in all the systems with zero-level lactic acid concentration. It can be explained that the formation of butyric acid is the metabolic path way for the hydrogen production whereas the formation of propionic acid is the metabolic path way for hydrogen consumption, according to Equation 4.3.(Hawkes *et al.*, 2002 and Zhang *et al.*, 2006). In comparisons of process performance in terms of COD removal (Figure 4.1) and hydrogen production efficiency (Figures 4.2-4.4) and total VFA concentration profile (Figure 4.3), the toxicity level to hydrogen-producing bacteria was around 14,000 mgL^{-1}. In general, the production of acetic and butyric acids is favorable when hydrogen production is dominant, according to Equations 4.1 and 4.2 (Mohan *et al.*, 2008).

Acetic acid production: $C_6H_{12}O_6 + H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2$ (4.1)

Butyric acid production: $C_6H_{12}O_6 \rightarrow CH_3(CH_2)_2COOH + 2CO_2 + 2H_2$ (4.2)

In addition, the production of valeric was also important in affecting the consumption of hydrogen initially produced, according to Equations 4.4-4.8 (Mohan *et al.*, 2008 and Zhu and Yu, 2002).

Propionic acid production: $C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + 2H_2O$ (4.3)

Valeric acid production:

$$CH_3CH_2COOH + CH_3(CH_2)_2COOH \rightarrow CH_3(CH_2)_3COOH + CH_3COOH \quad (4.4)$$

$$CH_3CH_2COOH + CH_3COOH + H_2 \rightarrow CH_3(CH_2)_3COOH + 2H_2O \quad (4.5)$$

$$CH_3CH_2COOH + 2CO_2 + 6H_2 \rightarrow CH_3(CH_2)_3COOH + 4H_2O \quad (4.6)$$

Moreover, from previous study demonstrated that the production of acetate and butyrate propionate could consume hydrogen by the following reactions.

$$2CO_2 + 4H_2 \rightarrow CH_3COOH + 2H_2O \quad (4.7)$$

$$C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3\,CH_2COOH + 2H_2O \quad (4.8)$$

4.1.2 Methane Production

4.1.2.1 Gas Production Rate and COD Removal

The COD removal as a function of cassava residue concentration is shown in Figure 4.6. The COD removal dramatically increased with increasing COD loading rate, reached a maximum value of 52 % at COD loading rate of 6 $KgCOD{\cdot}m^{-3}{\cdot}d^{-1}$ based on methane UASB unit. After that, it decreased with further increasing COD loading rate from 6 to 10 $KgCOD{\cdot}m^{-3}{\cdot}d^{-1}$ based on methane UASB unit. The gas production rate also had a similar trend to the COD removal.

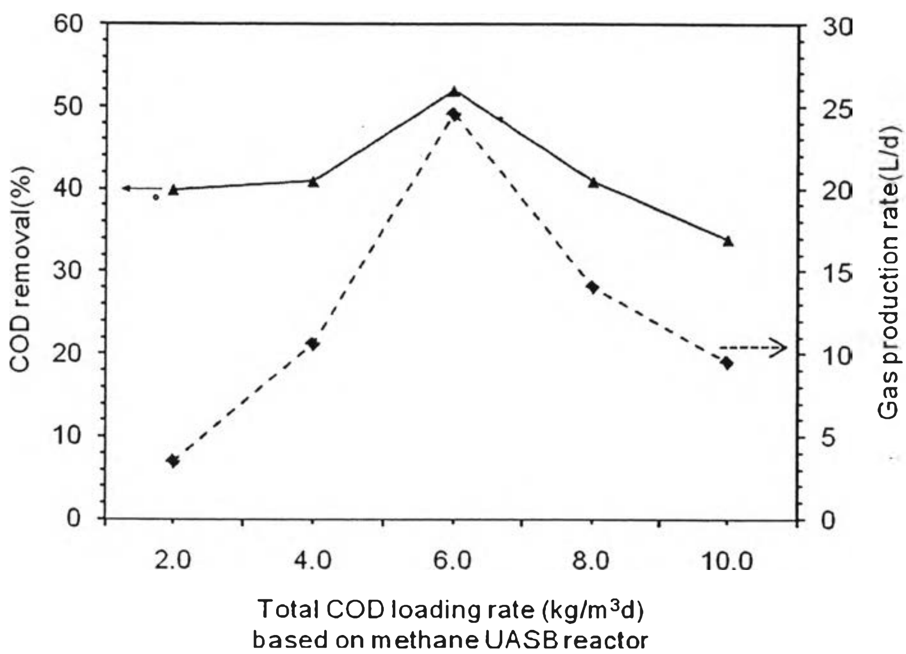

Figure 4.6 Effect of COD loading rate on COD removal and gas composition rate on methane UASB unit at 37°C and without pH control.

4.1.2.2 Gas Composition and Methane Production Rate

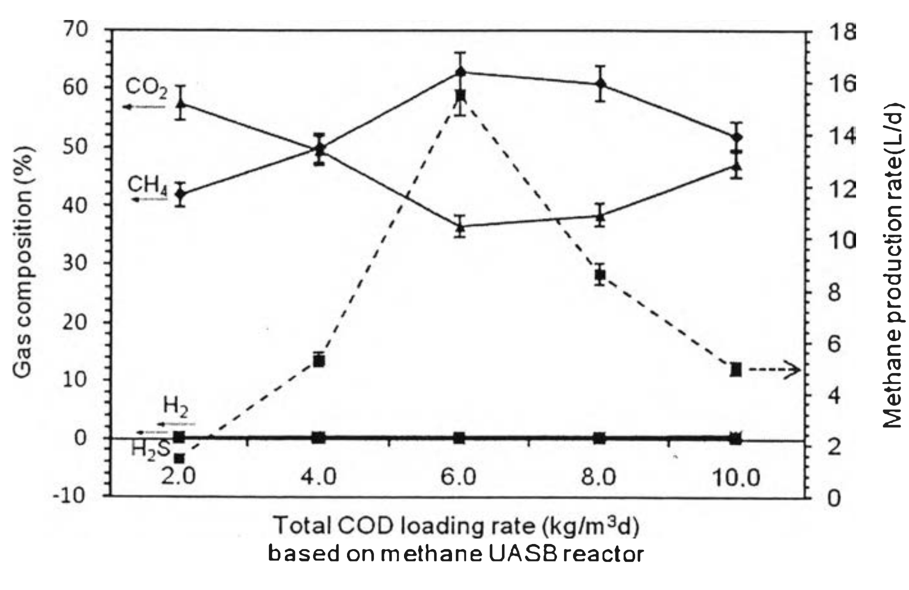

Figure 4.7 Effect of COD loading rate on gas composition and methane production rate on methane UASB unit at 37°C and without pH control.

