Faculty of Engineering

MATHEMATICAL MODELLING AND OPTIMIZATION OF HYDROGEN PRODUCTION FROM MICROBIAL ELECTROLYSIS CELL BY USING SAGO MILL EFFLUENT

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Final Year Project Report	√
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MATHEMATICAL MODELLING AND OPTIMIZATION OF HYDROGEN PRODUCTION FROM MICROBIAL ELECTROLYSIS CELL BY USING SAGO MILL EFFLUENT

SHATHISHKOMAR RAMESH

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering with Honours
(Chemical Engineering)

Faculty of Engineering

Universiti Malaysia Sarawak

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Dedicated to my parents and family who have always bestow me with sustainable motivations and encouragement

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ABSTRACT

The rapid population growth in Malaysia has been causing various environmental problems. The main problems caused is managing the waste that is produced by this large population. Industrial effluents are one of the main contributors to the total wastewater production in Malaysia. These effluents must be treated to meet the standards set by the Department of Environment before discharged to the rivers. Untreated effluents can cause health-related risks to the population near the area of discharge. Sago mill industry is one of the large wastewaters releasing industries in Malaysia. Sarawak being the largest producer of sago, have to manage the large wastewater release while being cost effective and cleaning the environment. Therefore, microbial electrolysis cell method was used to treat the sago mill effluent while producing hydrogen that can be used as a substitute for conventional fuel source. A mathematical model was developed to simulate the hydrogen production from microbial electrolysis cell using sago mill effluent as the substrate. The mathematical model was optimized to maximize the hydrogen production from the MEC.

Keywords: *microbial electrolysis cell, mathematical model, optimization, sago mill effluent*

ABSTRAK

Peningkatan penduduk yang pesat di Malaysia telah menyebabkan pelbagai masalah alam sekitar. Masalah utama yang timbul adalah pengurusan sisa yang dihasilkan oleh penduduk yang besar ini. Efluen industri adalah salah satu penyumbang utama kepada jumlah pengeluaran air sisa di Malaysia. Justeru, efluen perlu dirawat untuk memenuhi piawaian yang ditetapkan oleh Jabatan Alam Sekitar sebelum dilepaskan ke dalam sungai. Efluen yang tidak dirawat boleh menyebabkan risiko kesihatan kepada penduduk berhampiran kawasan pelepasan. Industri kilang sagu adalah salah satu daripada industry yang menghasilkan air sisa yang banyak di Malaysia. Sarawak sebagai pengeluar terbesar sagu, perlu menguruskan pelepasan air sisa yang besar pada masa yang sama kos efektif dan membersihkan alam sekitar. Oleh itu, kaedah sel elektrolisis mikrob telah digunakan untuk merawat efluen kilang sagu sambil menghasilkan hidrogen yang boleh digunakan sebagai pengganti untuk sumber bahan api konvensional. Model matematik telah dihasilkan untuk mensimulasikan pengeluaran hidrogen dari sel elektrolisis mikrob menggunakan kilang sagu efluen sebagai substrat. Model matematik telah dioptimumkan untuk memaksimumkan pengeluaran hidrogen dari MEC.

Kata Kunci: sel elektrolisis mikrob, model matematik, optimum, efluen kilang sagu

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ABBREVIATION

F	:	Faraday constant
R	:	Ideal gas constant
P	:	Cathode pressure
Y_{CH4}	:	Methane yield
$q_{max,e}$	:	Max reaction rate
$q_{max,m}$	:	Max reaction rate
$q_{max,f}$	:	Max reaction rate
$\mu_{max,e}$	:	Max growth rate
$\mu_{max, m}$	:	Max growth rate
$\mu_{max,f}$	:	Max growth rate
$\mu_{max,h}$	:	Max growth rate
$K_{a,e}$	:	Half-rate constant
$K_{A,m}$	:	Half-rate constant
$K_{S,f}$	:	Half-rate constant
K_M	:	Half-rate constant
m	:	Electrons transferred per mol of H_2
γ	:	Mediator molar mass
M_{total}	:	Mediator fraction
$K_{d,e}$	:	Decay rate
$K_{d,m}$	:	Decay rate

