CHAPTER IV
RESULTS AND DISCUSSION

4.1 Anaerobic Digestion of Cassava Wastewater with Added Ethylenediaminetetraaceticacid Disodium salt (EDTA) Chelant

The cassava wastewater was digested in the anaerobic digestion (Eqs 2.1-2.3) under the CSTR system with and without added all of chelants, ferric chloride ($FeCl_3$) and cobalt chloride ($CoCl_2$) under the optimum COD loading rate of 1.710 kg/m^3 (Oijai, 2013). The non biodegradable chelants; ethylenediaminetetraaceticacid disodium salt (EDTA) was added with the cassava wastewater. The contents of EDTA were varied from 3 to 10 ppm and mixed with the cassava wastewater under the optimum COD loading rate of 1.710 kg/m^3. At this COD loading rate the pH value is in the range of 6.8-7.06. 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). For this COD loading rate, the gas production rate and gas composition were measured daily until the system reached steady state. The effects of EDTA on the anaerobic digestion were investigated

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 (Eq 3.3) was kept constant at 51.9 % at without added EDTA dosage. After added EDTA at 3 ppm the COD removal also constant. In addition, the COD removal was increased from 51.9 % to 62.9 % with futher increase the concentrations of EDTA from 3 to 5 ppm . Moreover COD removal was kept constant at 62.9 % with increased the concentration of EDTA from 5 to 10 ppm. The maximum COD removal was 62.9 % at 5 ppm of EDTA concentrations. It could explained that the increaseing of the EDTA concentrations results in the increasing anions in cassava wastewater that used to catch with divalent cation to form micronutrient in water soluble complex. Thus, the microorganisms could degrade increasingly the organic compound. The gas production rate shows the similar trend to the COD removal. That is the maximum gas production rate is .902 mL/d at the EDTA concentrations of 5 ppm. In other words, the optimum EDTA concentrations at 5 ppm results in the maximum COD removal and gas production rate.

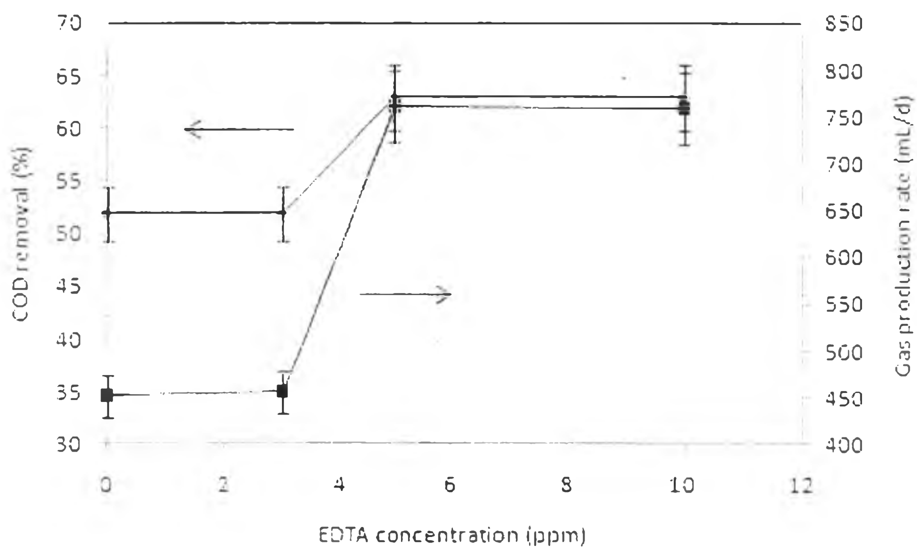

Figure 4.1 Effects of added EDTA on COD removal and gas production rate.

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 were kept constant at 74.4 and 456 mL/d, respectively, with the increasing in the concentrations of EDTA from 0 to 3 ppm. However, when the EDTA concentrations were increased from 3 to 5 ppm, the methane composition was increased from 74.4 % to 84.3 %, and the methane production rate was increased from 456 to 760 mL/d. Moreover, the methane composition and methane production rate were kept constant at 84.3 % and 760 mL/d, respectively, when the EDTA concentrations were increased from 5 to 10 ppm. The results indicate that the higher EDTA concentrations were suitable for the methane production because the higher EDTA concentrations have higher anions which sufficiently combine with micronutrients for the productions of microbial enzymes. Thus, the microorganisms could degrade increasingly the organic compound. On the contrary, the lower EDTA concentrations were not appropriately for methane production because the lower EDTA concentrations have lower anions which insufficiently combine with micronutrients for production of microbial enzymes. Both specific methane production rate and methane yield show similar trend (Figures 4.3 and 4.4). The maximum specific methane production rate of 190 mL CH_4/L d (Eq 3.6) (or 19 mL CH_4/g MLVSS d (Eq 3.7)) and the maximum methane yield of 338 mL CH_4/g COD removed (Eq 3.4) (or 126 mL CH_4/g COD applied (Eq 3.5)) is observed at the EDTA concentrations at 5 ppm. In addition, the optimum concentrations of EDTA results in about 0.06 % hydrogen sulfide.

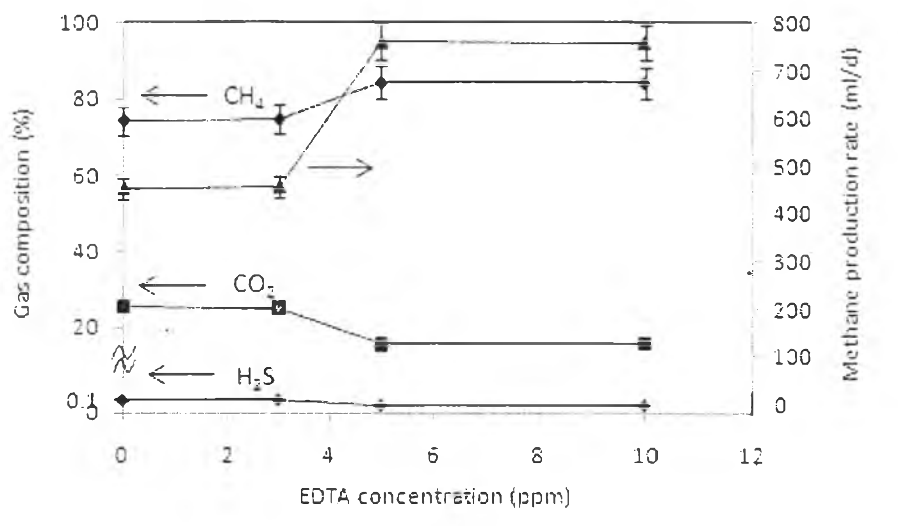

Figure 4.2 Effects of added EDTA on gas composition and methane production rate.

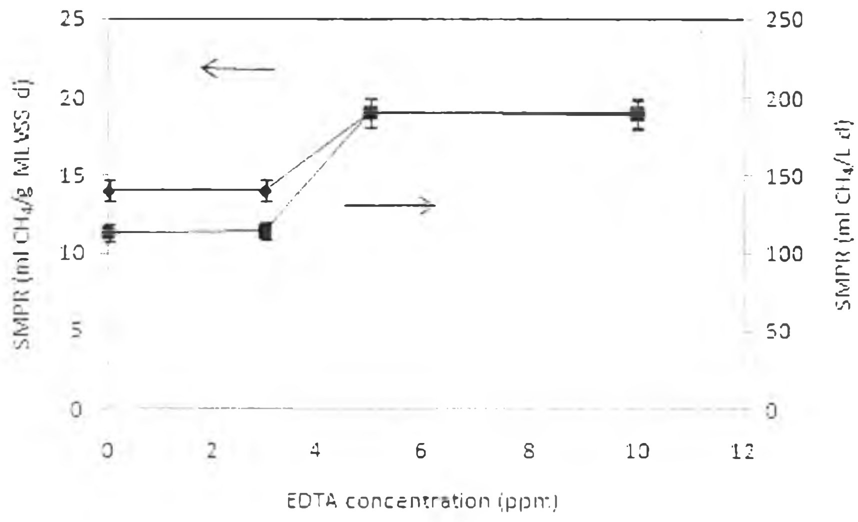

Figure 4.3 Effects added EDTA on SMPR (specific methane production rate).