Figure 4.7 shows the different COD loading rate of the methane production in term of gas compositions and methane production rate in the mesophilic reactor throughout the experiment. For COD loading rate increased from 2 to 6 $KgCOD \cdot m^{-3} \cdot d^{-1}$ based on methane UASB unit, the methane content increased. The main produced gases were methane and carbon dioxide with a small amount of hydrogen of 0.4% and hydrogen sulfide under 0.3% (0.22%). The highest methane content (63%) and the lowest carbon dioxide(36.6%) were obtained at 6 $KgCOD \cdot m^{-3} \cdot d^{-1}$ based on methane UASB unit. Additionally, the biogas production rate was sharply increased when COD loading rate increased from 2 to 6 $KgCOD \cdot m^{-3} \cdot d^{-1}$ based on methane UASB unit, reaching a peak at over 15%(maximal content 15.6%). However, the methane production rate gradually decreased with the continuously increasing COD loading rate from 6 to 10 $KgCOD \cdot m^{-3} \cdot d^{-1}$ based on methane UASB unit which illustrate that the increase of COD loading rate significantly affect the performance of the UASB reactor. And this trends demonstrate that the UASB reactor could stably operate with 6 $KgCOD \cdot m^{-3} \cdot d^{-1}$ based on methane UASB unit under mesophilic temperature and without pH controlling on methane UASB unit.

4.1.2.3 Methane Yield and Specific Methane Production Rate

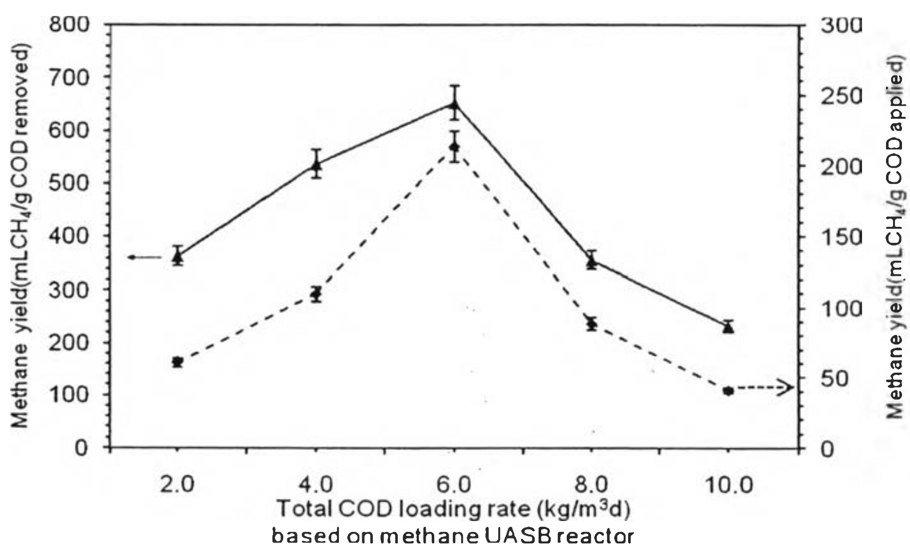

Figure 4.8 Effect of COD loading rate on methane yield on methane UASB unit at 37°C and without pH control.

The methane yields and specific methane production rates (SMPR) were shown in Figures 4.8-4.9, respectively. They increased with increasing the COD loading rate from of 2, 4, 6, 8, 10 KgCOD·m^{-3}·d^{-1} based on methane UASB unit(HRT of 14, 7, 3.5, 1.75, 0.875 d), and then decreased with further increasing COD loading rate from 6 to 10 KgCOD·m^{-3}·d^{-1} based on methane UASB unit because of the increasing toxicity of VFA accumulation. The methane yield (652 mL CH4·g^{-1} COD removed or 213 mL CH4·g^{-1} COD applied) and the maximum SMPR (647 mL CH_4·L^{-1}·d^{-1} or 80 mLCH_4·g^{-1} MLVSS· d^{-1}) found at an optimum COD loading rate of 6 KgCOD·m^{-3}·d^{-1} based on methane UASB unit.

