Enhanced photosynthetic growth, biodiesel and electricity production using *C. vulgaris* and *P. pudita* /*S. cerevisiae*

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Outline

- Introduction
- Objectives
- Materials and Methods
  - Cultures
  - Growth Kinetics and Biodiesel Production
    - → ELAPB Set Up
    - →Algae Cultivation
    - →Biodiesel Extraction
  - Electricity Generation
    - →MFC Construction
    - →Resistance Loading Effects and Modeling
- Results and Discussion
  - Growth Kinetics of *C. vulgaris* and Oil Yield
  - Effects of Resistance on Voltage in *C. vulgaris* – *P. pudita* MFC
  - Effects of Resistance on Voltage in *C. vulgaris* – *S. cerevisiae* MFC
- Conclusions & Recommendations
- Acknowledgements

Introduction

- Decreasing supplies & increasing costs of existing energy sources – need alternative energy sources

- Canada: the 7th largest greenhouse gas emitter (per capita basis), by emitting about 747 megatonnes (79% CO_2) annually (Environment Canada, 2008)

- Reduction of emissions by sequestration & production of alternative biofuels are desirable

- Microbial Fuel Cell (MFC) generates electrical current

Introduction

Why Microalgae?

- ❖A potential alternative energy source
- ❖Photosynthesize CO_2
- ❖ Up to half their mass is made up of natural oils
- ❖ Algal 'crude', or refined to higher-grade hydrocarbon products, ranging from biodiesel to bio-jet fuel for aircraft
- ❖ Grow anywhere with less nutrients
- ❖ Algae yield 100 tonnes/ha and 2.2 tonnes CO_2 needed/1 tonnes algae (from coal-fired power stations)

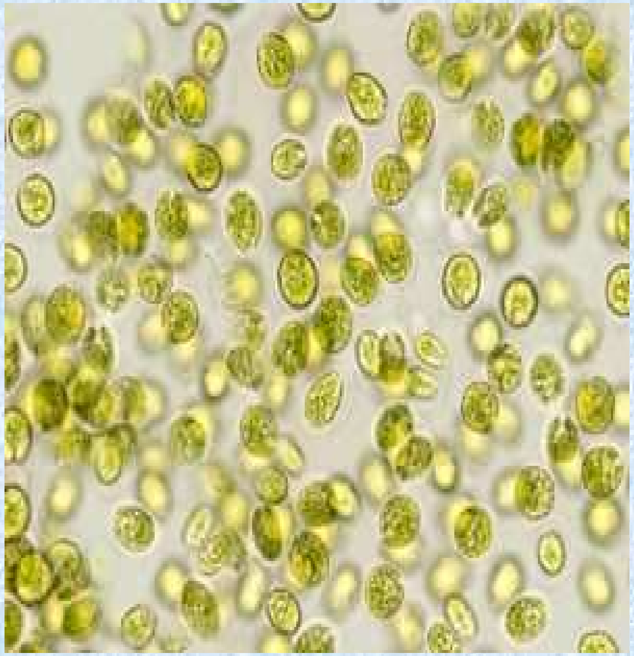
Introduction

Why *Chlorella vulgaris* ?

A great potential biodiesel source due to:
—high oil production capacity per unit cultivation area
— fast growth rate and low-cost culture conditions
—Tolerance for 0.03 to 40% CO_2
—High photosynthetic efficiency

AND

The same micro-algal cultures - used as a promising source for production of electrical energy in a MFC



Photomicrograph : *Chlorella vulgaris*

Introduction

The growth rate of *C. vulgaris* and its oil content depend on environmental factors such as

– light intensity

– growth media

– CO_2 supplied

AND

The economic feasibility of *C. vulgaris* culture for biodiesel production greatly depends on high biomass productivity and appreciable oil yields

SO

Optimization of these factors is needed to maximize biodiesel production and to increase its production rate

AND

The biodiesel content in *C. vulgaris* can be increased by controlling growth conditions in an ELAPB

Introduction

Microbial Fuel Cell (MFC)

- A microbial fuel cell is a system that recovers electrons produced during microbial metabolism and channels them to generate electrical current
- A wide variety of MFC designs and microbial species have been studied for generation of electrical flow
- A lot of fundamental work needs to be achieved in order to develop a ready-to-use technology for commercial applications.

Objectives

- To investigate the photosynthetic growth kinetics of *C. vulgaris* in a novel circulating loop photobioreactor

- To maximize biodiesel yield

- To produce electricity by developing a *C. vulgaris-P. pudita*/ *C. vulgaris-S. cerevisiae* MFC.