$K_{d,f}$	:	Decay rate
$K_{d,h}$	:	Decay rate
$X_{max,1}$	:	Max biofilm density
$X_{max,2}$	:	Max biofilm density
R_{MIN}	:	Min internal resistance
R_{Max}	:	Max internal resistance
K_R	:	A parameter in Eqn (29)
Y_M	:	yield
Y_{COD}	:	Yield
$Y_h X_{max,3}$	:	Yield and max biofilm density
E_{CEF}	:	Counter electromotive force
T	:	MEC anode temperature
β	:	Red-ox transfer coefficient
i_0	:	Exchange current density
$Y_{H2/CH4}$	:	Yield between H2 and CH4
Y_{H_2}	:	Cathode efficiency
$\bar{y}_{j,i}^{exp}$	:	experimental values of i-th state variable and j-th sampling time
$\bar{y}_{j,i}^{sim}$	:	simulated values of the i-th state variable and j-th sampling time
w_i	:	weight constant of i-th state variable
n_i	:	number of measurements of samples
m	:	number of measurable state variables
S	:	concentration of organic substrate (COD of sago mill effluent)
A	:	concentration of acetate
n	:	stoichiometric coefficient of the conversion

M_{ox}	:	oxidized forms of mediator fraction per electrogenic microorganisms
M_{red}	:	reduced forms of mediator fraction per electrogenic microorganisms
f, e, m, h	:	fermentative, electricigenic, acetoclastic methonogenic and hydrogenotrophic methanogenic organisms
1, 2, 3	:	Biolayer number
x	:	concentration
q	:	substrate consumption rate
K_d	:	microbial decay rate
D	:	dilution rate
Y_{COD}	:	acetate yield from an organic substrate
S_o and S	:	organic substrate concentration, influent and anodic compartment respectively
A_o and A	:	acetate concentration, influent and anodic compartment respectively
Q	:	production rate
Y_{H2}	:	dimensionless cathode efficiency
Y_h	:	yield rate for hydrogen consuming methanogenic microorganisms
m	:	number of electrons transferred per mole of hydrogen
R	:	ideal gas constant
V	:	anodic compartment volume
Y_M	:	oxidized mediator yield
γ	:	mediator molar mass
μ	:	growth rate

K	:	half-rate constant
Q	:	maximum substrate consumption rate
max	:	maximum
E_{CEF}	:	counter-electromotive force
η_{ohm}	:	ohmic overpotential
η_{conc}	:	concentration overpotential
η_{act}	:	activation overpotential
β	:	reduction or oxidation transfer coefficient
$A_{sur,A}$	:	surface area of the anode
R	:	resistance
K_R	:	curve steepness constant

NOMENCLATURE

%	:	Percent
°C	:	Degree Celsius
kg	:	Kilogram

CHAPTER 1

INTRODUCTION

1.1 Global wastewater production

The global population is rapidly increasing especially in city areas. 2.1 billion people are expected to move to cities in progressing countries by the year 2030, making the trend particularly intense in these areas (United Nations, 2012). These areas are prone to produce wastewater in the scale of billion tons every year, from municipal to wastewater from industries. **Figure 1.1** shows the consumption and wastewater production globally (ISoil, 2019). Municipal wastewater, industrial wastewater and sludge contain resources that can be recovered for beneficial uses such as water, organic matter, and energy (Drechsel et al, 2015). These recoveries can help in economic, social and environmental purposes. Proper wastewater treatment is crucial to maintain the environment and resources.

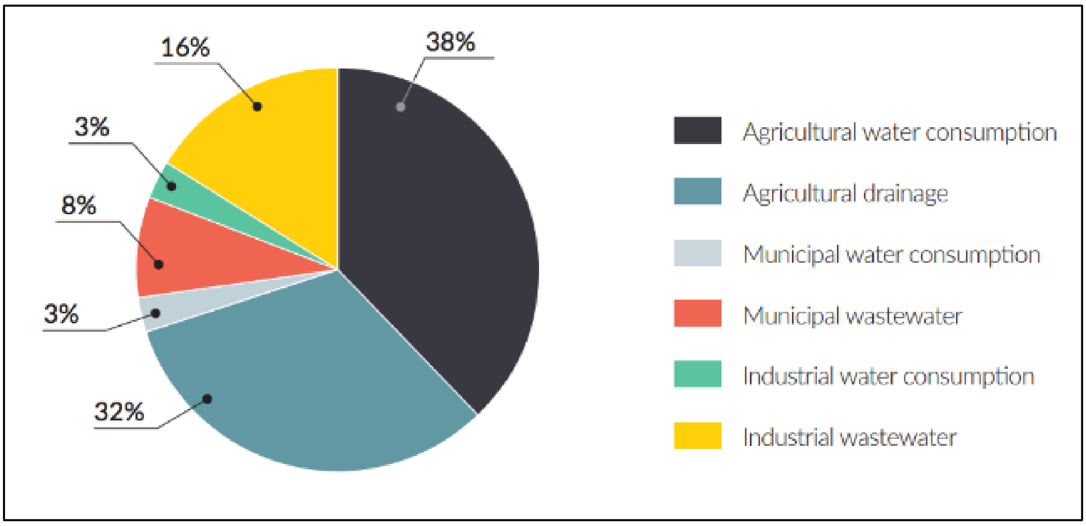

Figure 1.1: Global consumption and wastewater production (ISoil, 2019).