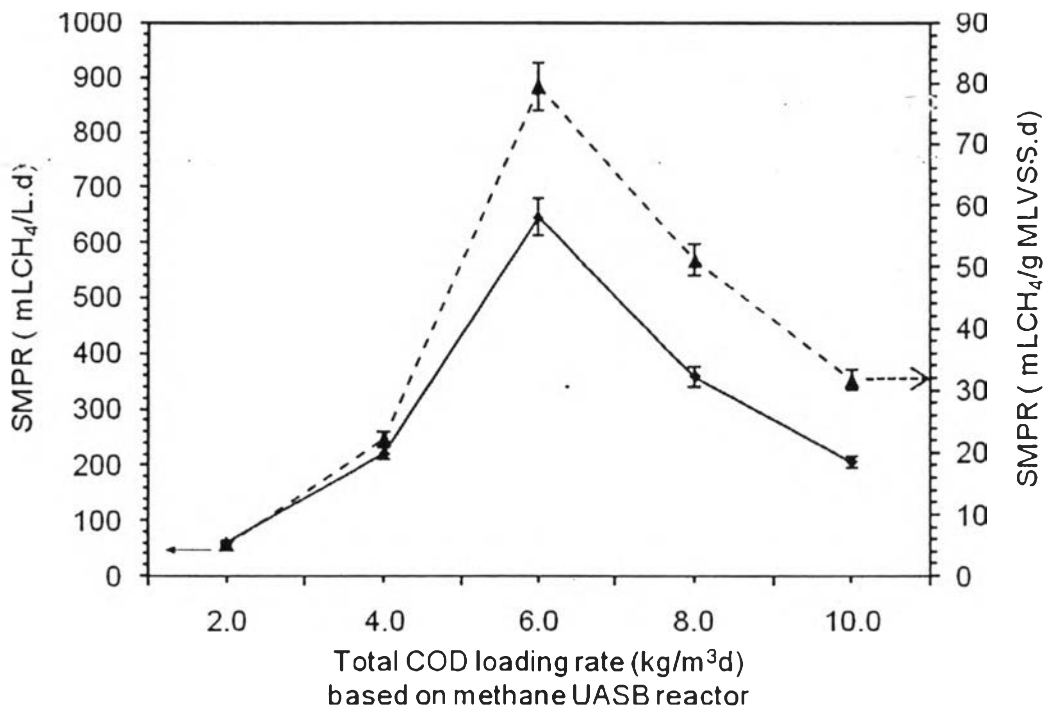

Figure 4.9 Effect of COD loading rate on Specific methane production rate (SMPR) on methane UASB unit at 37°C and without pH control.

4.1.2.4 The Amount of Organic Acid and Ethanol Concentration and Total Volatile Fatty Acid (VFA) Concentration

Figure 4.10 shows data for organic acid concentration and total VFA for mesophilic reactors. At steady state was achieved for the process at

COD loading rate 2 to 6 $KgCOD \cdot m^{-3} \cdot d^{-1}$ based on methane UASB unit by reducing HRT.

For organic concentration. Acetic acid and propionic acid in VFA of the effluent were major components, accounting for more than 90% of total VFA as acetic acid and other VFA was detected at insignificant concentrations. After at COD loading rate from 8 to 10 $KgCOD \cdot m^{-3} \cdot d^{-1}$ based on methane UASB unit, it is interesting that propionic acid in the effluent began to be dominant until the termination of the experiment. So far, several reports have also reports that propionic acid degradation was the rate-limiting step of the overall methane production in anaerobic digestion of various substrates (Wiegant *et al.*, 1986). The methane can be produced by acetotrophic pathway, as shown in Equation 4.9. Moreover, methane can be generated via hydrogenotrophic pathway which converts hydrogen and carbon dioxdide to methane, as shown in Equation 4.10 (Abbasi *et al.*, 2012).The higher acetic acid concentration, the higher methane production performance in the methane UASB unit. However, at a very high total VFA concentration (278 $mg \cdot L^{-1}$ as acetic acid), the system showed the lower methane production performance because of the negative effect of toxicity from volatile fatty acid(VFA) accumulation to microorganism and the toxic level to methane-producing bacteria.

Acetotrophic pathway

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (4.9)$$

Hydrogenotrophic pathway

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \quad (4.10)$$

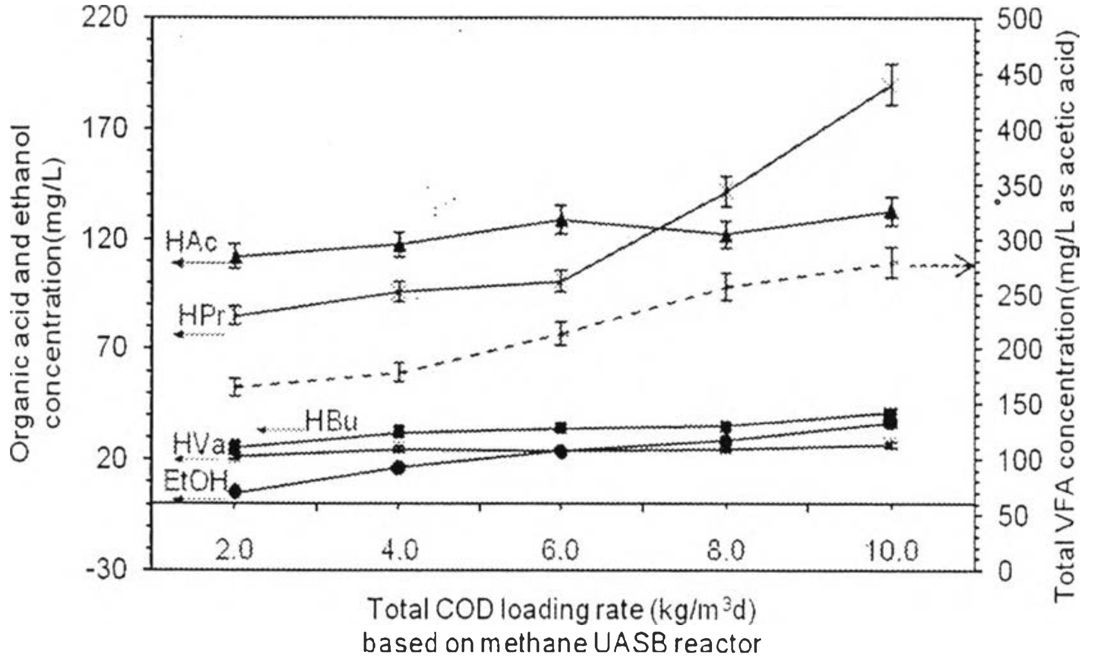

Figure 4.10 Effect of COD loading rate on total VFA, organic acid and alcohol concentration on methane UASB unit at 37°C and without pH control.