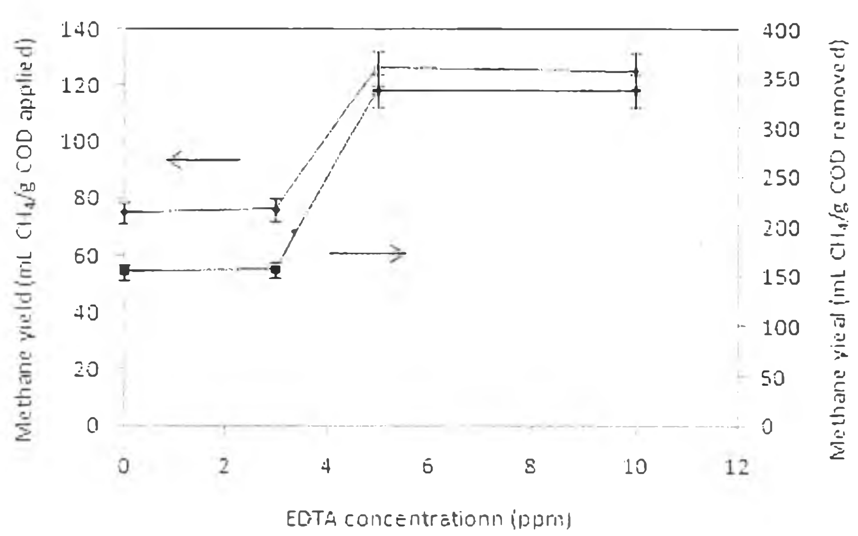

Figure 4.4 Effects of added EDTA on methane yield.

4.1.3 Amount of Volatile Fatty Acid

The total VFA concentration (mg/L as acetic acid) and composition are shown in Figure 4.5 The total VFA concentration was increased with the increasing in the EDTA concentrations and attains the maximum value of 315 mg/L as acetic acid at the highest EDTA concentrations concentration of 5 ppm (pH 7.02), whereas the methane production increases (Figures 4.2 - 4.4). When the EDTA concentrations were increased in the cassava wastewater, additional anions were combined with all micronutrients resulting in the system. At the EDTA concentrations of 5 ppm, the system provides the highest methane production in terms of the highest methane yield and SMPR; hence, this EDTA concentration was 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 (Figure 4.1). Under the optimum EDTA concentration of 5 ppm, the total VFA concentration is 315 mg/L as acetic acid, and the concentration of acetic acid is highest (97 mg/L). These values indicate that both acidogenic and acetogenic bacteria work under the operating condition.

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) (Eq 3.2). The MLVSS increases with the increasing in the concentration of EDTA from 3 to 5 ppm and then were kept constant with further increased in the EDTA concentration from 5 to 10 ppm. For the effluent VSS, the opposite trend to that of the MLVSS is observed. The maximum MLVSS (9,910 mg/L) and minimum effluent VSS (2,210 mg/L) are obtained at the EDTA concentration. The results indicated that when the EDTA concentration was increased from 3 to 5 ppm, the ability of the microorganisms to utilize the organic compounds increases. However, further increase in the EDTA concentration from 5 to 10 ppm results also trend to the 5 ppm of EDTA concentration.

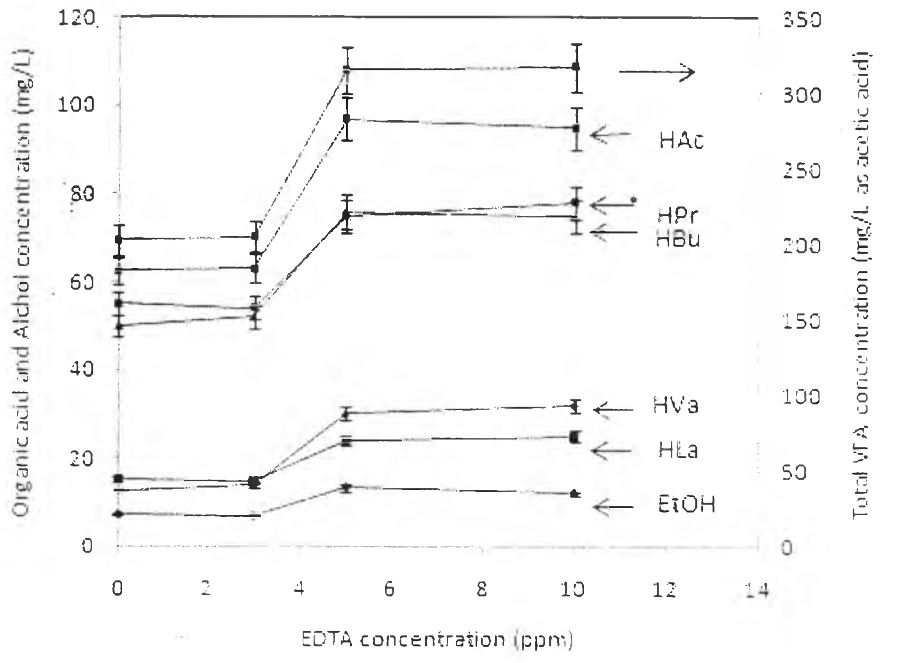

Figure 4.5 Effects of added EDTA concentration on total VFA, organic acid, and alcohol concentration.

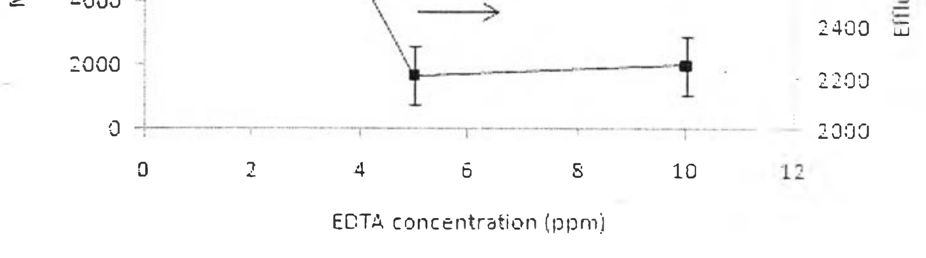

Figure 4.6 Effects of added EDTA on MLVSS and effluent VSS.

4.1.5 The Amount of Micronutrient Concentration

Table 4.2 showed the amount of micronutrient without added EDTA and added EDTA at different concentration, respectively. All micronutrients (Co, Ni, Cu, Mo, and Fe) in which are necessary for the production of microbial enzymes were almost disappeared because the micronutrients were precipitated by sulfide in anaerobic digesters when compared with feed substrate. The micronutrients concentrations were returned to feed substrate with increasing EDTA concentration to 5 ppm. Moreover, the micronutrients concentrations were kept constant with increasing EDTA concentration to 10 ppm. This condition corresponds to the maximum COD removal (Figure 4.1) under the optimum EDTA concentration of 5 ppm. The results depend on the log stability constant of metal chelating compounds (K1) (Table 4.1) showed that the metal which were interested as the micronutrients. EDTA have K1. The calculation form (Eqs 4.1 - 4.2).

$$M + L \longleftrightarrow ML \tag{4.1}$$

$$[ML] = K1\,[M][L] \tag{4.2}$$

where [M] = metal ion concentration (ppm)

[L] = ligand concentration (ppm)

[ML] = concentration of water soluble complex (ppm)