1.2 Biogas production from Industrial wastewater

Most industries produce a large amount of wastewater from their manufacturing processes or steps. It is also the major factors of pollution to aquatic ecosystem that could significantly endanger the floras and faunas and the surrounding environments in that ecosystem (Abbasi et al., 2016). Wastewaters, especially from the agro and food industries, can easily deplete the dissolved oxygen in the aquatic ecosystem due to the biodegradable substance found in the wastewater (Chan et al., 2009). Their large increase in volume is caused by the growing population and demand which is also expected to increase in the mere future. Treatment of wastewater before being released to the environment requires a big scale of energy to process and is unavoidable. The cost of the processing must be managed by the industries involved. The overall cost can be reduced if proper bioenergy harvesting technology is adapted. This is possible due to the organic materials that are present in industrial wastewater which is a good source for bioenergy production. Anaerobic technology which can organic pollutants into biogas such as methane should be used for bioenergy production from wastewater (Mohan, 2010). In general, this treatment method hydrolyzes complex biological matters which is then converted into volatile fatty acids and lastly converted into acetate and hydrogen which forms methane. Methane is a greenhouse gas that has a higher capacity than carbon dioxide to trap heat, thus increasing global warming (C. Li & Fang, 2007). Therefore, hydrogen gas is preferred compared to methane biogas production as it is a good source of energy and to reduce the implications to the environment.

1.3 Hydrogen production from Industrial wastewater

Conventional biogas production from industrial wastewater was aimed to produce methane. But due to its implications on global warming, hydrogen is produced as a new source of biofuel which is safer to the environment due to its natural occurrence. Besides, hydrogen is carbon-free and is fuel-rich in energy in which 142 kilojoule per kilogram is stored in it. It can also be easily transported for easier storage (Ferreira et al., 2018). Biohydrogen production has wider usability in various industries compared to methane which promotes higher demand.

Industrial wastewaters can be used as a source for biohydrogen production due to a large amount of organic compounds present in the wastewater especially from brewery and dairy industries because it contains high amounts of organic compounds like proteins, phosphates, ammonia and nitrate (Ferreira et al., 2018). Proper technique is needed to harvest biohydrogen to fulfill the requirement to treat the wastewater and effective harvesting. Figure 1.1 shows the possible pathways for biohydrogen production (Moreno-Andrade et al.,2015).