4.2 Anaerobic Digestion of Cassava Wastewater with Microaeration

The enhancement of anaerobic digestion of the cassava wastewater was investigated by supplying oxygen from 5.2 to 7.9 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$(or 5.04 to 7.55 $mgO_2 \cdot g^{-1}$CODapplied$\cdot d^{-1}$) under the optimum COD loading rate of 6 $KgCOD \cdot m^{-3} \cdot d^{-1}$ based on methane UASB unit(36 $KgCOD \cdot m^{-3} d^{-1}$ based on hydrogen UASB unit).

4.2.1 COD Removal and Gas Production Rate

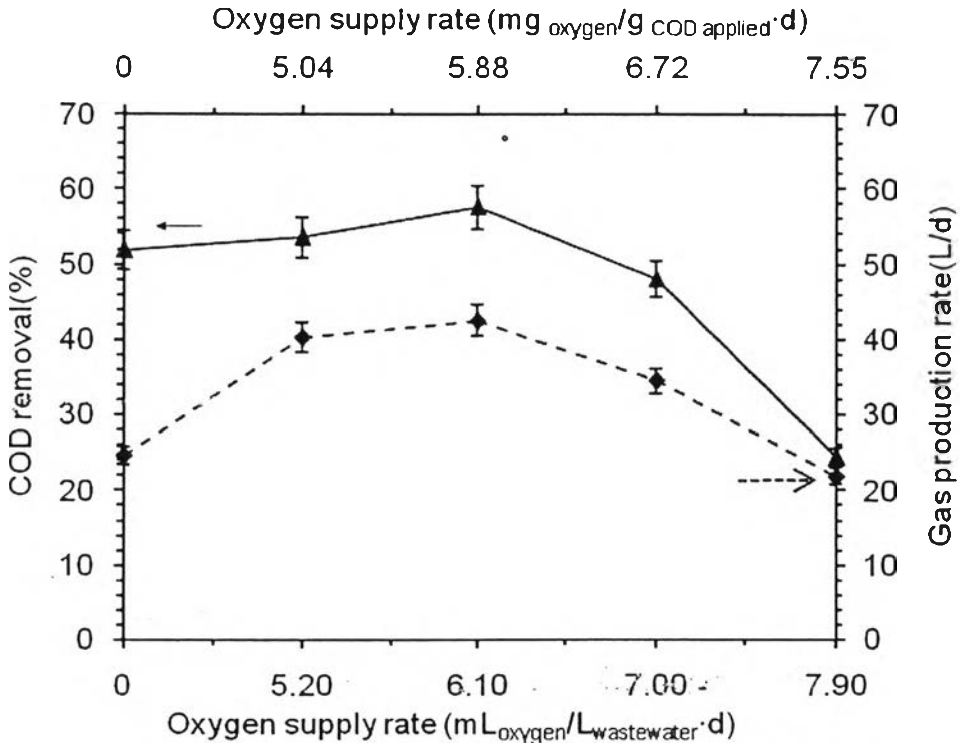

Figure 4.11 Effects of oxygen supply rate on COD removal and gas production rate on methane UASB unit at 37°C and without pH control.

The variation of COD removal with oxygen supply rate is depict in Figure4.11 the COD removal increased with increasing oxygen supply rate and reach a maximum. After that, it decreased with further increasing oxygen supply rate. The COD removal reached the maximum of 57.69 % at a oxygen supply rate of 6.1 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$. In addition, the COD removal sharply dropped to 24.35 % with further increase in the oxygen supply rate from 6.1 to 7.9 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$. For the gas production rate, it has the similar trend to the COD removal. The maximum COD removal of 57.69 % and the maximum gas production rate of 42.64 $L \cdot d^{-1}$ are obtained at the oxygen supply rate of 6.1 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$. The rising 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(7.0 and 7.9 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$), The results also suggest that the oxygen content is higher resulting in the toxic environment on the activity of the strict anaerobic bacteria.

4.2.2 Gas Composition and Methane Production Rate

the methane composition and methane production rate at different oxygen supply rate is represented in figure 4.12. When the oxygen supply rate increased from increased from 0.0 to 6.1 mL O_2·L^{-1} wastewater·d^{-}1, the methane composition and methane production rate were increase from 63% to 67 % and 15.51 to 28.56 mL·d^{-1}, respectively. With further increasing oxygen supply rate from 6.1 to 7.9 mL$O_2$$L^{-1}$wastewater·$d^{-1}$, the methane composition and methane production rate is rapidly decreased to 41 % and 21.85 L·d^{-1},respectively, while a large amount of carbon dioxide (41% and 48 %) and oxygen (5% and 9 %) can be observed at the oxygen supply rate of 7.0 and 7.9 mLO_2·L^{-1}wastewater·d^{-1}, respectively. The comparative results shown 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.

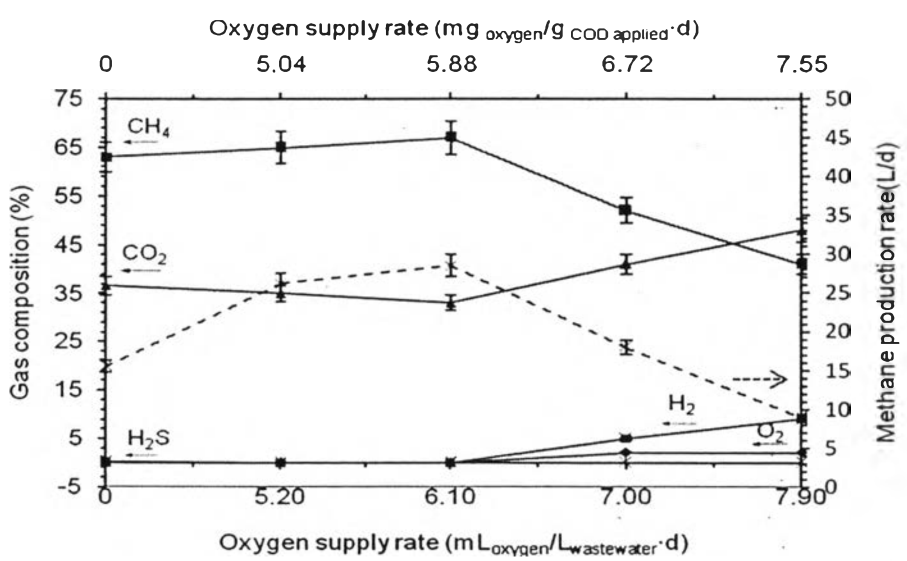

Figure 4.12 Effects of oxygen supply rate on gas composition and methane production rate on methane UASB unit at 37°C and without pH control.