Materials and Methods

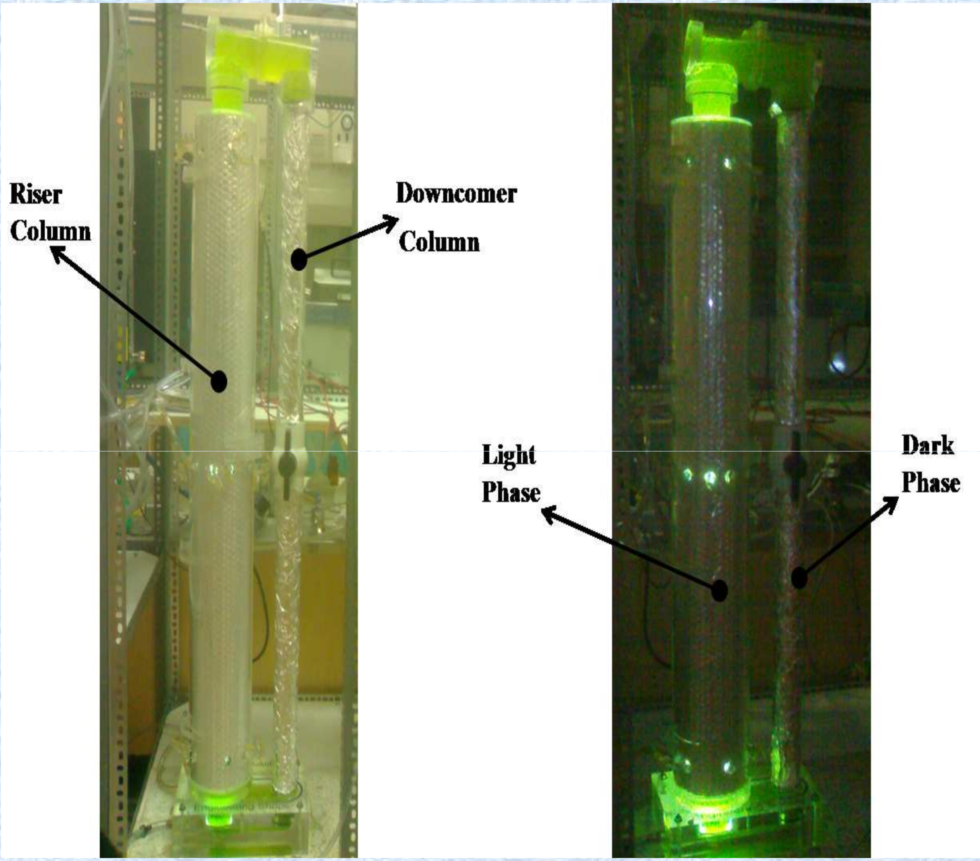
Cultures

Chlorella vulgaris

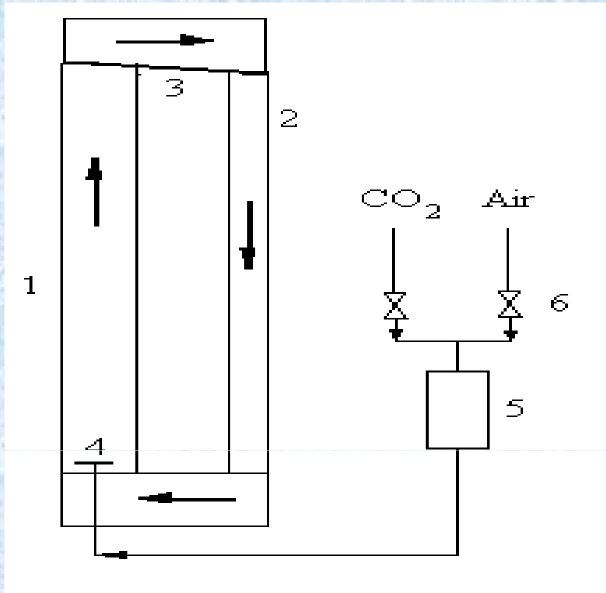
Saccharomyces cerevisiae

Pseudomonas putida

Materials and Methods



A Novel External Loop Airlift Photobioreactor (ELAPB)



Schematic of ELAPB (Sasi, D., 2009). Riser (1), Downcomer (2), Gas disengagement zone (3), Gas sparger (4), Flow meter (5)

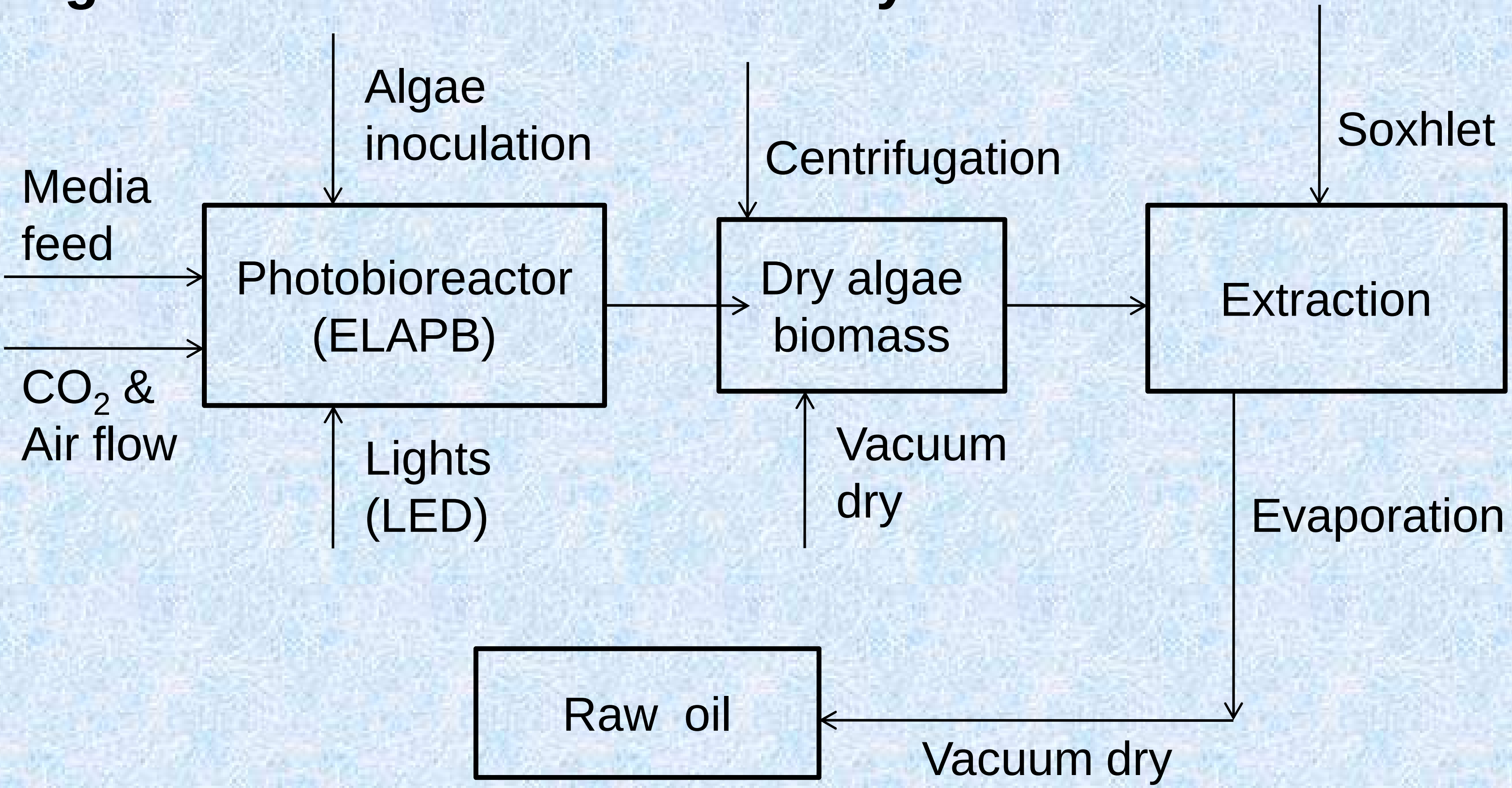
Materials and Methods

Specification of ELAPB

Total bioreactor loop length	3.058 m
Total circulation time	26.5 s
Average circulation velocity	0.12 m/s
Inner diameter of riser	50.8 mm
Inner diameter of downcomer	38.1 mm
Working volume	4.5 L
Number of orifices in sparger	12
Material	Acrylic