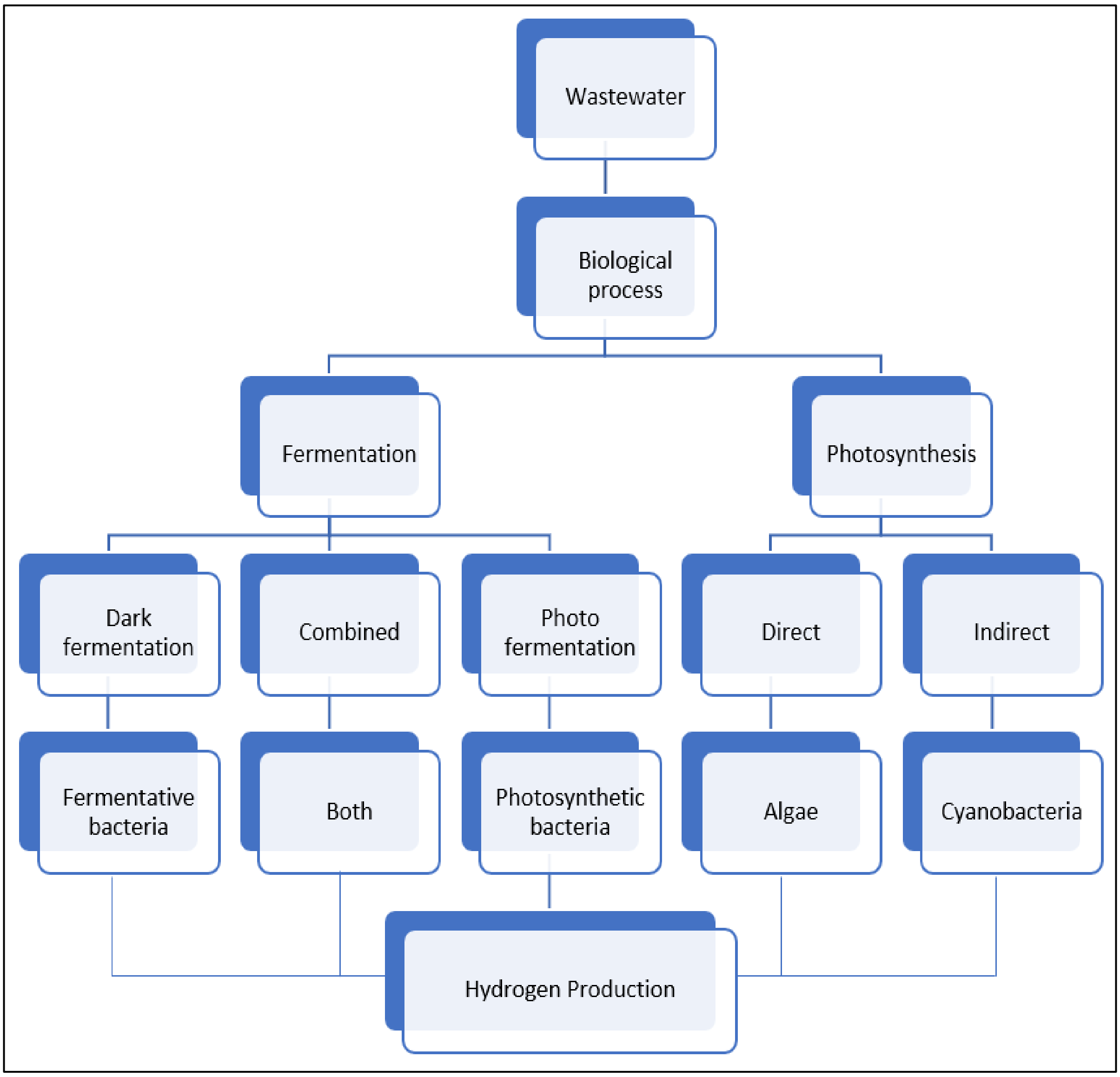

Figure 1.2: Possible pathways for biohydrogen production (Moreno-Andrade et al.,2015).

As a conclusion, various industrial wastewaters can be used as a substrate providing energy source for hydrogen biogas production, thus reducing treatment costs and facilitate newer energy production methods without impacting the environment. **Table 1.1** shows the industrial wastewaters and their properties that can be used to produce biohydrogen (Moreno-Andrade et al.,2015).

Table 1.1: Industrial wastewaters to produce biohydrogen (Moreno-Andrade et al.,2015).

Industrial Wastewater	pH	BOD (mg/L)	COD (mg/L)	Carbohydrate (mg/L)	Protein (mg/L)	Lipid (mg/L)
Brewery wastewater	4.6–7.3	775	1220	-	31.4 ± 0.04	17.9 ± 0.6
Chemical wastewater	4.2–7.7	3250-21,000	5100-33,400	-	-	-
Citric acid wastewater	5–6	15,000-21,000	8400-14,300	-	-	-
Diary processing wastewater	8.5–10.3	27,000-60,000	50,000-102,100	-	53 ± 0.1	18. 0 ± 0.9
Food processing wastewater	4.12–4.28	6860	11,220	-	-	-
Soybean protein processing wastewater	4.5–6.2	2250-8000	5000-16,300	-	14.31–42.4	-
Palm oil mill effluent (POME)	4–5	24,710	59,300	20.55	9.07	13.21

1.4 Sago Mill Effluent as a source for biohydrogen production

Sago is a starch that is derived from palm stems known as Metroxylon spp., Arenga spp., and Maurilia spp. The palm stems should at least be of age eight years old. These palm species are mainly found in South East Asia regions. The main production areas of sago starch are Sarawak and Papua New Guinea Metroxylon Sago is the most popular species in these areas. Sago production is done at household level by hand in which the palm trunks are cut and split to scoop out the pith which contains about 40% starch. The starch is released when the pith is kneaded with water, then the fiber is removed by sieving and later filtered and dried. In the commercial production of sago, a similar process to the household level is used but is done mechanically to knead the trunk, pith is washed and sieved and is dried using hot air. 90-180