4.2.3 Methane Yield and Specific Methane Production Rate

The specific methane production rate and methane yield illustrate the similar trend as can be seen in Figures 4.13 and 4.14 to the methane production rate. The maximum methane yield of 682.33 mL $CH_4 \cdot g^{-1}$ COD removed (or 393.64 mL $CH4 \cdot g^{-1}$ COD applied) and the maximum specific methane production rate of 1190.36 mL $CH4 \cdot L^{-1} \cdot d^{-1}$ (or 192.03 mL $CH_4 \cdot g^{-1}$ $MLVSS \cdot d^{-1}$) is obtained with the oxygen supply rate of 6.1 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$. Therefore,the oxygen supply rate of 6.1 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$ 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 UASB system (Equation 4.11).

$$H_2S\text{-consumming bacteria} + H_2S + \text{Organic substrate} + O_2 \rightarrow S^0 + \text{New cells} \quad (4.11)$$

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 UASB system (Equation 4.11). The reaction that take place are shown in Equation 4.12, 4.13 and 4.14 (Madigan et al., 2009).

$$H_2S + 1/2O_2 \rightarrow S^0 + H_2O \qquad \Delta G^0 = -209.4 \text{ kJ/reaction} \quad (4.12)$$

$$S^0 + 2H_2O + 3/2O_2 \rightarrow SO_4^{2-} + 2H^+ \qquad \Delta G^0 = -587.1 \text{ kJ/reaction} \quad (4.13)$$

$$H_2S + 2O_2 \rightarrow SO_4^{2-} + 2H^+ \qquad \Delta G^0 = -798.2 \text{ kJ/reaction} \quad (4.14)$$

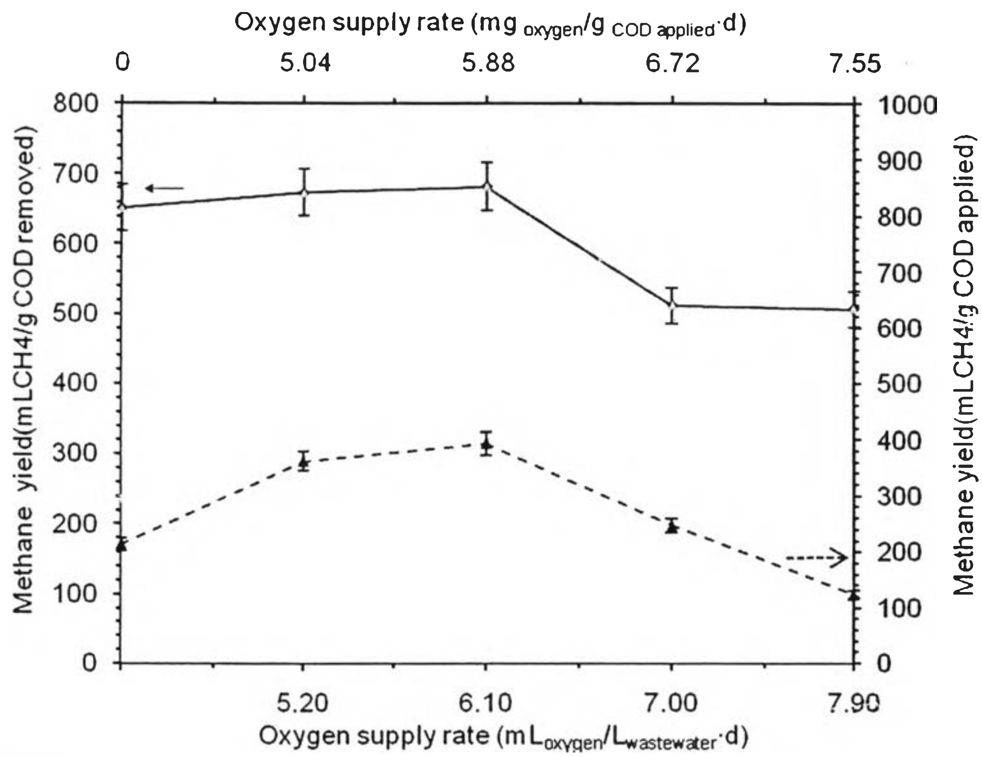

Figure 4.13 Effects of oxygen supply rate on methane yield on methane UASB unit at 37°C and without pH control.