Materials and Methods

Algae cultivation and biodiesel yield



Materials and Methods

Soxhlet Extraction: Experimental Set Up

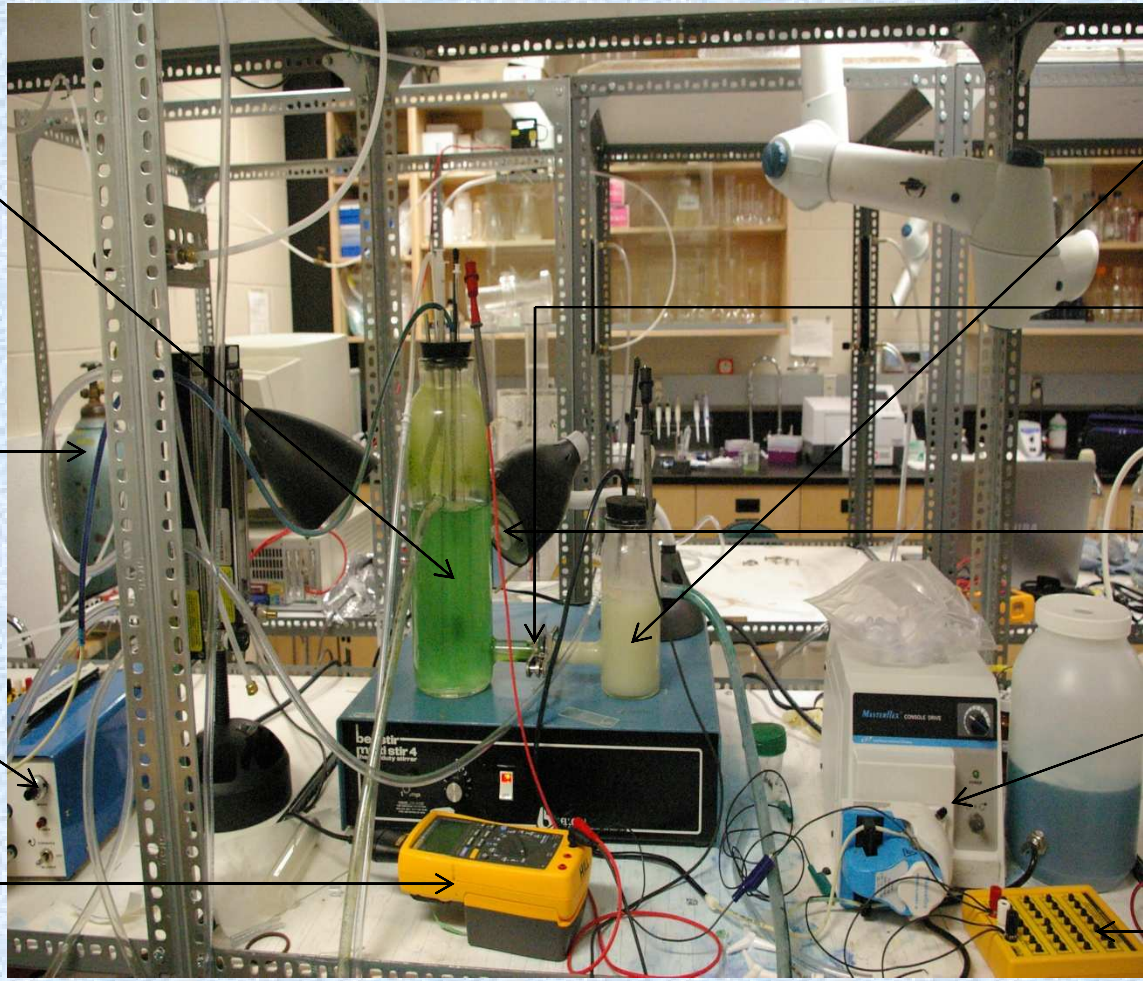
Materials and Methods

Biomass and Growth Rate Determination

Optical Density (OD): OD of biomass determined on a spectrophotometer (Shimadzu Corporation, Japan) at a wavelength of 620 nm.

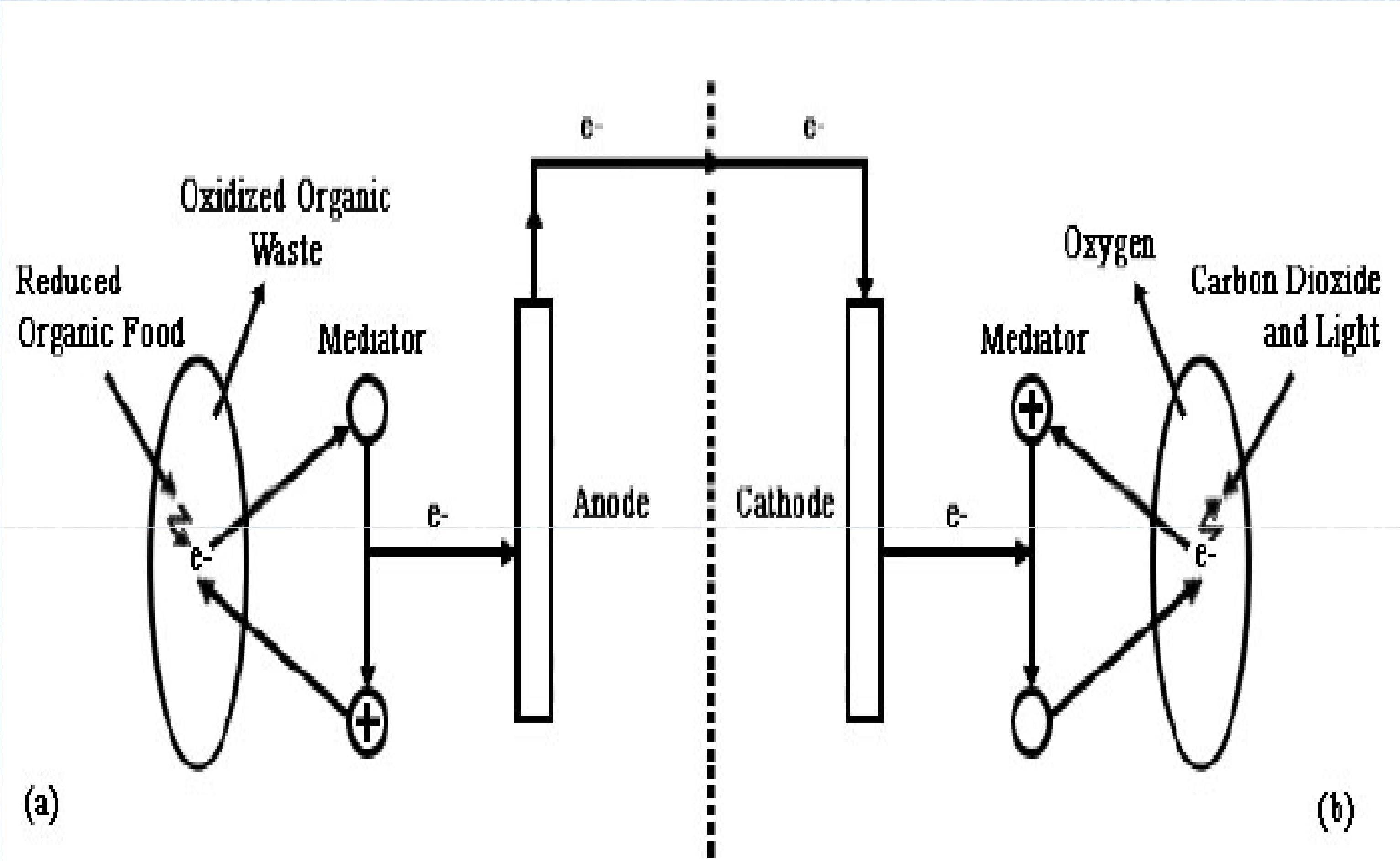
Cell concentration (dry weight, mg/L) = OD* Conversion factor of Shimadzu spectrophotometer

Materials and Methods



MFC : Original Laboratory Set Up

Materials and Methods



Schematic of electron flow in the completely biological MFC: (a) anodic release of electrons by consuming organic compounds, (b) cathodic capture of electrons by photosynthetic growth on CO_2 (Powell et al., 2009).