Table 4.1 The log stability constant of metal chelating compounds (Callander and Barford, 2006)

Chelating Agents	Log Stability Constants (K1)							
	Fe^{3+}	Co^{2+}	Zn^{2+}	Cu^{2+}	Fe^{2+}	Mn^{2+}	Ca^{2+}	Mg^{2+}
EDTA	25.1	1	16.3	16.2	14.3	13.6	10.7	8.7
GLDA	-	5.06	5.45	-	4.6	3.3	2.05	1.9

Table 4.2 The amount of micronutrient without added EDTA and added EDTA at different concentration

Element	Micronutrient Concentration (ppm)				
	Feed Cassava Waste Water	Steady State by Without Added Chelant	Added EDTA (ppm)		
			3 ppm	5 ppm	10 ppm
Co	0.012	0	0.01	0.012	0.012
Ni	0.037	0.01	0.02	0.03	0.032
Cu	0.08	0	0.04	0.08	0.08
Mo	0.168	0.148	0.15	0.164	0.165
Fe	1.483	0.48	0.5	1.45	1.46
Ca	1.364	1.36	1.31	1.36	1.36
Mn	0.174	0.164	0.167	0.172	0.173

4.2 Anaerobic Digestion of Cassava Wastewater with Added Tetrasodiumglutamate Diacetate (Na_4GLDA) Chelant

The biodegradable chelant (GLDA) were added as a feed. The contents of GLDA concentrations were varied from 1 to 10 ppm and mixed with the cassava wastewater under the optimum COD loading rate of 1.710 kg/m^3 d. The effects of added GLDA at different concentration on the anaerobic digestion were investigated.

4.2.1 COD Removal and Gas Production Rate

The COD removal (Figure 4.7) is increased from 51.9 to 63.1 % (Eq 3.3) by increasing the GLDA concentration from 0 to 3 ppm. Moreover, the COD removal was also kept constant at 63.1 % when increased GLDA concentration to 5 and 10 ppm. The gas production rate shows the similar trend to the COD removal. The maximum COD removal is 63.1 % and the maximum gas production rate is 917 mL/d at the GLDA concentration of 3 ppm. It may be explained that the increase in the GLDA concentration results in the increasing anions more than EDTA in cassava wastewater. All micronutrients were combined by the anions from GDLA.
The additions of GLDA are effectively chelated to form water soluble complexes. Thus, the microorganisms could degrade increasingly the organic compound. The gas production rate shows the similar trend to the COD removal. That is the maximum gas production rate is 1,060 mL/d at the GLDA concentrations of 3 ppm. In other words, the optimum GLDA concentrations at 3 ppm results in the maximum COD removal and gas production rate.

4.2.2 Gas Composition and Methane Production Rate

Both methane composition and methane production rate (Figure 4.8) are increased from 74.4 to 86.5 % and 452 to 917 mL/d, respectively, with the increase in the GLDA concentration from 0 to 3 ppm. The maximum specific methane production rate is 229.2 mL CH_4/L d (Eq 3.6) (or 23.16 mL CH_4/g MLVSS d (Eq 3.7)) and the maximum methane yield is 413 mL CH_4/g COD removed (Eq 3.4) (or 152 mL CH_4/g COD applied (Eq3.5)) (Figures 4.9 - 4.10). However, when the GLDA concentration further increased from 3 to 5 and 10 ppm, respectively, methane production were also kept constant. The results indicated that the GLDA concentration range of 3 to 10 ppm is suitable for methane production because of higher anions were sufficient for combine with micronutrients. However, at the lowest GLDA concentration (1 ppm), the methane production was not increase due to the insufficient micronutrients. Because inadequate GLDA concentration to combine micronutrients. In addition, under the optimum GLDA concentration of 3 ppm, hydrogen sulfide gas composition is 0.1 %.

4.2.3 Amount of Volatile Fatty Acid

The total VFA concentration (mg/L as acetic acid) and composition are shown in Figure 4.11. The total VFA concentration increases with the increase in the GLDA concentration and attains the maximum value of 322 mg/L as acetic acid at the highest GLDA concentration of 3 ppm, while the methane production was increased (Figures 4.9 - 4.10). At the GLDA concentration of 3 ppm, the system provides the highest methane production in terms of the highest methane yield and SMPR; hence, this GLDA 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 (Figure 4.8). Under the optimum GLDA concentration of 3 ppm, the total VFA concentration is 322 mg/L as acetic acid, and the concentration of acetic acid is highest (98 mg/L). These values indicate that both acidogenic and acetogenic bacteria work under the operating condition.

4.2.4 Microbial Concentration and Microbial Washout

Figure 4.12 shows the growth of microorganisms in the reactor (MLVSS) and the microorganism washout from the system (effluent VSS) (Eq 3.2). The MLVSS increases with the increasing in the concentration of GLDA from 1 to 3 ppm and then were kept constant with further increased in the GLDA concentration from 3 to 5 and 10 ppm, respectively. For the effluent VSS, the opposite trend to that of the MLVSS is observed. The maximum MLVSS (9850mg/L) and minimum effluent VSS (2,270 mg/L) are obtained at the GLDA concentration. The results indicated that when the GLDA concentration was increased from 1 to 3 ppm, the ability of the microorganisms to utilize the organic compounds increases. However, further increase in the GLDA concentration from 3 to 5 and 10 ppm, respectivly results also trend to the 3 ppm of EDTA concentration.

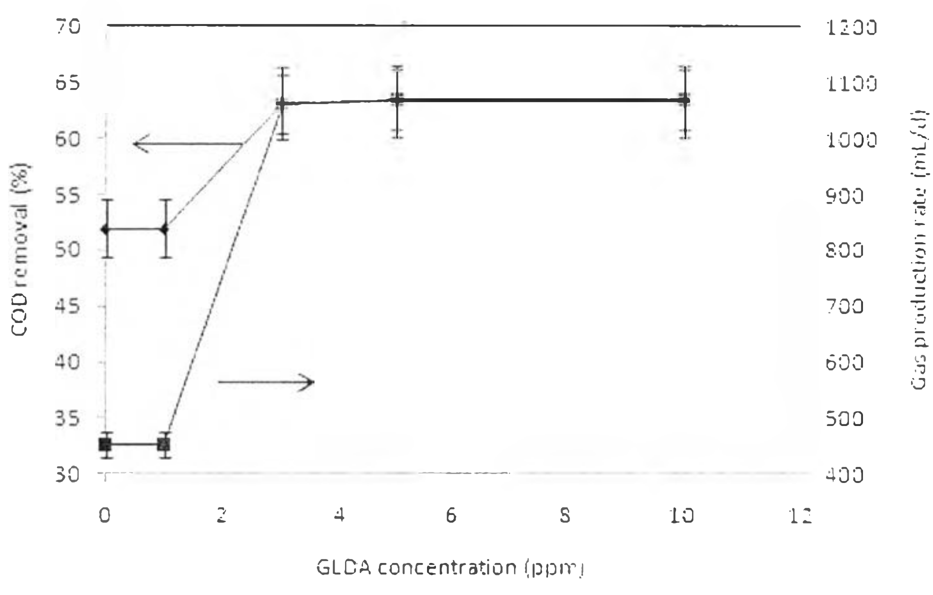

Figure 4.7 Effects of added GLDA on COD removal and gas production rate.