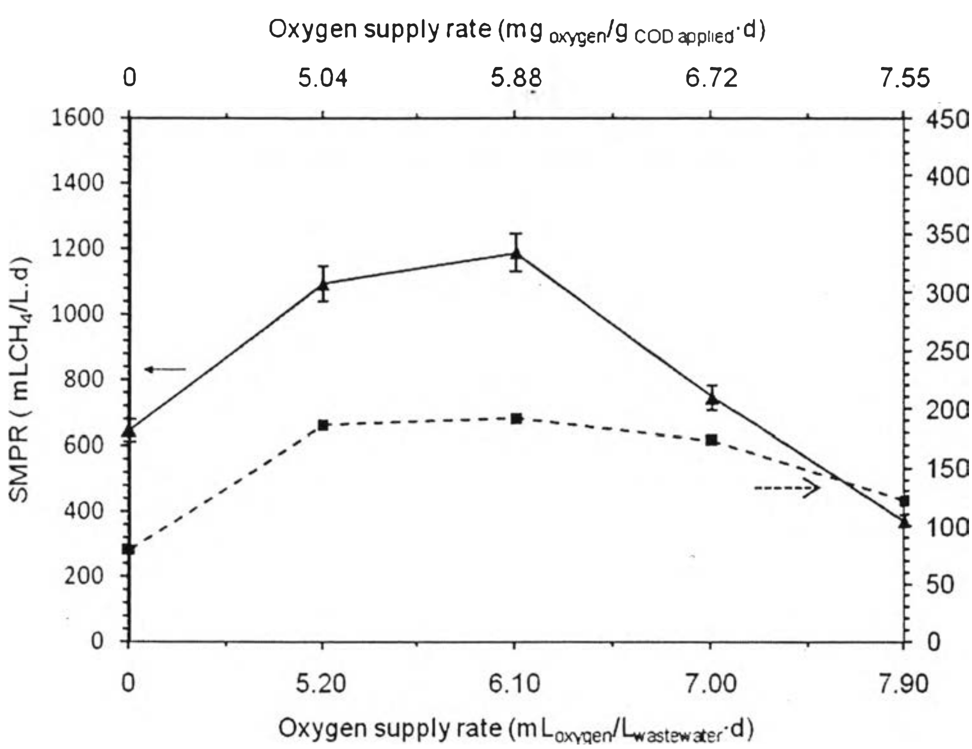

Figure 4.14 Effects of oxygen supply rate on SMPR (specific methane production rate) on methane UASB unit at 37°C and without pH control.

4.2.4 The Amount of Organic Acid and Ethanol Concentration and Total Volatile Fatty Acid (VFA) Concentration.

Figure 4.14 shows the amount of organic acid and ethanol concentration and total volatile fatty acid (VFA) concentration that gradually increase with the rising in the oxygen supply rate and obtain the maximum total VFA value of 233.37 mgL^{-1} as acetic acid at the oxygen supply rate of 6.1 mL $O_2 \cdot L^{-1}$ wastewater$\cdot d^{-1}$, whereas the methane production rate decreases with the increase in the oxygen supply rate from 6.1 and 7.9 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$ The results indicate that, under the oxygen supply rate from 0.0 to 6.1 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$, 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.

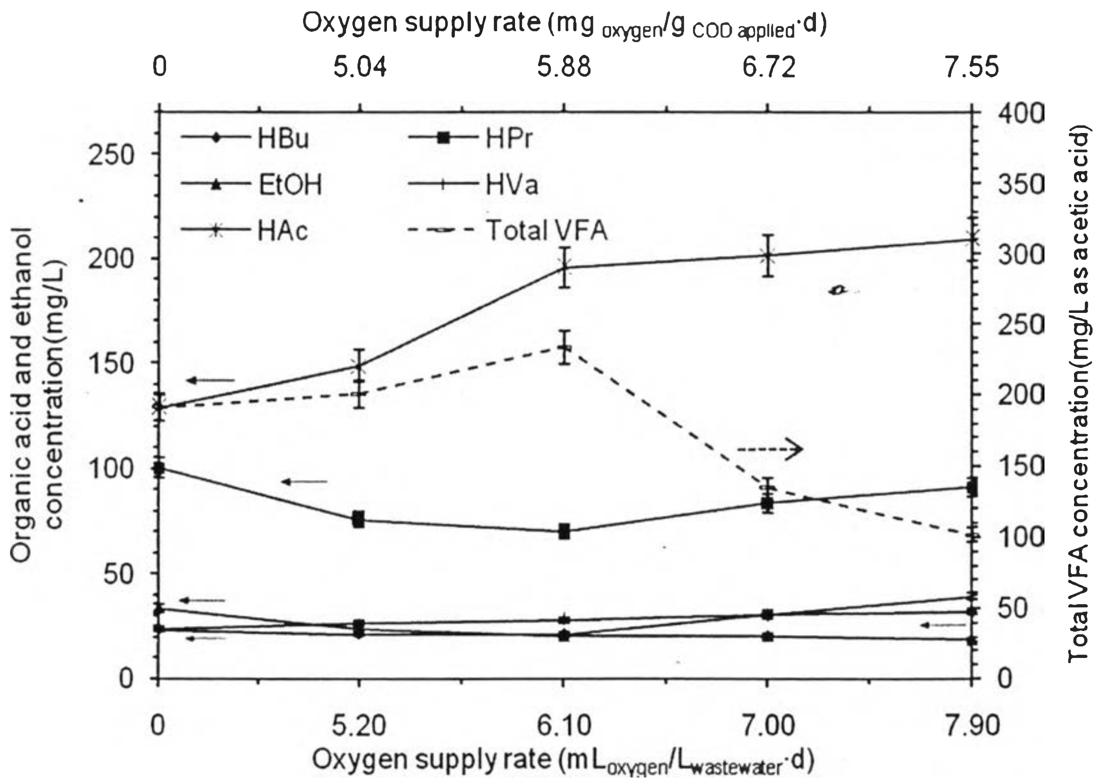

Figure 4.15 Effects of oxygen supply rate on total VFA, organic acid and alcohol concentration on methane UASB unit at 37°C and without pH control.

4.3 Microbial Concentration and Microbial Washout Results

4.3.1 Without Microaeration

The concentration of microbial can also be quantified by using MLVSS shown in Figures 4.16-4.17, with the higher of COD loading rate in two-stage UASB system and the microbial associated with cassava substrate wash out(effluent VSS) distribution from each bioreactor. The MLVSS fell gradually with increasing COD loading rate while the effluent VSS had an opposite trend. With the gradual increase of COD loading rate, the sustainable growth of biogas production made the water and the sludge completely mixed, From the production performance of hydrogen and methane in previous results will be enhanced. It can be referred that the microbial concentration contained mainly hydrogen-producing bacteria in the hydrogen UASB unit and methane-producing bacteria in methane UASB unit(Intanoo *et al.*, 2014). On the other hand, a over height level of COD loading rate at 36 KgCOD·m^{-3}·d^{-1} based on hydrogen UASB unit (6 KgCOD·m^{-3}·d^{-1} based on methane UASB unit), the performance of hydrogen and methane production dropped definitely due to the over large amount of the toxic level of organic acid accumulation become toxic to the microorganisms.