Material and Methods

Specifications of the Complete MFC

Specifications	Cathode	Bridging	Anode
Working volume of the vessel	1.5 L	Cathode and anode were linked by a NAFION 112 membrane for proton exchange	350 mL
Culture	*C. vulgaris*		*P. pudita*/*S. cerevisiae*
Media	Bold’s		1 dose McKinney’s/yeast media
Air flow	190 mL/min		25 mL/min
CO_2 flow	10 mL/min		-
Mediator (methylene blue)	5 mg/L		10mg/L
Lights	2 GE 26 W helical fluorescent bulbs		-
Media feeding rate	15 mL/h		35 mL/h
Electrode	Carbon rod		Carbon rod

Materials and Methods

Modeling

Applied loading resistances: 10000, 8000, 5000, 2000, 1000 & 250 Ω

First order empirical equation represents dynamic response:

$$\mathbf{V_{model} = V_{final} - (V_{final} - V_{initial}) \times e^{-kt}}$$

Where,

$V_{initial}$ = voltage (mV) recorded for the starting point of loading or unloading

V_{final} = voltage (mV) recorded for the end point of loading and unloading

k = rate constant (min^{-1})

t = elapsed time (min)

Results and Discussion

Growth Kinetics of *C. vulgaris* and Biodiesel Yield

Input variables (growth factors)

- ❖Media
- ❖Lights
- ❖Carbon dioxide
- ❖Dark phase duration

Output

- ➢ Growth rate (h^{-1}) of *C. vulgaris*
- ➢ Biodiesel yield

Results and Discussion (on ELAPB)

The Growth kinetics of *Chlorella vulgaris* in ELAPB

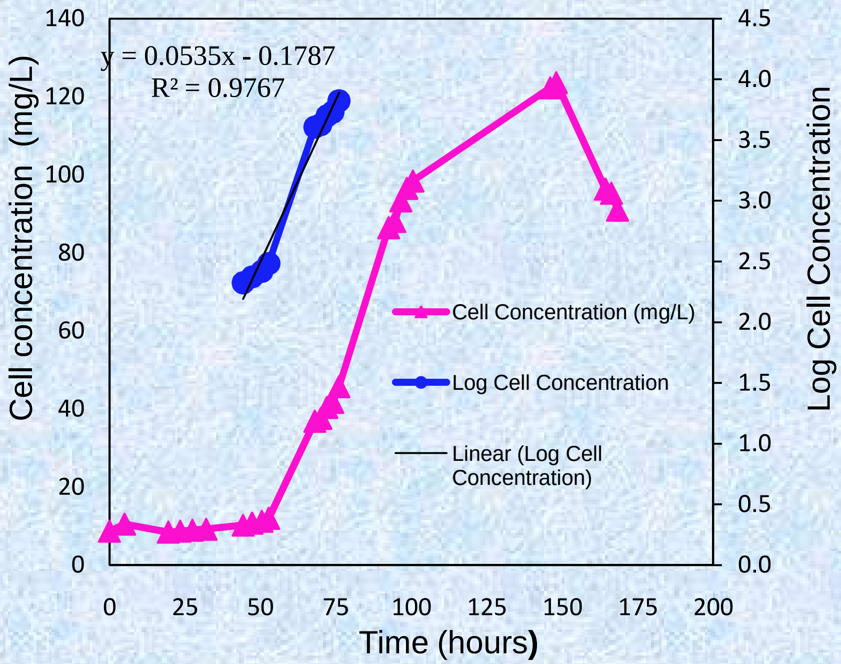


Fig. 1 Growth kinetics of C. *vulgaris* at highest growth rate.

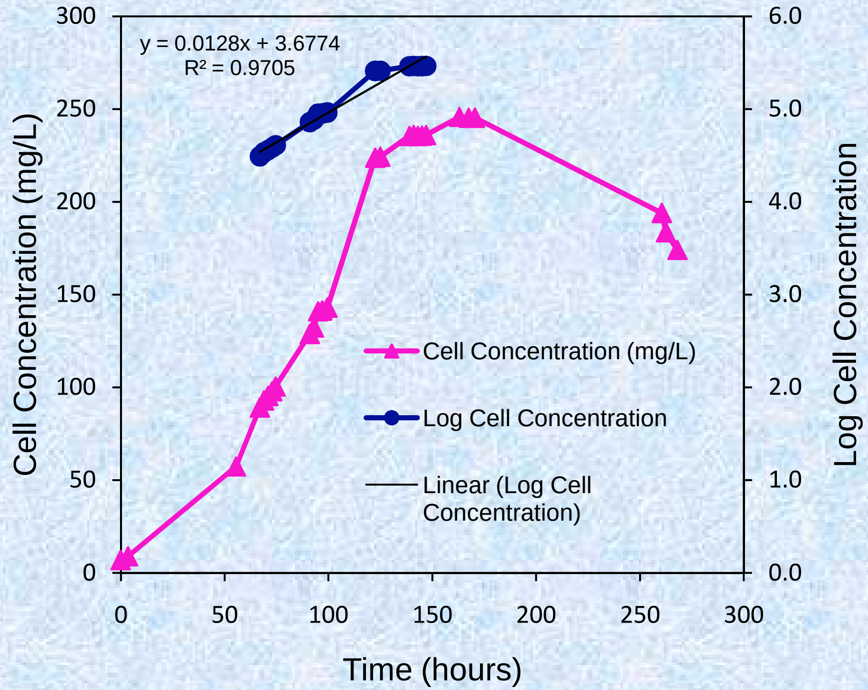


Fig. 2 Growth kinetics of C. *vulgaris* at lowest growth rate

Results and Discussion (on ELAPB)

Table 1 Experimental conditions, growth rates and oil yields

Run No.	CO_2 conc. (%)	Lights around Riser	Lights around Downcomer	Dark phase (hr.)	Media	Growth rate (hr^{-1})	Oil yield (%)
1	5	6	-	8	Bold's	0.04	12
2	5	6	-	8	$NaNO_3$	0.05	4.5
3	5	6	-	8	2ppm $FeCl_3$	0.04	4.5
4	10	16	10	-	Bold's	0.01	33
5	10	16	10	8	Bold's	0.03	26
6	10	16	5	-	Bold's	0.04	18

Results and discussion (on Algae-Bacteria MFC)

Electricity Generation in an Algae-Bacteria MFC

Input

Resistances :
10000, 8000, 5000, 2000, 1000 and 250 Ω

Output

- ❖ Resistance effect on voltage
- ❖ Response time and voltage history of the model

Results and Discussion (on Algae-Bacteria MFC)

