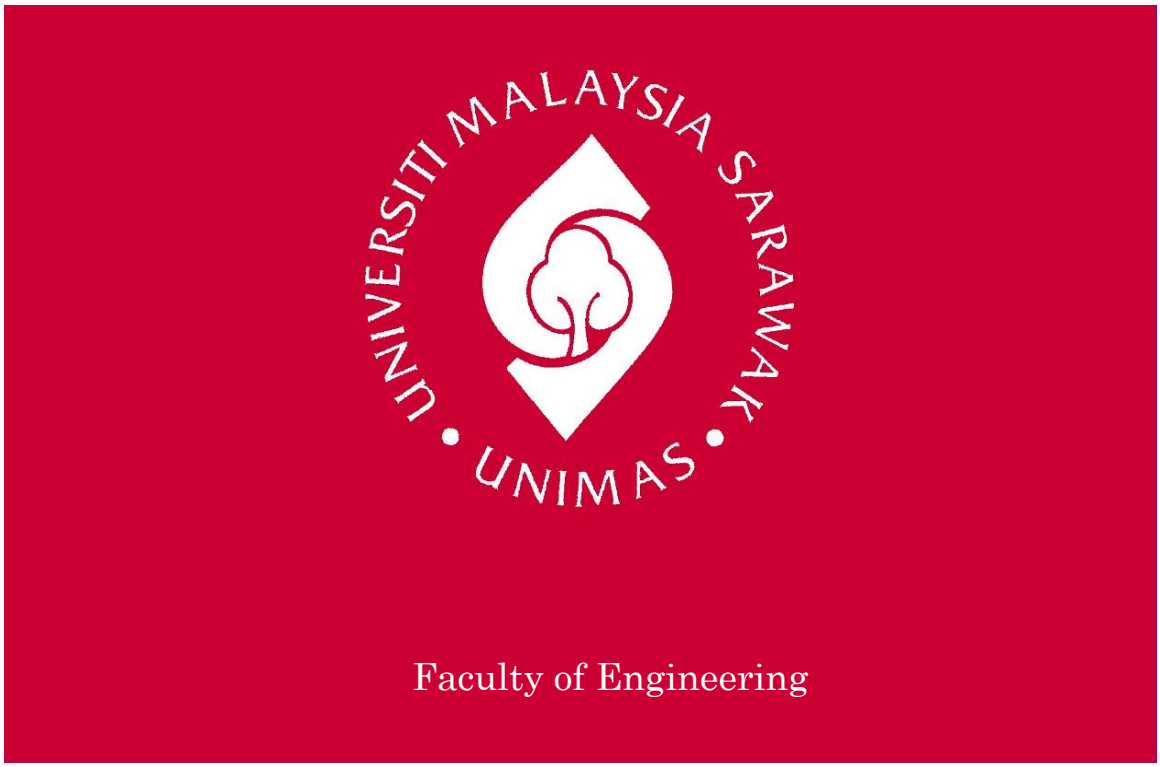

PRODUCTION OF BACTERIAL PIGMENT BY FERMENTATION OF *Serratia marcescens* FOR DYE SENSITIZED SOLAR CELL

CHONG LI YEE

Bachelor of Engineering with Honours
(Chemical Engineering)
2016/2017

UNIVERSITI MALAYSIA SARAWAK

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This declaration is made on the 26 day of May 2017.

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_____

Dr Nor Hasmaliana Abdul Manas
(Final Year Project Coordinator)

26 May 2017
Date

PRODUCTION OF BACTERIAL PIGMENT BY FERMENTATION OF *Serratia marcescens* FOR DYE SENSITIZED SOLAR CELL

CHONG LI YEE

A dissertation submitted in partial fulfillment

of the requirement for the degree of

Bachelor of Engineering with Honours

(Chemical Engineering and Energy Sustainability)

Faculty of Engineering
Universiti Malaysia Sarawak

2017

Dedicated to my beloved parents and my family who always bestow me sustainable motivations and encouragements