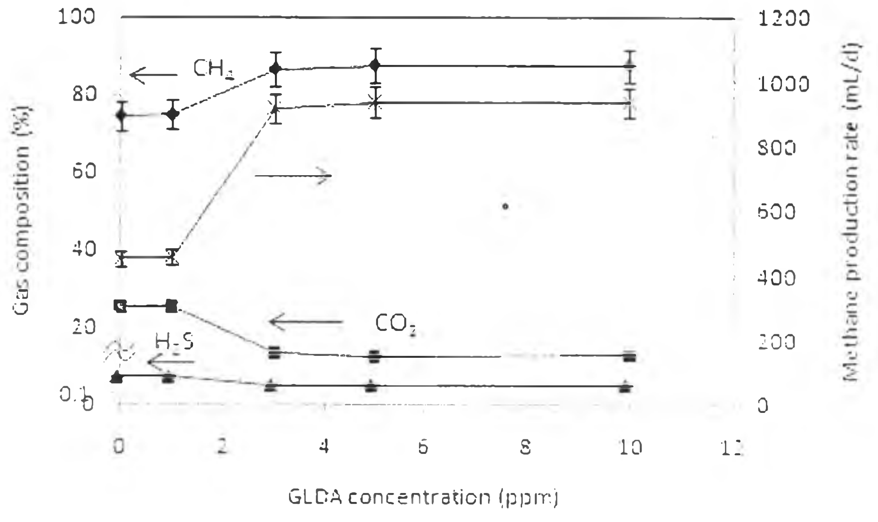

Figure 4.8 Effects of added GLDA on gas composition and methane production rate.

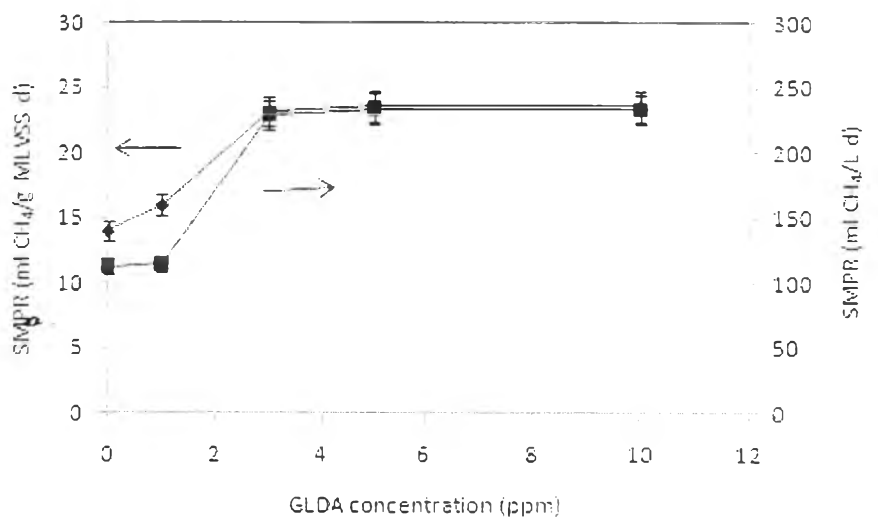

Figure 4.9 Effects of Added GLDA on SMPR (specific methane production rate).

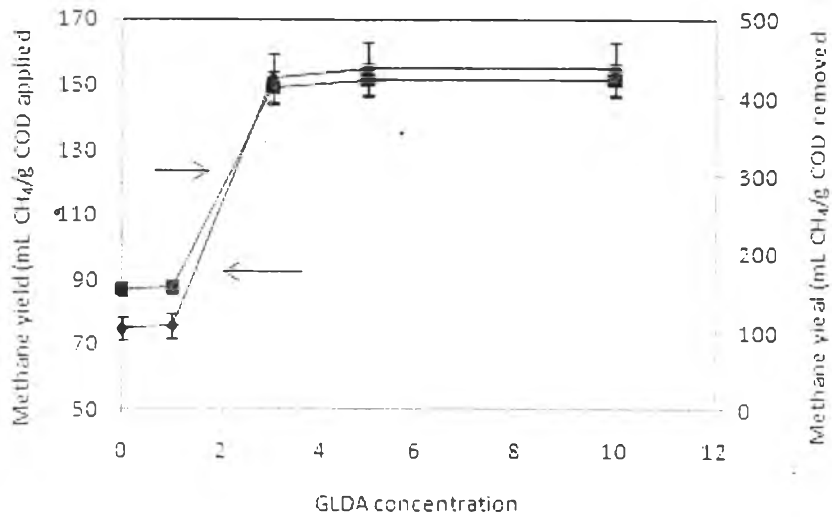

Figure 4.10 Effects of added GLDA on methane yield.

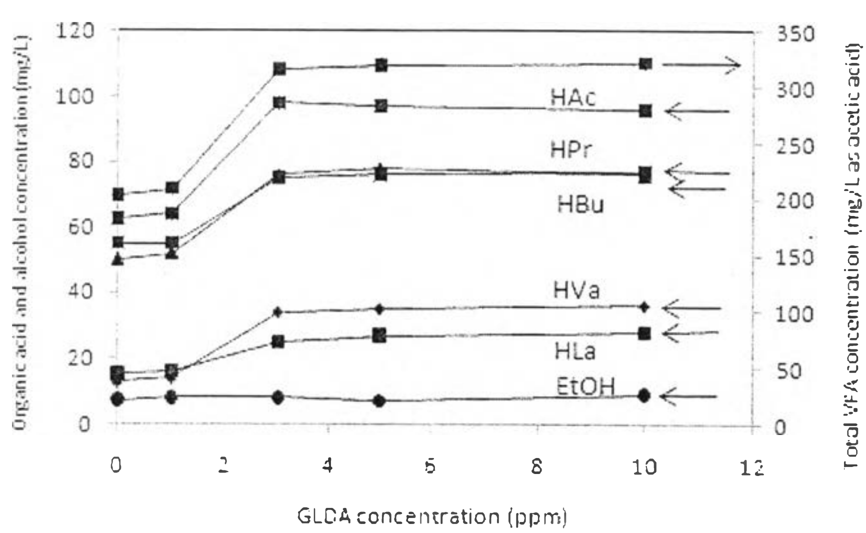

Figure 4.11 Effects of added GLDA on total VFA, organic acid, and alcohol concentration.

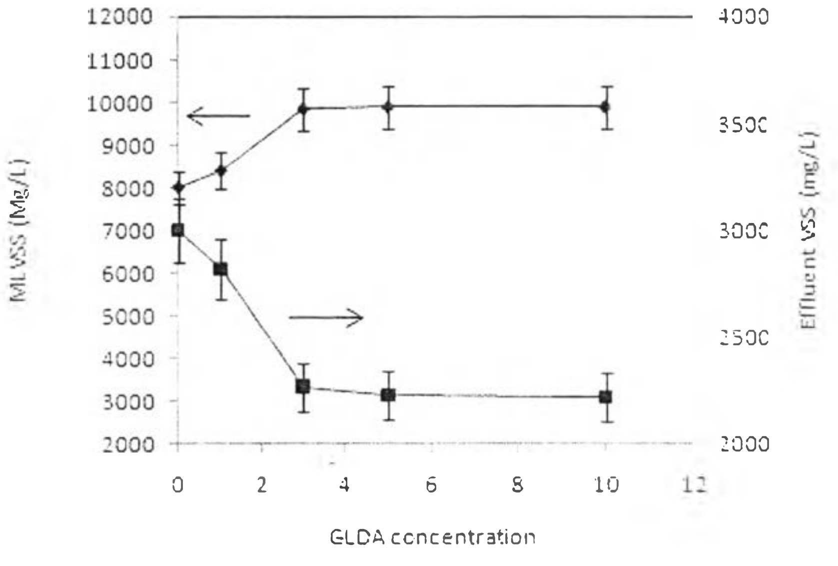

Figure 4.12 Effects of added GLDA on MLVSS and effluent VSS.