Loading and Unloading Effect on the Circuit

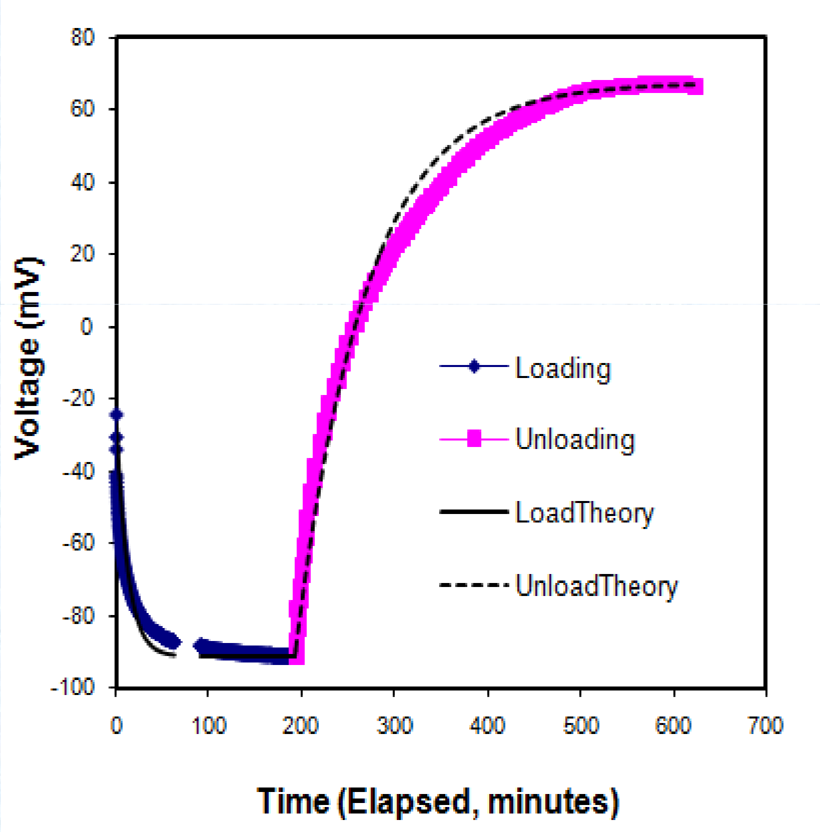


Fig. 3 Effect of resistance (10000 Ω)

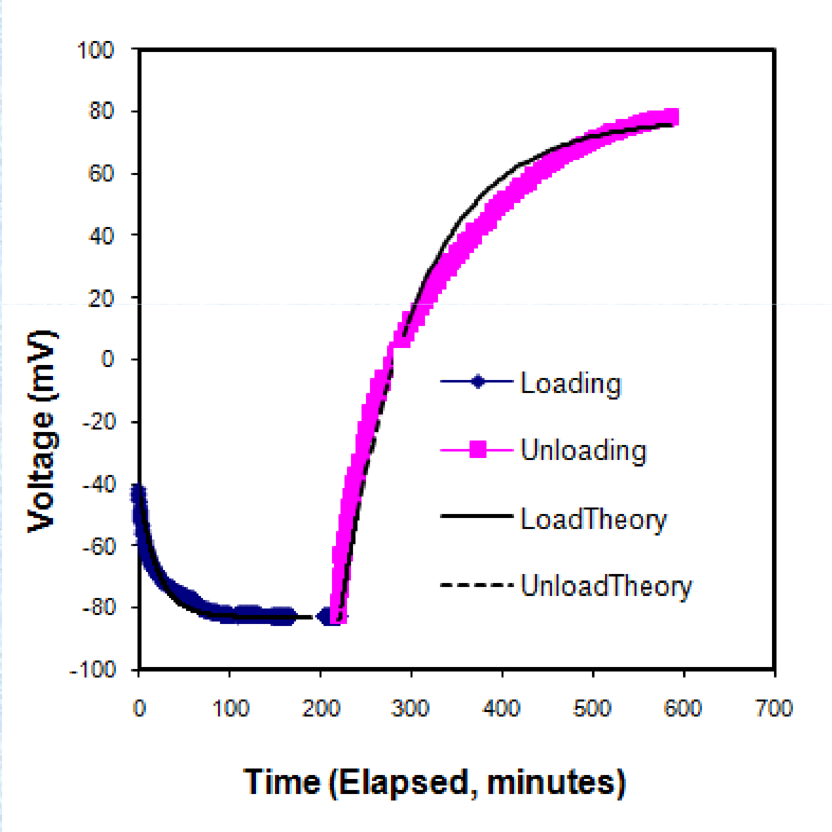


Fig. 4 Effect of resistance (8000 Ω)

Results and Discussion (on Algae-Bacteria MFC)

Loading and Unloading Effect on the Circuit

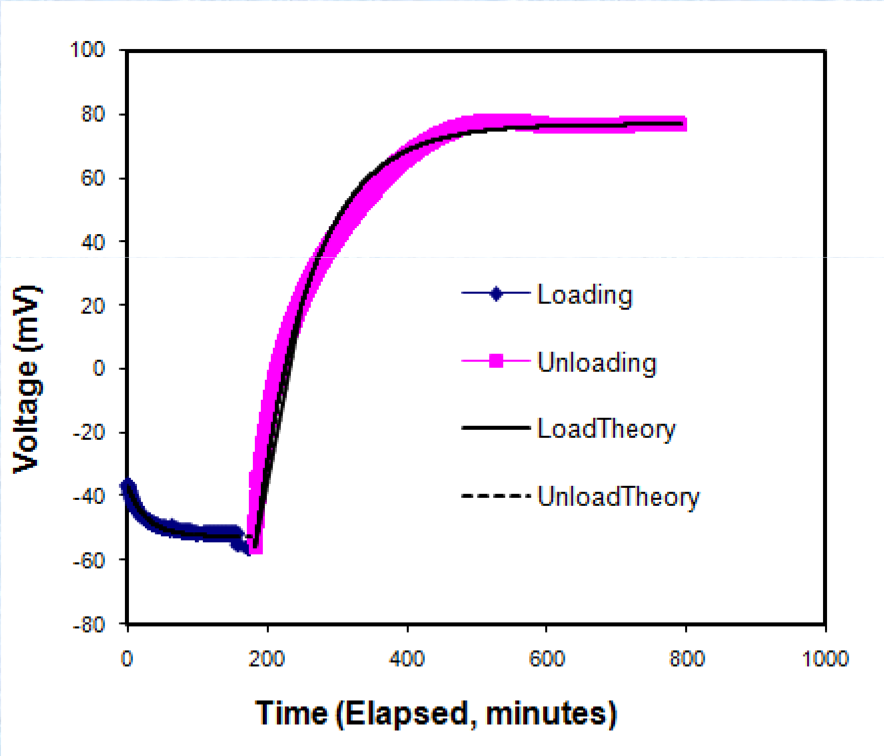


Fig. 5 Effect of resistance (5000 Ω)