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ABSTRACT

A conventional ruthenium complex based dye sensitized solar cell (DSSC) is costly. The process of the ruthenium complex production and ruthenium complex based DSSC disposal are not environmental friendly. Organic pigment has been proposed as alternative photosensitizer for DSSC. Bacterial pigment has high potential due to the clean and cheaper microbial synthesis process. In this project, prodigiosin was aimed to be produced from the fermentation of *S. marcescens* in a bioreactor for the application of dye-sensitized solar cell. The optimum pH level for prodigiosin production identified through experiments was pH 7. By examining the impact of olive oil, peanut oil and palm oil towards fermentation of *S. marcescens*, the palm oil has the best performance in terms of cell growth yield and prodigiosin yield among other studied oil substrate. For 1g of palm oil substrate, 0.017g of biomass and 3.499mg of prodigiosin had been produced. This project had stand a novelty in study of impact of palm oil towards cultivation of *S. marcescens* and prodigiosin production. This study had also further proven that the production of prodigiosin is favourable in presence of oil substrate with high saturated fat content. The pink prodigiosin produced from cultivation of *S. marcescens* with presence of oil substrate had comparable performance with other bacterial pigment and is highly potential to be used in DSSC application. 336.1 mV and 0.098 mA had been generated by fabricated DSSC in this study.

ABSTRAK

Kos sel solar pewarna sensitive konvensional yang berdasarkan ruthenium kompleks tinggi. Proses penghasilan ruthenium kompleks serta perlupusan sel solar pewarna sensitive konvensional yang berdasarkan ruthenium kompleks dipercayai seringkali membahayakan alam sekitar. Pigmen oganik telah dicadangkan untuk menggantikan ruthenium kompleks. Pigmen hasilan bakteria berpotensi tinggi disebabkan proses penghasilannya yang murah lagi mesra alam. Tujuan projek ini adalah menghasilkan prodigiosin dengan fermentasi *S. marcescens* dalam bioreaktor.untuk kegunaan sel solar pewarna sensitive. Tahap pH yang paling sesuai untuk penghasilan prodigiosin adalah pH 7. Dengan mengkaji impak minyak zaitun, minyak kacang dan minyak sawit terhadap fermentasi *S. marcescens,* minyak kelapa sawit boleh dikatakan mempunyai keputusan yang terbaik dari segi pertumbuhan bakteria dan kadar hasil prodigiosin. .017g sel *S.* marcescens dan 3.499mg prodigiosin dapat dihasilkan dari 1 gram minyak sawit. Projek ini merupakan projek pertama yang mengkaji impak minyak kelapa sawit terhadap pertumbuhan bakteria dan kadar hasil prodigiosin.Projek ini juga membuktikan bahawa minyak yang mengandungi kandungan lemak tepu yang tinggi lebig sesuai kepada penghasilan prodigiosin. Prodigiosin berwarna merah jambu yang dihasil selepas penambahan minyak dalam fermentasi *S. marcescens* berpotensi tinggi untuk diaplikasi dalam sel solar pewarna sensitive. 336.1mV dan 0.098 mA telah dihasilkan dengan sel solar pewarna sensitive dalam projek ini.

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LIST OF ABBREVIATIONS

DSSC	-	Dye-sensitized solar cell
hr	-	Hour
LB	-	Lysogeny Broth
TiO_2	-	Titanium oxide

LIST OF SYMBOLS

C	-	concentration of dissolved oxygen, g/L
C*	-	oxygen solubility, g/L
ff	-	fill factor value
I_{max}	-	maximum current
I_{sc}	-	short circuit current
k	-	carrying capacity coefficient
k'$_d$	-	first order death rate constant, h^{-1}
$k_L a$	-	volumetric oxygen transfer coefficient
N	-	cell concentration at the end of stationary phase, g/L
P	-	concentration of prodigiosin, g/L
q_{o_2}	-	specific oxygen uptake rate, mmol O_2/g/L·h
t	-	Time, h
V_{max}	-	maximum voltage
V_{OC}	-	open circuit voltage
X	-	cell concentration at time t, g/L
$\bar{X}$		mean of cell concentration, g/L
X_m	-	maximum cell concentration, g/L
μ_{net}	-	nett specific growth rate, h^{-1}

CHAPTER 1

INTRODUCTION

1.1 Introduction

Solar cell is a device converting light energy into electrical energy. There are mainly three types of conventional solar cell which are monocrystalline silicon solar cell, polycrystalline silicon solar cell and thin film solar cell. Dye-sensitized solar cell is one type of thin film solar cell which uses photosensitized dye as light absorber rather than semiconductor such as silicon.