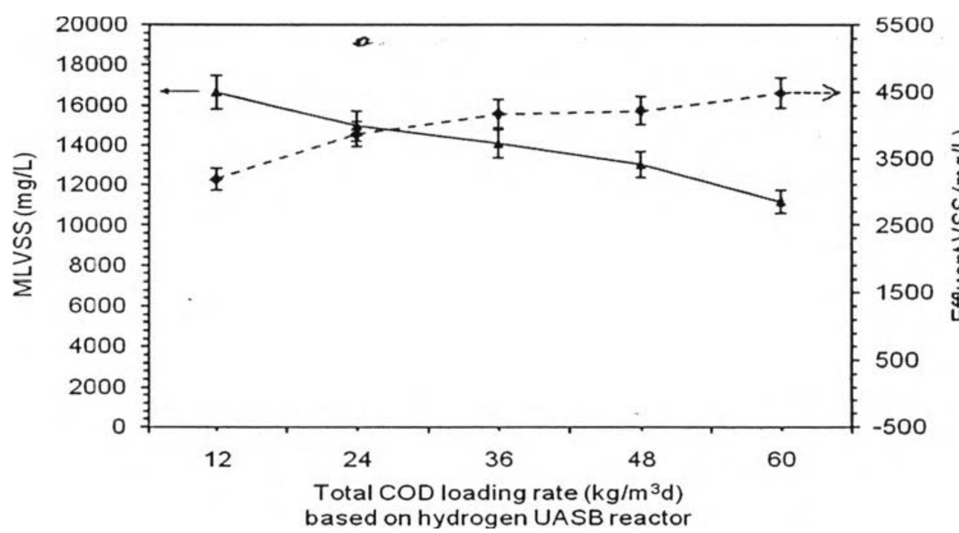

Figure 4.16 Effect of COD loading rate on MLVSS and Effluent VSS on hydrogen UASB unit at 37°C and pH 5.5.

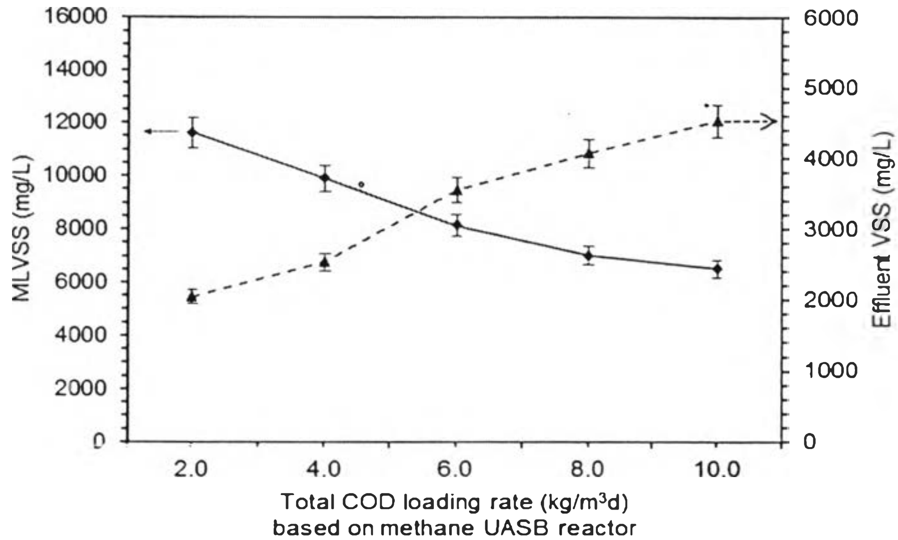

Figure 4.17 Effect of COD loading rate on MLVSS and Effluent VSS on methane UASB unit at 37°C and without pH control.

4.3.2 <u>With Microaeration</u>

Figure 4.18 shows the microbes washout from the system (effluent VSS). The MLVSS increases with the increase in the oxygen supply rate from 0.0 to 6.1 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$and then decreases with further increase in the oxygen supply rate 6.1 to 7.9 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$. For the effluent VSS, it has the opposite trend to that of the MLVSS. The minimum effluent VSS (2,524 $mg \cdot L^{-1}$) is obtained at the oxygen supply rate of 6.1 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$.The results indicate that at the oxygen supply rate 0.0 to 6.1 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$, the anaerobic bacteria in UASB perform well. In contrast, beyond the oxygen supply rate of 6.1 $mLO_2 \cdot L^{-1}$wastewater$\cdot d^{-1}$, inactive anaerobic bacteria were washed out at a greater extend from the UASB system.