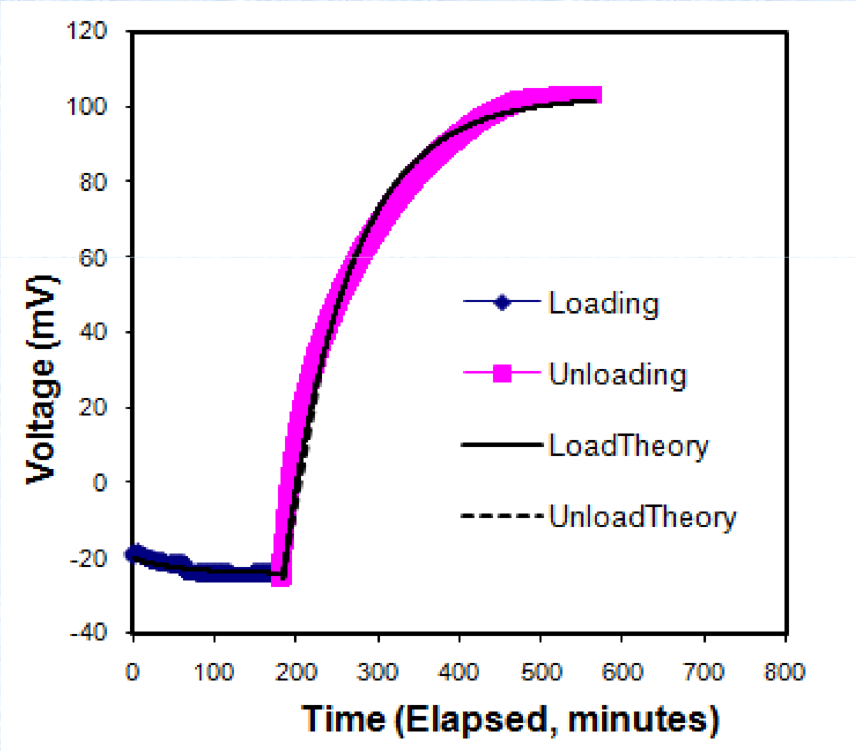


Fig. 6 Effect of resistance (2000 Ω)

Results and Discussion (on Algae-Bacteria MFC)

Loading and Unloading Effect on the Circuit

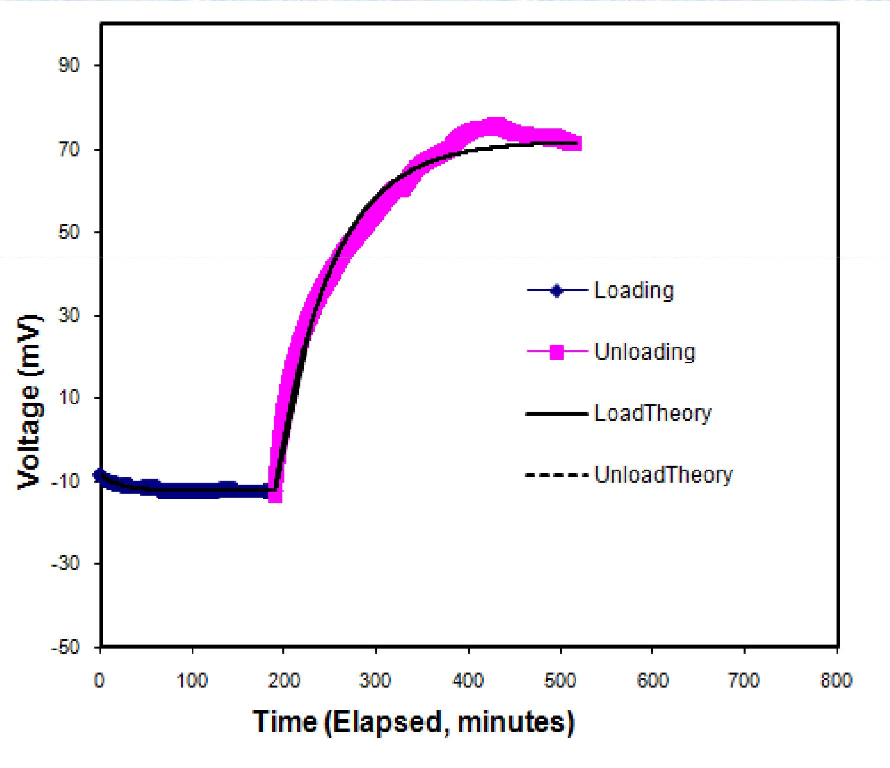


Fig. 7 Effect of resistance (1000 Ω)

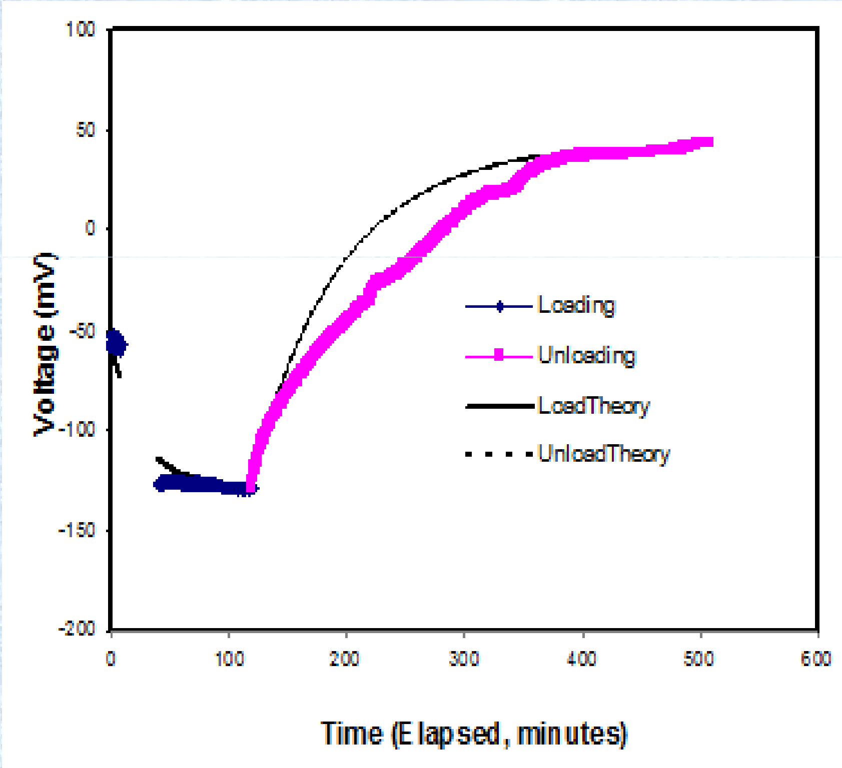


Fig. 8 Effect of resistance (250 Ω)

Results and Discussion (on Algae-Bacteria MFC)

Table 2 Voltage and response time for loading and unloading resistance (algae – bacteria MFC)

			Loading Resistance					
			10000Ω	8000Ω	5000Ω	2000Ω	1000Ω	250Ω
Voltage (mV)	Loading	Initial	-28	-40	-36.5	-24	-8.3	-55.5
		Final	-91	-82.9	-52.3	-20	-12.3	-128.8
	Unloading	Initial	91	-83.5	-55.6	-25	-11.3	-127.8
		Final	67.3	77.8	77	102.7	72	44
Response time(min)	Loading		12.3	20	27.8	58.4	21.5	24.5
	Unloading		75.3	83.7	78.7	81	59.5	75.3