Back in 1960s, the electrochemical study of spectral sensitization has been carried out (Grätzel, 2003). However, the dye-sensitized solar cell technology has achieved a great improvement in year 1991. Before year 1991, less than 1% of incident light could be harvested by the smooth monolayer dye (Hagfeldt, Boschloo, Sun, Kloo, & Pettersson, 2010). According to study done, by depositing monolayer of trimetric ruthenium complex on mesoporous titanium dioxide electrode which contain large internal surface area, light harvesting has achieved 100% efficiency for the whole visible light region (O'Regan, Grätzel, & Fitzmaurice, 1991)

Metal complex especially the ruthenium complex has been widely applied as photosensitizer due to their photovoltaic properties and wide absorption spectra. However, the ruthenium complex has a limited adsorption near the infrared region. Besides that, the ruthenium complex is costly as compared to organic dye (Hagfeldt et al., 2010). Besides that, the ruthenium complex is highly toxic, mutagenic and carcinogenic (Yasbin, Matthews, & Clarke, 1980). Improper disposal of ruthenium complex content solar cell could result in environment issue. These drawbacks could be overcome by replacing it with organic dye.

Few studies have demonstrated the possibility of application of natural organic dye as a photosensitizer in dye-sensitized solar cell. The dye-sensitized solar cell with blackberries extracted anthocyanin dye has 1% of power conversion (Smestad, 1998). And the latest research recorded the highest efficiency at 1.7% which is by red turnip (Calogero et al., 2010) The latest studies have also considered the pigment extracted from bacteria to be the photosensitizer for the dye-sensitized cell. In 2016, a study found that the dye-sensitized solar cell using pigment extracted from Antarctic bacteria, lutein as photosensitizer produced 548.79mV (Ordenes-Aenishanslins et al., 2016).

These organic natural dyes stand advantages over the metal complex. Firstly, the metal complex based dyes are costlier (Narayan, 2012). Secondly, the organic dyes generally have a higher molar extinction coefficient (Hagfeldt et al., 2010). Lastly, the natural dyes are environmental friendlier (Hao, Wu, Huang, & Lin, 2006). According to Órdenes-Aenishanslins et. al (2016), production of pigments from bacteria is relatively a higher efficiency process due to its low cost of production and high yield of biomass production. The process of extraction is also relatively simpler as compared to extraction from plants. (Ordenes-Aenishanslins et al., 2016).

In this thesis, the pigment prodigiosin was produced through fermentation of *S. marcescens*. *S. marcescens* is widespread in the environment and easily available (Fender et al., 2012). The effect of medium pH and oil substrate towards the production of prodigiosin and cell growth was studied. The performance of bioreactor was compared with the flask cultivation to study the feasibility of upscaled production of prodigiosin for dye-sensitized solar cell application.

Up to date, there is no any specific study on upscaled production of bacteria pigment for dye-sensitized solar cell application although microbial biosynthesis process with a higher efficiency (Ordenes-Aenishanslins et al., 2016). A bench scale prodigiosin production from *S. marcescens* fermentation for dye-sensitized solar cell application could act as a pioneer in the field. The potential of mass production of bacteria pigment could be evaluated through the outcome of this study.

1.2 Problem Statement

The conventional ruthenium complex based dye-sensitized solar cell is costly and toxic. The inappropriate disposal of ruthenium complex based dye-sensitized solar cell could potentially lead to the environmental problem. Alternatively, organic natural dye

could replace the conventional ruthenium complex as it is a non-toxic and environmental friendly sensitizer.

