

CONTENTS

	Page
CONTENTS	IX
LIST OF TABLES	XIII
LIST OF FIGURES	XV
CHAPTER I Introduction	1
1.1 Rationale and background	1
1.2 Thesis objectives	4
1.3 Research scope	5
CHAPTER II Literature review	6
2.1 Substrates used	6
2.1.1 Skim latex serum	6
2.1.1.1 Compositions of non-rubber materials in the serum	6
2.1.1.1.1 Carbohydrates	6
2.1.1.1.2 Proteins	7
2.1.1.1.3 Lipids and phospholipids	7
2.1.2 Palm oil mill effluent	9
2.2 The biogas process	12
2.2.1 Hydrolysis	13
2.2.2 Acidogenesis	14
2.2.3 Acetogenesis	14
2.2.4 Methanogenesis	14
2.3 Two-stage anaerobic digestion process	15
2.4 Factors affecting the stability of the biogas production by dark fermentation	16
2.4.1 Substrate	16
2.4.2 Nutrients	16
2.4.3 Operating conditions	17

CONTENTS (Continued)

	Page
2.4.3.1 Temperature	17
2.4.3.2 pH and buffers	17
2.4.3.3 Organic loading rate	18
2.4.3.4 Hydraulic retention time	18
2.4.4 Toxic/inhibiting compounds	18
CHAPTER III Hydrogen and methane production by using batch two-stage co-digestion of skim latex serum (SLS) and palm oil mill effluent (POME): Optimization of mixing ratio and nutrients	21
3.1 Abstract	21
3.2 Introduction	22
3.3 Materials and methods	23
3.3.1 Anaerobic seed sludge	23
3.3.2 Skim latex serum	24
3.3.3 Palm oil mill effluent	24
3.3.4 Empty fruit bunch (EFB) ash	24
3.3.5 Optimization of SLS and POME mixing ratio in biohydrogen production	25
3.3.6 Effect of NaHCO ₃ , Na ₂ HPO ₄ .12H ₂ O and EFB ash concentrations on biohydrogen production	25
3.3.7 Methane potential from co-digestion of SLS with POME	27
3.3.8 Analytical methods	28
3.4 Results and discussion	28
3.4.1 Characteristics of substrates used	28
3.4.2 Optimization of SLS and POME mixing ratio in biohydrogen Production	29

CONTENTS (Continued)

	Page
3.4.3 Effect of NaHCO ₃ , Na ₂ HPO ₄ .12H ₂ O and EFB ash concentrations on biohydrogen production	33
3.4.4 Soluble metabolite products and COD balance	36
3.4.5 Methane potential of co-fermentation of SLS and POME	44
3.5 Conclusions	46
CHAPTER IV Thermophilic dark co-digestion of skim latex serum (SLS) and palm oil mill effluent (POME) to sequentially produce hydrogen and methane	47
4.1 Abstract	47
4.2 Introduction	48
4.3 Materials and methods	49
4.3.1 Inoculum preparation	49
4.3.2 Skim latex serum	50
4.3.3 Palm oil mill effluent	50
4.3.4 Experimental set-up and operation	51
4.3.5 Analytical methods	53
4.4 Results and discussion	53
4.4.1 H ₂ -CSTR experiments	53
4.4.2 CH ₄ -UASB experiments	58
4.4.3 Energy achieved from two-stage co-digestion of SLS with POME	61
4.5 Conclusions	62
CHAPTER V Conclusions	63
5.1 Summary	63
5.2 Suggestions	64
REFERENCES	65

CONTENTS (Continued)

	Page
APPENDICES	72
VITAE	83

*Prince of Songkla University
Pattani Campus*

LIST OF TABLES

	Page
Table 2.1 Physical and chemical characteristics of skim latex serum	8
Table 2.2 Physical and chemical characteristics of palm oil mill effluent	9
Table 2.3 Hydrogen and methane production from anaerobic digestion of POME under mesophilic and thermophilic conditions	10
Table 3.1 Physical and chemical characteristics of skim latex serum and palm oil mill effluent	29
Table 3.2 Experimental variables and concentration levels investigated by using central composite design	26
Table 3.3 Central composite experimental design matrix defining NaHCO_3 , $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$ and EFB ash concentrations on hydrogen production yield	27
Table 3.4 Analysis of variance (ANOVA) for the regression model	35
Table 3.5 Model coefficients estimated by multiples linear regression (significance of regression coefficients), where $X_1 = \text{NaHCO}_3$ concentration (g/L), $X_2 = \text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$ concentration (mg/L) and $X_3 = \text{EFB}$ ash concentration (g/L)	35
Table 3.6 pH and results on hydrogen production yield achieved from buffer and macro- nutrient optimization stage.	36
Table 3.7 Soluble metabolites obtained from different mixing ratio of SLS to POME with initial organic loading of 7 g- $\text{VS}_{\text{added}}/\text{L}$	39
Table 3.8 Soluble metabolites obtained from different mixing ratio of SLS to POME with initial organic loading of 21 g- $\text{VS}_{\text{added}}/\text{L}$	41
Table 3.9 Soluble metabolite products and COD balance obtained from different mixing ratio of SLS to POME with initial organic loading of 7 g- $\text{VS}_{\text{added}}/\text{L}$ at the end of fermentation	43
Table 3.10 Soluble metabolite products achieved from methane production in batch experiment	45