4.2.5 The Amount of Micronutrient Concentration

From table 4.3 showed the amount of micronutrient without added GLDA at steady state. All of micronutrients in which are necessary for the production of microbial enzymes were almost disappeared because the micronutrients were precipitated by sulfide in anaerobic digesters when compared with feed substrate. From added GLDA the micronutrients concentrations were returned to feed substrate with increasing GLDA concentration to 3 ppm. Moreover, the micronutrients concentrations were kept constant with increasing GLDA concentration to 5 and 10 ppm, respectively. This condition corresponds to the maximum COD removal (Figure 4.7) under the optimum GLDA concentration of 3 ppm. The results depend on the log stability constant of metal chelating compounds (K1) (Table 4.1) showed that the metal which were interested as the micronutrients. EDTA have K1. The calculation form (Eqs 4.1 - 4.2). Although, EDTA have more K1 than GLDA but it have higher solubility than EDTA. Therefore, only 3 ppm of GLDA could made all of micronutrients returned to feed substrate.

Table 4.3 The amount of micronutrient without added GLDA and added GLDA at different concentration

Element	Micronutrient Concentration (ppm)					
	Feed Cassava Waste Water	Steady State by Without Added Chelant	Added GLDA (ppm)			
			1 ppm	3 ppm	5 ppm	10 ppm
Co	0.012	0	0	0.012	0.012	0.012
Ni	0.037	0.01	0.01	0.03	0.032	0.032
Cu	0.08	0	0.01	0.07	0.07	0.07
Mo	0.168	0.148	0.15	0.165	0.166	0.166
Fe	1.483	0.48	0.48	1.45	1.46	1.46
Ca	1.364	1.36	1.36	1.36	1.36	1.36
Mn	0.174	0.164	0.166	0.173	0.173	0.174

4.3 Anaerobic Digestion of Cassava Wastewater with Added Ferric Chloride ($FeCl_3$)

Ferric ion is one of necessary micronutrient. The excess of $FeCl_3$ could reduced H_2S composition. The Contents of $FeCl_3$ concentrations were varied from 200 to 500 ppm and mixed with the cassava wastewater under the optimum COD loading rate of 1.710 kg/m^3 d. The effects of added $FeCl_3$ at different concentration on the anaerobic digestion were investigated.

4.3.1 COD Removal and Gas Production Rate

The COD removal (Figure 4.13) is increased from 51.9 to 63 % (Eq 3.3) by increasing the $FeCl_3$ concentration from 0 to 300 ppm. Moreover, the COD removal was also kept constant at 63 % when increased $FeCl_3$concentration to 400 and 500 ppm, respectively. The gas production rate shows the similar trend to the COD removal. The maximum COD removal is 63 % and the maximum gas production rate is 770 mL/d at the $FeCl_3$ concentration of 300 ppm. It may be explained that the increase in the $FeCl_3$ concentration results in the increasing to excess anions for combined with sulfide from anaerobic. Thus, the microorganisms could degrade increasingly the organic compound. The gas production rate shows the similar trend to the COD removal. That is the maximum gas production rate is 770 mL/d at the $FeCl_3$ concentrations of 300 ppm. In other words, the optimum $FeCl_3$ concentrations at 300 ppm results in the maximum COD removal and gas production rate.

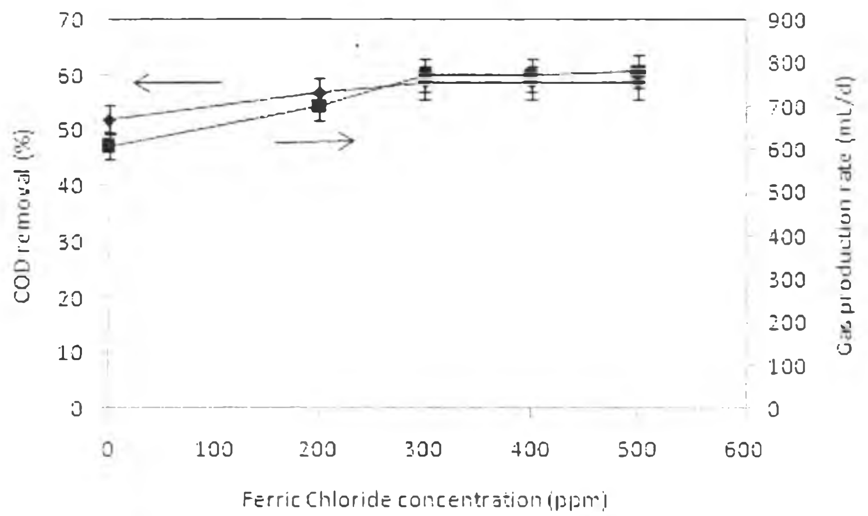

Figure 4.13 Effects of added ferric chloride on COD removal and gas production rate.

4.3.2 Gas Composition and Methane Production Rate

Both methane composition and methane production rate (Figure 4.14) are increased from 74.4 to 79 % and 452 to 602 mL/d, respectively, with the increase in the $FeCl_3$ concentration from 0 to 300 ppm. The maximum specific methane production rate is 151 mL CH_4/L d (Eq 3.6) (or 16 mL CH_4/g MLVSS d (Eq 3.7)) and the maximum methane yield is 270 mL CH_4/g COD removed (Eq 3.4) (or 100 mL CH_4/g COD applied (Eq 3.5)) (Figures 4.15 - 4.16). However, when the $FeCl_3$ concentration further increased from 300 to 400 and 500 ppm, respectively, methane production were also kept constant. The results indicated that the $FeCl_3$ concentration range of 300 to 500 ppm is suitable for methane production because of higher anions were sufficient for combine with sulfide ion. However, at the lowest

$FeCl_3$ concentration (200 ppm), the methane production was not increase due to the hydrogen sulfide anaerobic digester system. Because inadequate $FeCl_3$ concentration to combine hydrogen sulfide. In addition, under the optimum $FeCl_3$ concentration of 300 ppm, hydrogen sulfide gas composition is 0 %.

4.3.3 Amount of Volatile Fatty Acid

The total VFA concentration (mg/L as acetic acid) and composition are shown in Figure 4.17. The total VFA concentration increases with the increase in the $FeCl_3$ concentration and attains the maximum value of 246 mg/L as acetic acid at the highest $FeCl_3$ concentration of 300 ppm, while the methane production was increased (Figures 4.14- 4.15). At the $FeCl_3$ concentration of 300 ppm, the system provides the highest methane production in terms of the highest methane yield and SMPR; hence, this $FeCl_3$ 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 (Figure 4.18). Under the optimum $FeCl_3$ oncentration of 300 ppm, the total VFA concentration is 334 mg/L as acetic acid, and the concentration of acetic acid is highest (74 mg/L). These values indicate that both acidogenic and acetogenic bacteria work under the operating condition.

4.3.4 Microbial Concentration and Microbial Washout

Figure 4.18 shows the growth of microorganisms in the reactor (MLVSS) and the microorganism washout from the system (effluent VSS) (Eq 3.2). The MLVSS increases with the increasing in the concentration of $FeCl_3$ from 200 to 300 ppm and then were kept constant with further increased in the $FeCl_3$ concentration from 300 to 400 and 500 ppm, respectively. For the effluent VSS, the opposite trend to that of the MLVSS is observed. The maximum MLVSS (9193mg/L) and minimum effluent VSS (2,860 mg/L) are obtained at the $FeCl_3$ concentration. The results indicated that when the $FeCl_3$ concentration was increased from 200 to 300 ppm, the ability of the microorganisms to utilize the organic compounds increases. However, further increase in the $FeCl_3$ concentration from 300 to 400 and 500 ppm, respectivly results also trend to the 300 ppm of $FeCl_3$ concentration.