Results and Discussion (on Algae-Yeast MFC)

Loading and Unloading Effect on the Circuit

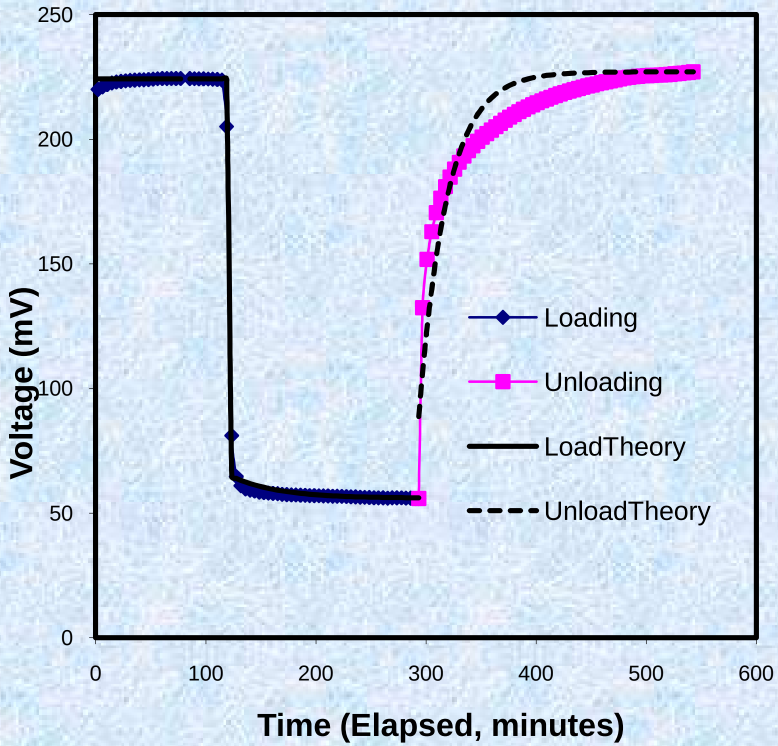


Fig. 9 Effect of resistance (10000 Ω)

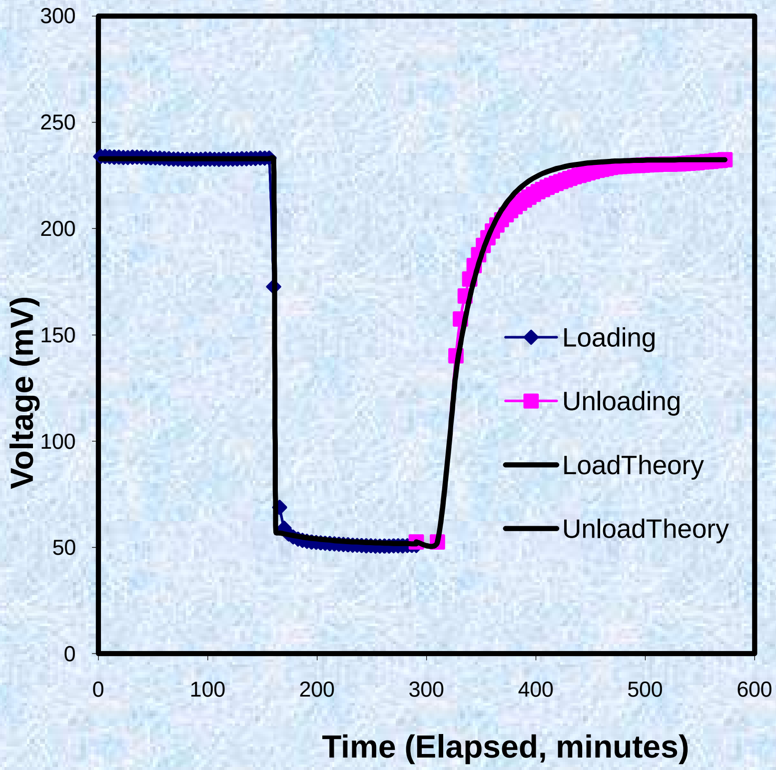


Fig. 10 Effect of resistance (8000 Ω)

Results and Discussion (on Algae-Yeast MFC)

Loading and Unloading Effect on the Circuit

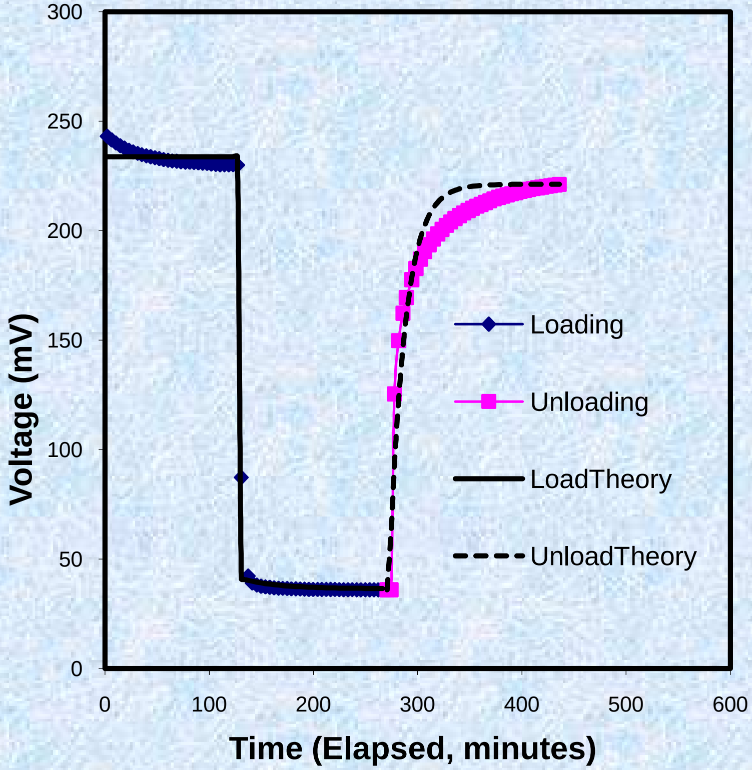


Fig. 11 Effect of resistance (5000 Ω)