LIST OF TABLES (Continued)

	Page
Table 4.1 Physical and chemical characteristics of the skim latex serum and palm oil mill effluent used	51

*Prince of Songkla University
Pattani Campus*

LIST OF FIGURES

	Page
Figure 1.1 Schematic diagram of research plan for hydrogen and methane production from co-digestion of skim latex serum and palm oil mill effluent under thermophilic condition	5
Figure 2.1 Process involved in concentration of natural latex using centrifugation method	8
Figure 2.2 Process involved in milling of oil palm	12
Figure 2.3 Carbon flow diagram of the biogas process	13
Figure 2.4 Flow diagram of two-stage anaerobic process	15
Figure 3.1 Cumulative hydrogen achieved from different mixing ratio of SLS and POME with initial organic loading of 7 g-VS _{added} /L	32
Figure 3.2 Cumulative hydrogen achieved from different mixing ratio of SLS and POME with initial organic loading of 21 g-VS _{added} /L	32
Figure 3.3 Hydrogen production yield achieved from different mixing ratio of SLS and POME with initial organic loading of 7 g-VS _{added} /L and 21 g-VS _{added} /L, respectively	33
Figure 3.4 Soluble metabolites obtained from different mixing ratio of SLS to POME with initial organic loading of 7 g-VS _{added} /L	38
Figure 3.5 Soluble metabolites obtained from different mixing ratio of SLS to POME with initial organic loading of 21 g-VS _{added} /L	41
Figure 3.6 Cumulative methane production achieved from the sequential methane production in batch experiment	44
Figure 3.7 Methane production yield achieved from the sequential methane production in batch experiment	45
Figure 4.1 Schematic description of lab-scale bioreactor operation for sequential production of biohydrogen and biomethane which operated under thermophilic temperature	52

LIST OF FIGURES (Continued)

	Page
Figure 4.2 Variation of pH in H ₂ -CSTR reactor which was operated at different HRTs under thermophilic temperatures; [1] HRT of 2.25 days and OLR of 20 g-VS/L d, [2,4] HRT of 4.50 days and OLR of 10 g-VS/L d, and [3] HRT of 4.50 days and OLR of 5 g-VS/L d	56
Figure 4.3 Variation of hydrogen content in biogas at different HRTs achieved from H ₂ -CSTR reactor; [1] HRT of 2.25 days and OLR of 20 g-VS/L d, [2,4] HRT of 4.50 days and OLR of 10 g-VS/L d, and [3] HRT of 4.50 days and OLR of 5 g-VS/L d	56
Figure 4.4 H ₂ -CSTR reactor performance achieved from co-digestion of SLS to POME at different HRTs under thermophilic temperatures; [1] HRT of 2.25 days and OLR of 20 g-VS/L d, [2,4] HRT of 4.50 days and OLR of 10 g-VS/L d, and [3] HRT of 4.50 days and OLR of 5 g-VS/L d	57
Figure 4.5 Variation of soluble metabolite products achieved from H ₂ -CSTR reactor at different HRTs under thermophilic temperatures; [1] HRT of 2.25 days and OLR of 20 g-VS/L d, [2,4] HRT of 4.50 days and OLR of 10 g-VS/L d, and [3] HRT of 4.50 days and OLR of 5 g-VS/L d	57
Figure 4.6 Variation of methane and carbon dioxide content achieved from CH ₄ -UASB reactor at different HRTs under thermophilic temperatures; [1, 4] BA medium + sucrose 2 g/L, [2] (BA medium + sucrose 2 g/L) + effluent H ₂ at 1:1 (%v/v), [3, 5, 7] BA medium + Effluent H ₂ and [6] Effluent H ₂ + NaHCO ₃ 2 g/L	59
Figure 4.7 Variation of soluble metabolite products achieved from CH ₄ -UASB reactor at different HRTs under thermophilic temperatures; [1, 4] BA medium + sucrose 2 g/L, [2] (BA medium + sucrose 2 g/L) + effluent H ₂ at 1:1 (%v/v), [3, 5, 7] BA medium + Effluent H ₂ and [6] Effluent H ₂ + NaHCO ₃ 2 g/L	60

LIST OF FIGURES (Continued)

	Page
Figure 4.8 Variation of methane production rate and methane production yield achieved from CH ₄ -UASB reactor at different HRTs under thermophilic temperatures; [1, 4] BA medium + sucrose 2 g/L, [2] (BA medium + sucrose 2 g/L) + effluent H ₂ at 1:1 (%v/v), [3, 5, 7] BA medium + Effluent H ₂ and [6] Effluent H ₂ + NaHCO ₃ 2 g/L	60
Figure 4.9 Variation of pH in CH ₄ -UASB reactor which was operated at different HRTs under thermophilic temperatures; [1, 4] BA medium + sucrose 2 g/L, [2] (BA medium + sucrose 2 g/L) + effluent H ₂ at 1:1 (%v/v), [3, 5, 7] BA medium + Effluent H ₂ and [6] Effluent H ₂ + NaHCO ₃ 2 g/L	61

Prince of Songkla University
Pattani Campus