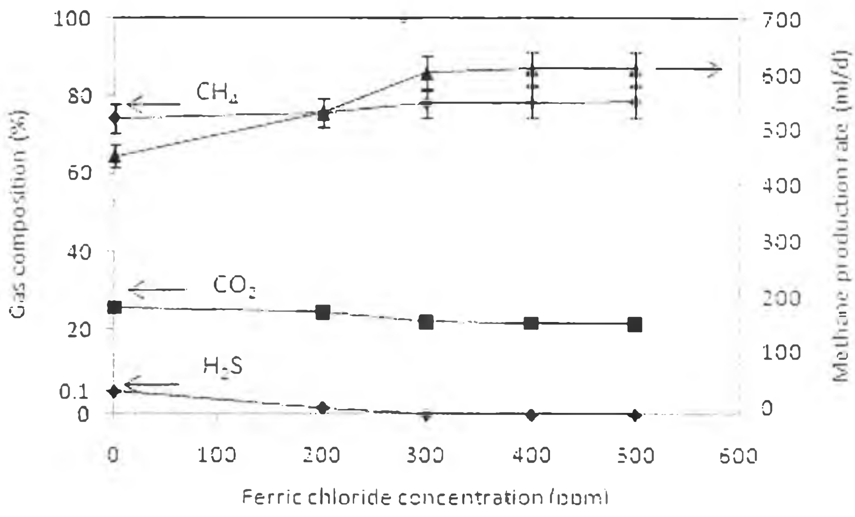

Figure 4.14 Effects of added ferric chloride on gas composition and methane production rate.

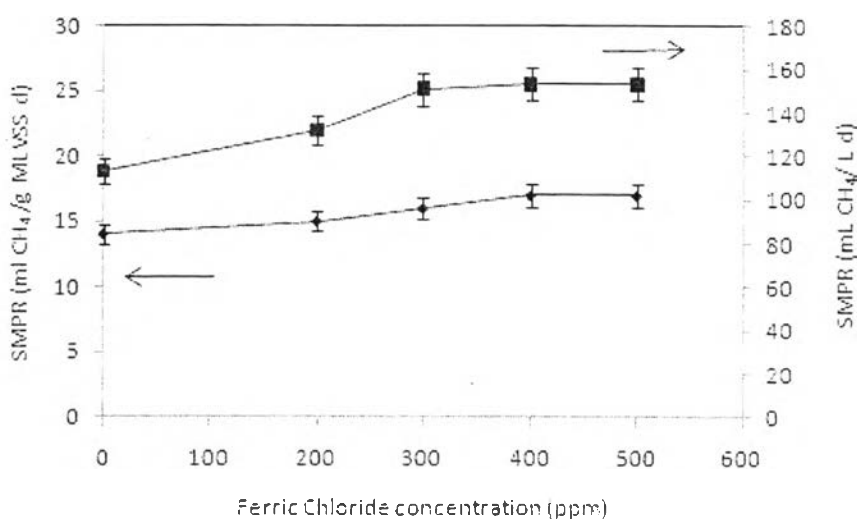

Figure 4.15 Effects of Added ferric chloride on SMPR (specific methane production rate).

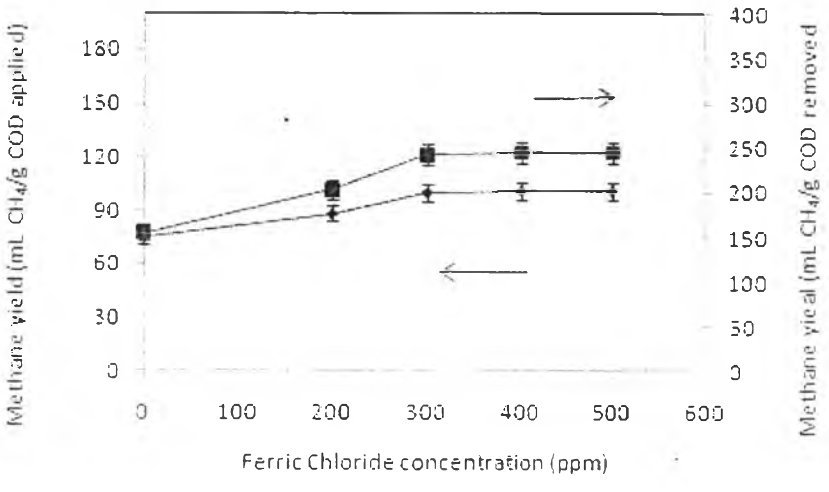

Figure 4.16 Effects of added ferric chloride on methane yield.

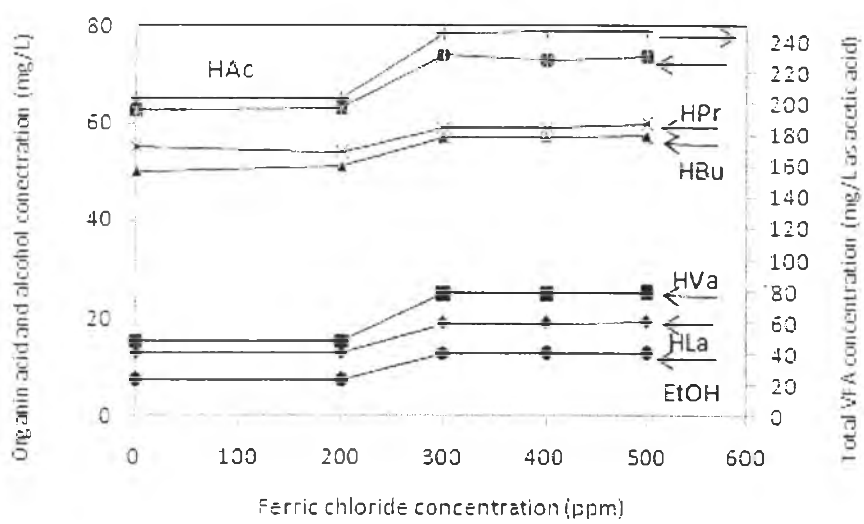

Figure 4.17 Effects of added ferric chloride on total VFA, organic acid, and alcohol concentration.

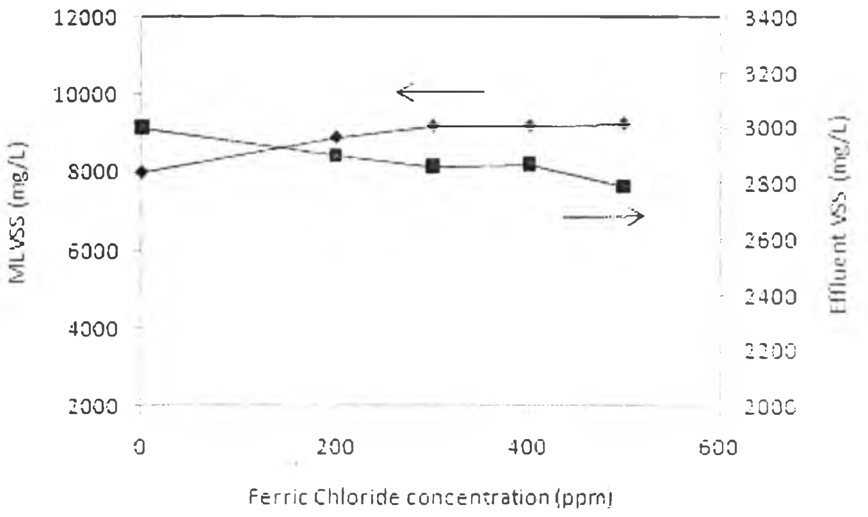

Figure 4.18 Effects of added ferric chloride on MLVSS and effluent VSS.

4.3.5 <u>The Amount of Micronutrient Concentration</u>

From Table 4.4 showed the amount of micronutrient with and without added $FeCl_3$. All micronutrients in which are necessary for the production of microbial enzymes were almost disappeared because the micronutrients were precipitated by sulfide in anaerobic digesters when compared with feed substrate. After added $FeCl_3$ showed the some micronutrients concentrations were returned to feed substrate with increasing $FeCl_3$ concentration to 300 ppm. Moreover, the micronutrients concentrations were kept constant with increasing $FeCl_3$ concentration to 400 and 500 ppm, respectively. This condition corresponds to the maximum COD removal (Figure 4.13) under the optimum Ferric chloride concentration of 300 ppm.