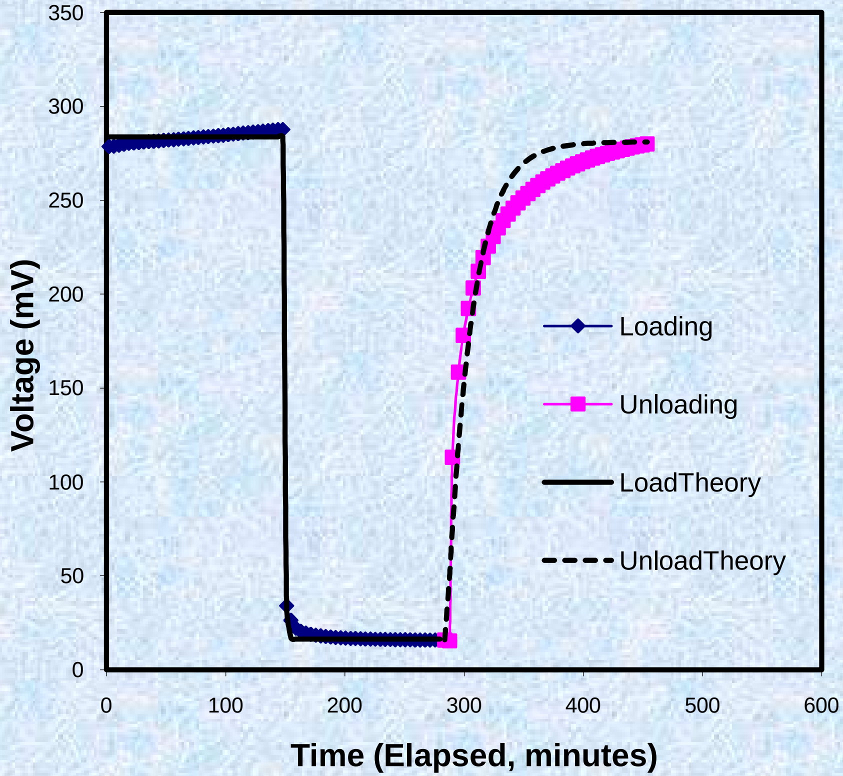


Fig. 12 Effect of resistance (2000 Ω)

Results and Discussion (on Algae-Yeast MFC)

Loading and Unloading Effect on the Circuit

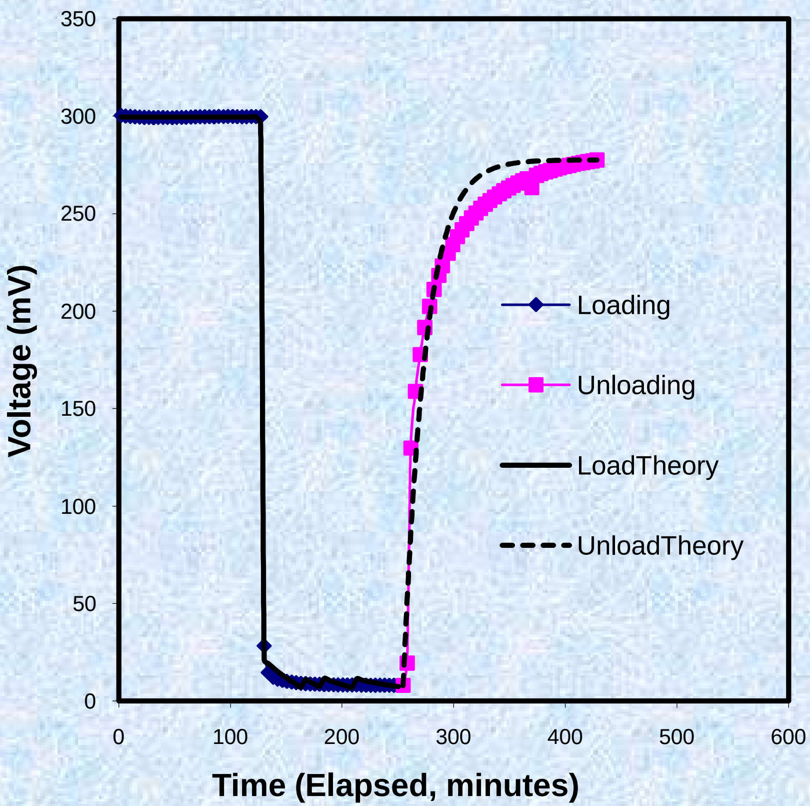


Fig. 13 Effect of resistance (1000 Ω)

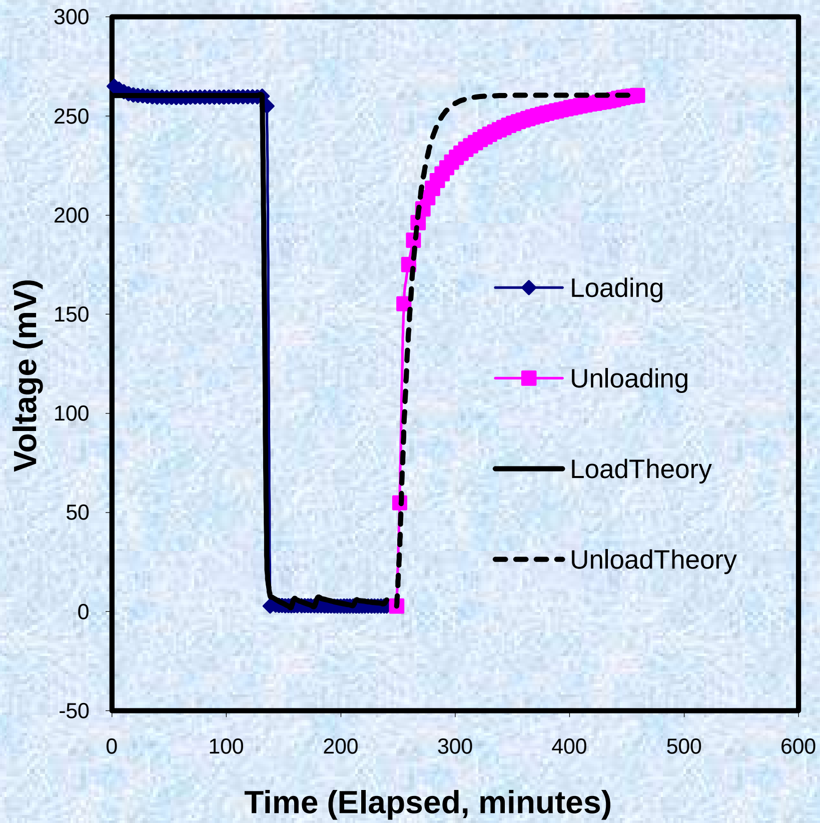


Fig. 14 Effect of resistance (250 Ω)

Results and Discussion (on Algae-Yeast MFC)

Table 3 Voltage and response time for loading and unloading resistance (algae – yeast MFC)

			Loading Resistance					
			10000 Ω	8000Ω	5000Ω	2000Ω	1000Ω	250Ω
Voltage (mV)	Loading	Initial	224	233	234	284	300	260
		Final	56	51.3	36.5	16.3	8	2.75
	Unloading	initial	56	53	36	16	8	2.75
		Final	227	232	221	281	278	261
Response time (min)	Loading		2.0	3.0	0.5	1.0	4.5	0.4
	Unloading		25.5	29.0	15.0	20.5	19.5	18.5

Conclusions & Recommendations

- ELAB Photobioreactor can enhance photosynthetic algae growth by a factor of 5 compared to well-mixed bioreactors.
- Ideal light conditions cause high oil yields, as much as 35% of dry weight.
- Electricity was generated by constructing an algae-bacteria/yeast based MFC. The experimental potential differences and response times were effectively modeled to predict the effect of voltage drops and response times.
- Higher photosynthetic productivity now needs to be achieved using cell recycle (high biomass) and high electricity production

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Thank You

&

Questions?