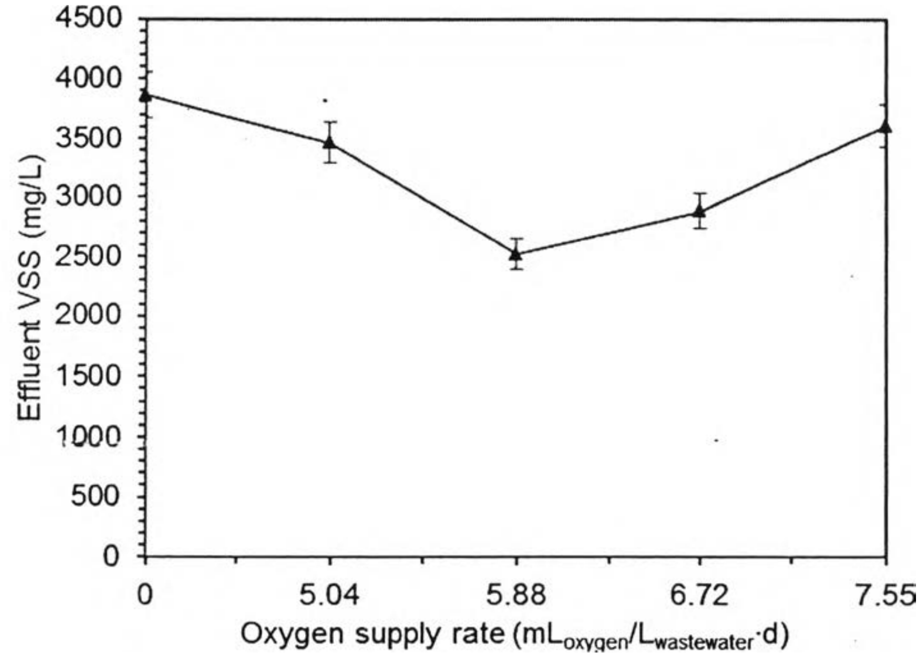

Figure 4.18 Effects of oxygen supply rate on effluent VSS on methane UASB unit at 37°C and without pH control.

4.4 Overall Performance

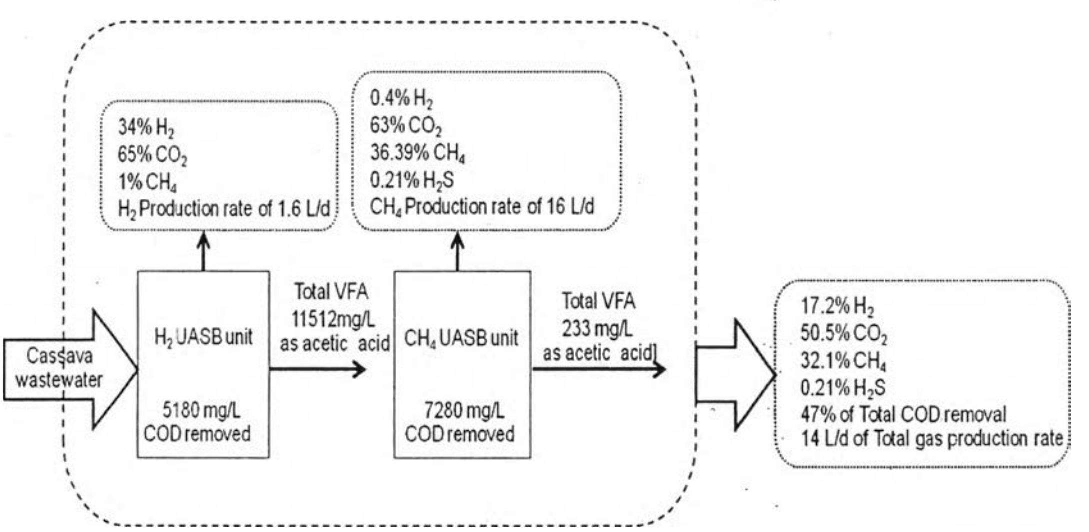

Figure 4.19 Overall performance of two stage UASB processes without microaeration.

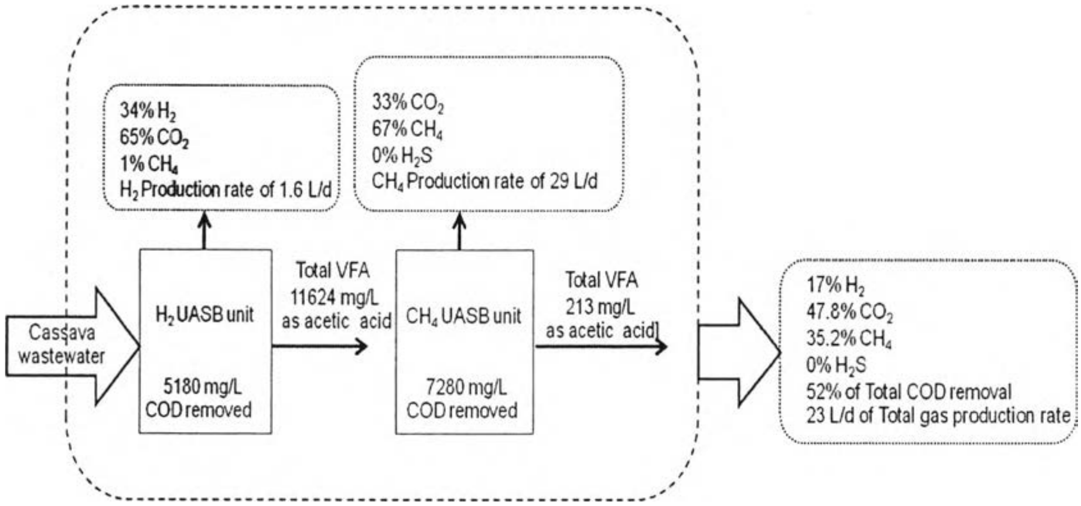

Figure 4.20 Overall performance of two stage UASB processes with microaeration.

The overall performance of two stage UASB processes operated under the mesophilic temperature without microaeration and with microaeration is shown in Figure4.19-4.20, respectively. From the result of system without microaeration, it can be concluded that at the optimum COD loading rate of 36 kg COD$\cdot$m$^{-3}\cdot$d^{-1} based on hydrogen UASB unit (6 kg COD$\cdot$m$^{-3}\cdot$d^{-1} based on methane UASB unit), the total COD removal efficiency was 47 % and the total gas production rate was 14 L$\cdot$d^{-1}. The mixed gas contents 17.2 % H_2, 32.1% CH_4, and 50.5% CO_2 and 0.21% H_2S . From the result of system with microaeration (6.1 mL $O_2$$\cdot$L^{-1} wastewater$\cdot$d^{-1}), the total COD removal efficiency was 52 % and the total gas production rate was 23 L$\cdot$d^{-1}. The mixed gas contents 17% H_2, 35.2% CH_4, and 47.8% CO_2 and 0 % H_2S . Under microaeration with optimum oxygen supply rate, the H_2S removal is responsible for the enhancement of methane production, the loss of micronutrients from the system.