Currently, most of the organic natural dyes for dye-sensitized solar cell are extracted from plants. The extraction of pigment from the plant is expensive and less efficient. Conversely, the microbial synthesis of pigment is relatively cost intensive process and highly effective. However, the study on the upscale production of bacteria pigment through fermentation has yet to be carried out.

1.3 Aim and Objectives

This study is aimed to produce prodigiosin from the fermentation of *S. marcescens* in a bioreactor for the application of dye-sensitized solar cell. The objectives are as listed below:

i. To study the effect of medium pH and oil substrate towards the production of prodigiosin from the fermentation of *S. marcescens*
ii. To upscale the fermentation of *S. marcescens* in a bioreactor
iii. To study the performance of prodigiosin-based dye-sensitized solar cell

1.4 Scopes

The scopes of this thesis are as listed:

i. Bench scale production of prodigiosin for application of dye-sensitized solar cell by fermentation of *S. marcescens* in the bioreactor.
ii. Identification of the optimum pH for maximum prodigiosin production
iii. Identification of the effect of oil substrate addition to the prodigiosin production
iv. Fabrication of prodigiosin-based dye-sensitized solar cell
v. Evaluation of the performance of the fabricated solar cell

1.5 Contribution

This study is suggesting prodigiosin as an alternative sensitizer to replace ruthenium complex for dye-sensitized solar cell as it could be viable with minimum associated environment and human health impact. The novelty of this work is to evaluate the impact of presence of palm oil substrate in prodigiosin production from fermentation of *S.*

marcescens. This study demonstrated and evaluated production of prodigiosin in a bioreactor for the application of dye-sensitized solar cell. The result of this project could be a reference for further study of the mass production of bacterial pigment for the application of dye-sensitized solar cell.

CHAPTER 2

LITERATURE REVIEW

2.1 Solar Cell

Solar cell technology has been discovered and further studied since 1839 when a French scientist Edmond Becquerel realized that the electricity generated from electrolytic cell increases when it was exposed to light (Zhu et al., 2011). In 1954, the first solar cell that capable in converting adequate solar energy into electrical energy has been discovered by Bell Lan (Zhu et al., 2011). The conventional solar cell is the first-generation silicon wafer-based solar cell (Hagfeldt et al., 2010). Although the technology is relatively matured, the production cost is relatively high (Green, 2001).

Due to the high production cost, a second generation solar cell which is a thin film based technology has been proposed (Hagfeldt et al., 2010). One of the examples of a second-generation solar cell is an amorphous silicon solar cell. The electricity generation cost for the second generation is as low as USD 0.02-004/kwh (Green, 2001). The performance of the solar cell can be quantified by the conversion efficiency which measuring the portion of solar energy being converted to electricity. The conversion efficiency of solar cell increased throughout the year. Currently, the world highest conversion efficiency of 26.33% was achieved by crystalline solar cell by Kaneka Corporation (Kaneka Corporation, 2016). Both first and second generation solar cell are silicon based and are a photovoltaic device (Archer, 2002).

Dye-sensitized solar cell is the third-generation solar cell. The dye-sensitized solar cell is a photo-electrochemistry device which is different from first and second generation solar cell. It is a ‘wet’ device rather than the traditional ‘dry’ photovoltaic devices (Archer, 2002). According to Archer (2002), the capability of the photo-electrochemistry device to produce energy without a nett chemical change in electrolyte has differentiated it from

two previous generation of the solar cell. The 'photo-functional interface' in dye-sensitized solar cell could improve the efficiency of solar energy conversion (Archer, 2002).

2.2 Dye-sensitized solar cell (DSSC)

Figure 2.1 shows a simplified schematic diagram of a dye-sensitized solar cell. The mesoporous oxide layer composed of nanoparticles is the essential part of a dye-sensitized solar cell (Grätzel, 2003). The most common used oxide is titanium oxide, TiO_2 due to its high efficiency and high internal surface to support monolayer of dye sensitizer (Hagfeldt et al., 2010). When the light is absorbed by dye sensitizer, its electron is energized. The gained energy electron will be promoted to higher energy level. The photoexcitation of dye sensitizer will lead to the injection of an electron into the conduction band of the oxide. Then, the dye sensitizer will receive an electron from redox electrolyte to restore its original state. The most common electrolyte is iodide (Grätzel, 2003). As shown in **Figure 2.1**, the iodide will be oxidized into triiodide. The triiodide will be then reduced into iodide once the external circuit is completed via migration of electron from the anode to cathode.