Table 4.4 The amount of micronutrient without added $FeCl_3$ and added $FeCl_3$ at different concentration

Element	Micronutrient Concentration (ppm)					
	Feed Cassava Waste Water	Steady State by Without Added Chelant	Added $FeCl_3$ (ppm)			
			200 ppm	300 ppm	400 ppm	500 ppm
Co	0.012	0	0	0	0	0
Ni	0.037	0.01	0.01	0.025	0.025	0.26
Cu	0.08	0	0	0.06	0.06	0.06
Mo	0.168	0.148	0.15	0.15	0.15	0.15
Fe	1.483	0.48	16.53	16.29	16.27	16.27
Ca	1.364	1.36	1.36	1.36	1.36	1.36
Mn	0.174	0.164	0.164	0.17	0.173	0.173

4.4 Anaerobic Digestion of Cassava Wastewater with Added Cobalt chloride ($CoCl_2$)

Cobalt ion is one of necessary micronutrient. The excess of $CoCl_2$ could reduce H_2S composition. The Contents of $CoCl_2$ concentrations were varied from 0.5 to 1 ppm and mixed with the cassava wastewater under the optimum COD loading rate of 1.710 kg/m^3 d. The effects of added $CoCl_2$ at different concentration on the anaerobic digestion were investigated.

4.4.1 COD Removal and Gas Production Rate

The COD removal (Figure 4.19) is increased from 51.9 to 61.4 % (Eq 3.3) by increasing the $CoCl_2$ concentration from 0 to 1 ppm. The gas production rate shows the similar trend to the COD removal. The maximum COD removal is

61.4 % and the maximum gas production rate is 800 mL/d at the $CoCl_2$ concentration of 1 ppm. It may be explained that the increase in the $CoCl_2$ concentration results in the increasing to excess anions for combined with sulfide from anaerobic. Thus, the microorganisms could degrade increasingly the organic compound. The gas production rate shows the similar trend to the COD removal. That is the maximum gas production rate is 800 mL/d at the $CoCl_2$ concentrations of 1 ppm. In other words, the optimum $CoCl_2$ concentrations at 1 ppm results in the maximum COD removal and gas production rate.

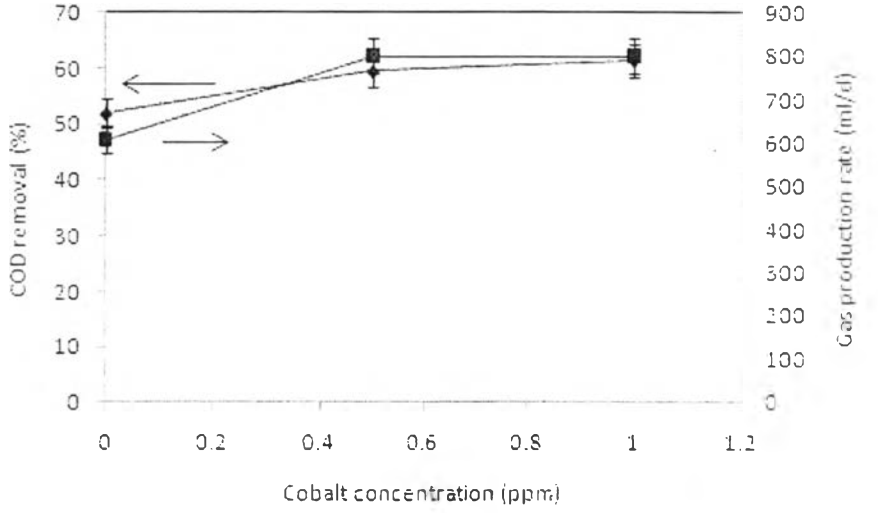

Figure 4.19 Effects of added cobalt chloride on COD removal and gas production rate.

4.4.2 Gas Composition and Methane Production Rate

Both methane composition and methane production rate (Figure 4.20) are increased from 74.4 to 82.6 % and 452 to 660.8 mL/d, respectively, with the increase in the $CoCl_2$ concentration from 0 to 1 ppm. The maximum specific methane production rate is 165.2 mL CH_4/L d (Eq 3.6) (or 17.7 mL CH_4/g MLVSS d (Eq 3.7)) and the maximum methane yield is 285 mL CH_4/g COD removed (Eq 3.4) (or 110 mL CH_4/g COD applied (Eq 3.5)) (Figures 4.21 - 4.22). The results indicated that the $CoCl_2$ concentration at 1 ppm is suitable for methane production because of higher anions were sufficient for combine with sulfide ion. However, at the lowest

$CoCl_2$ concentration (0.5 ppm), the methane production was not increase due to the hydrogen sulfide anaerobic digester system. Because inadequate $CoCl_2$ concentration to combine hydrogen sulfide. In addition, under the optimum $CoCl_2$ concentration of 1 ppm, hydrogen sulfide gas composition is 0 %.

4.4.3 Amount of Volatile Fatty Acid

The total VFA concentration (mg/L as acetic acid) and composition are shown in Figure 4.23. The total VFA concentration increases with the increase in the $CoCl_2$ concentration and attains the maximum value of 280 mg/L as acetic acid at the highest $CoCl_2$ concentration of 1 ppm, while the methane production was increased (Figures 4.21- 4.22). At the $CoCl_2$ concentration 1 ppm, the system provides the highest methane production in terms of the highest methane yield and SMPR; hence, this $CoCl_2$ 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 (Figure 4.19). Under the optimum $CoCl_2$ concentration of 1 ppm, the total VFA concentration is 320 mg/L as acetic acid, and the concentration of acetic acid is highest (80 mg/L). These values indicate that both acidogenic and acetogenic bacteria work under the operating condition.

4.4.4 Microbial Concentration and Microbial Washout

Figure 4.24 shows the growth of microorganisms in the reactor (MLVSS) and the microorganism washout from the system (effluent VSS) (Eq 3.2). The MLVSS increases with the increasing in the concentration of $CoCl_2$ from 0 to 1 ppm. For the effluent VSS, the opposite trend to that of the MLVSS is observed. The maximum MLVSS (9000mg/L) and minimum effluent VSS (2,798 mg/L) are obtained at the $CoCl_2$ concentration. The results indicated that when the $CoCl_2$ concentration was increased from 0 to 1 ppm, the ability of the microorganisms to utilize the organic compounds increases.

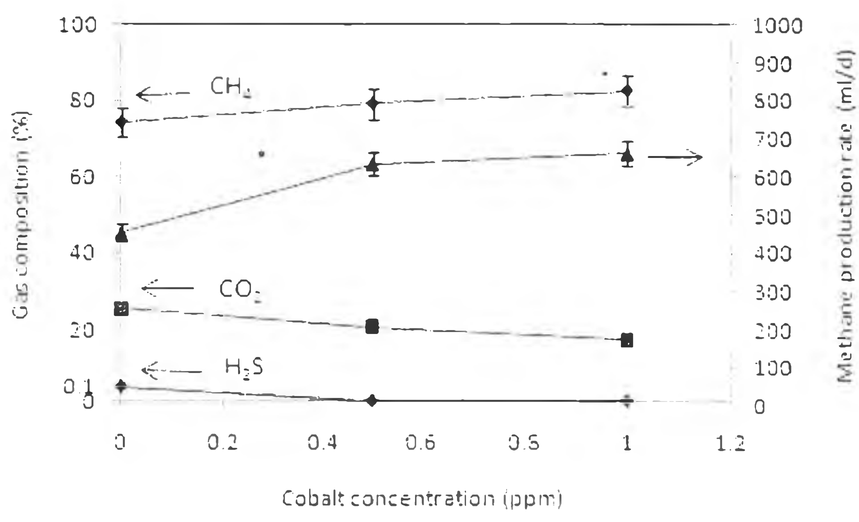

Figure 4.20 Effects of added cobalt chloride on gas composition and methane production rate.

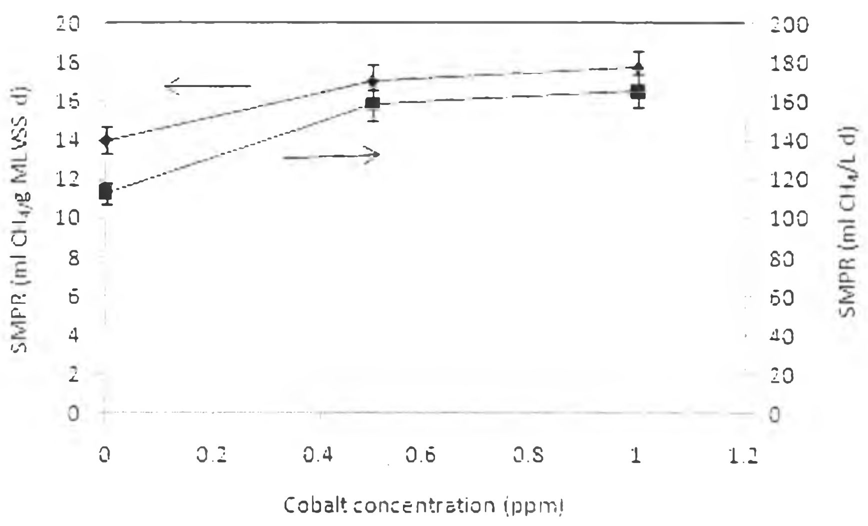

Figure 4.21 Effects of added cobalt chloride on SMPR (specific methane production rate).

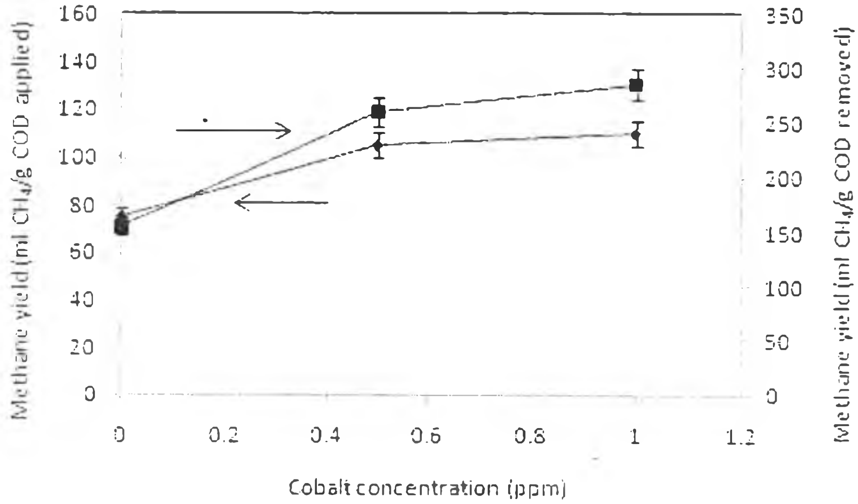

Figure 4.22 Effects of added cobalt chloride on methane yield.

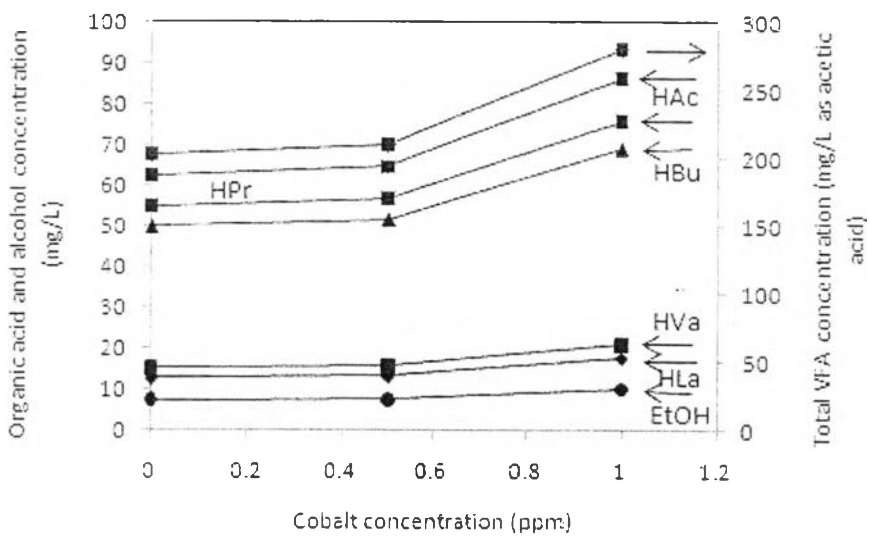

Figure 4.23 Effects of added cobalt chloride on total VFA, organic acid, and alcohol concentration.

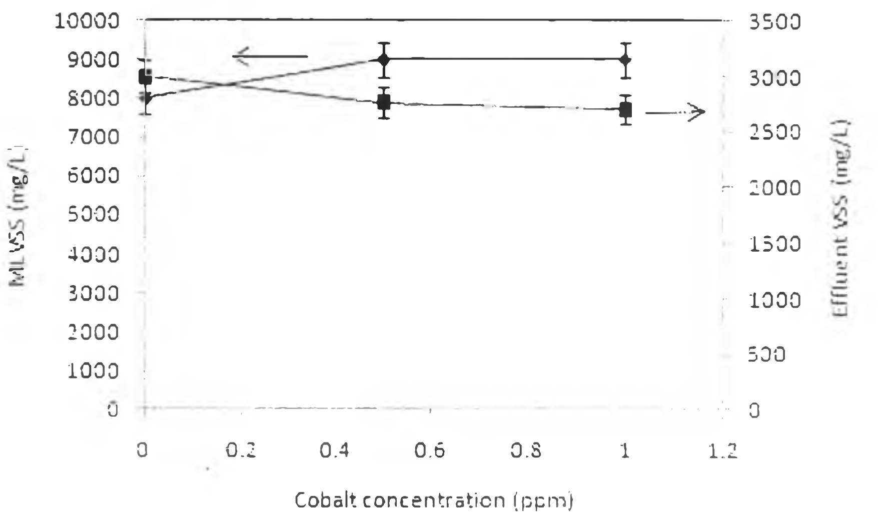

Figure 4.24 Effects of added cobalt chloride on MLVSS and effluent VSS.

4.4.5 The Amount of Micronutrient Concentration

From Table 4.5 showed the amount of micronutrient with and without added $CoCl_2$. All micronutrients in which are necessary for the production of microbial enzymes were almost disappeared because the micronutrients were precipitated by sulfide in anaerobic digesters when compared with feed substrate. After added $CoCl_2$ showed the some micronutrients concentrations were returned to feed substrate with increasing $CoCl_2$ concentration to 1 ppm. This condition corresponds to the maximum COD removal (Figure 4.19) under the optimum $CoCl_2$ concentration of 1 ppm.

Table 4.5 The amount of micronutrient without added $CoCl_2$ and added $CoCl_2$ at different concentration

Element	Micronutrient Concentration (ppm)			
	Feed Cassava Waste Water	Steady State by Without Added Chelant	Added $CoCl_2$ (ppm)	
			0.5 ppm	1 ppm
Co	0.012	0	0.024	0 .22
Ni	0.037	0.01	0.012	0.028
Cu	0.08	0	0.02	0.06
Mo	0.168	0.148	0.15	0.15
Fe	1.483	0.48	0.6	1.2
Ca	1.364	1.36	1.36	1.36
Mn	0.174	0.164	0.164	0.17