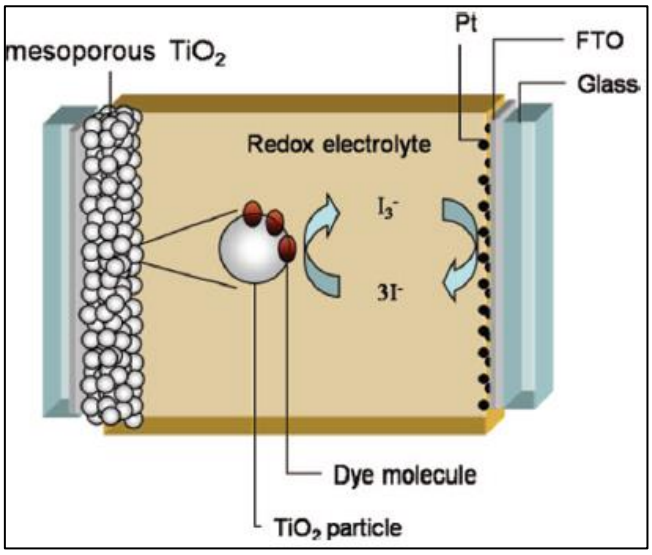

Figure 2.1 Simplified Schematic diagram of dye-sensitized solar cell (DSSC) (Hagfeldt et al., 2010)

The dye sensitizer is as crucial as the metal oxide electrode. The performance of a dye-sensitized solar cell is relying on the dye sensitizer very much. Among all the currently available dye sensitizer, ruthenium complex has shown the best efficiency. The first ruthenium complex based DSSC has been experimented in 1990. The result is very satisfying which has achieved as high as 7.9% of solar conversion (Mohammad K Nazeeruddin, Liska, Moser, Vlachopoulos, & Gratzel, 1990). The conventional dye, N3 has portrayed a broad visible light absorption spectrum and is one of the first sensitizers that has attained solar-to-electric energy conversion efficiency of 10% (M K Nazeeruddin et al., 1993). In the year of 1997, a ruthenium complex dye sensitizer named black dye has set a benchmark of solar-to-electric energy conversion efficiency at 10.7% (Md K. Nazeeruddin, Péchy, & Grätzel, 1997).

However, the ruthenium complex dye sensitizer is not perfect. The metal is rare and the metal complex possesses high toxicity (Narayan, 2012; Ordenes-Aenishanslins et al., 2016). The synthetic organic dye sensitizer does sound promising. However, the fabrication process of these dye sensitizers is expensive yet non-ecological (Ordenes-Aenishanslins et al., 2016). Natural dye could be a feasible alternative due to the abundant of raw material and cause no environment threat (Narayan, 2012).

2.3 Natural Dye

The currently available natural dye is mostly planted pigment which is extracted from flowers, leaves, fruits or traditional Chinese medicines. The betalain pigments from red turnip root have set a benchmark of solar to electric energy conversion efficiency for natural dye at 1.7% solar conversion with remarkable open circuit voltage and short circuit current density 0.43V and 9.5mA cm^{-2} respectively (Calogero et al., 2010). The dye-sensitized solar cell based on natural pomegranate juice has achieved second highest efficiency at 1.5% with open circuit voltage and short circuit current density 0.2V and 0.4mA cm^{-2} respectively (Hossein Bazargan, 2009)

In recent researches, the potential of bacterial pigment as dye sensitizer for the dye-sensitized solar cell has been studied. In 2015, Yonas *et al.* (2015) have successfully generated electricity using the bacterial pigments based dye-sensitized solar cell. According to Órdenes-Aenishanslins and co-workers (2016), the red carotenoid pigments from artistic bacteria, *Hymenobacter* sp was able to achieve 0.03% efficiency with open