Fluid Dynamic Analysis of Fluid Flow in a Raceway Tank for Cultivation of Macrophytic Red Algae, Gracilaria Vermiculophylla

by
Myles Willis

A THESIS

submitted to

Oregon State University

Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Mechanical Engineering and Innovation Management
(Honors Scholar)

Presented June 6, 2023
Commencement June 2023

AN ABSTRACT OF THE THESIS OF

Myles Willis for the degree of Honors Baccalaureate of Science in Mechanical Engineering and Innovation Management presented on June 6, 2023. Title: Fluid Dynamic Analysis of Fluid Flow in a Raceway Tank for Cultivation of Macrophytic Red Algae, Gracilaria Vermiculophylla.

Abstract approved:_____

Gregory Rorrer

As new cost-effective cultivation methods are needed for macrophytic red algae, this experiment expands upon a previously studied land-based approach. The experiment aimed to determine how the fluid dynamics of a previously researched land-based method affected the growth of the macrophytic red alga, Gracilaria Vermiculophylla. A clonal culture of *G. Vermiculophylla* was cut, immobilized into ten mesh panels, and grown for 42 days with the fluid velocity measured six times during the growing period. Velocity measurements were taken in six different locations around the raceway tank, with five different cross-sectional measurements at each location. This gave the view of a three-dimensional flow around the tank to compare with the growth of the samples measured in % per day. The samples that experienced more flow had a moderately positive correlation between the velocity and growth rate. Additionally, this experiment found that the bulk velocity of the tank decreased with the growth of G. Vermiculophylla. Overall, these findings can be used to improve the design of cost-effective land-based methods for growing macrophytic red alga.

Keywords: Gracilaria vermiculophylla, macrophytic red alga, fluid mechanics experiment

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Honors Baccalaureate of Science in Mechanical Engineering and Innovation Management project of Myles Willis presented on June 6, 2023.

APPROVED:

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Gregory Rorrer, Mentor, representing Chemical, Biological, and Environmental Engineering

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Deborah Pence, Committee Member, representing Mechanical, Industrial, and Manufacturing Engineering

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Toni Doolen, Dean, Oregon State University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

_____

Myles Willis, Author

Table of Contents

Acknowledgments

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1. Introduction

1.1 Background

Current research into the macrophytic red algae genus, *Gracilaria* has increased because of its potential sustainable uses. *Gracilaria* is mainly used as food, but recent research has shown the potential for use in carbon sequestration [1-3], sustainable biofuel production [3-4], bioproducts [4-5], and wastewater Treatment [6-7]. Even though *Gracilaria* has shown promise in sustainable uses, there are not many well-developed methods for large-scale inland cultivation.

Aquaculture of *Gracilaria* is mainly conducted in two different methods: offshore coastal cultivation [8-10], or near-shore tumble culture processes [11]. Some common offshore coastal techniques involve harvesting natural seaweed beds, and commercial farming that involves growing native and introduced seaweeds suspended in natural and artificial conditions [8]. The most common near-shore process is called tumble culture which is accomplished by introducing compressed air at the bottom of a tank and letting it rise to the surface through the suspended seaweed.

While those processes succeed in growing *Gracilaria*, algal production must be increased to pursue its potential sustainable uses. The drawbacks to the current processes include the necessity of expensive land near shores with high labor-cost methods that increases the cost of cultivation. This drives the need for *Gracilaria* cultivation in cheaper inland areas which only contributes to 0.09% of worldwide algae production [12]

This project started with the study of onshore *Gracilaria Vermiculophylla* cultivation using a 100L raceway tank with pumps to move the water through samples of *G. Vermiculophylla.* The success of this process shows the potential of its scalability, but more research is needed to optimize the growth of *G. Vermiculophylla*. Additionally, many experiments have been conducted to improve these cultivation methods. Many of such experiments focused on the uptake of CO2 into *Gracilaria* which is accomplished by adding air into the system. The air is added below the pumps to mix with the seawater and create bicarbonate because *Gracilar*ia has evolved to harvest bicarbonate for its photosynthesis process. The 20 SCFH of air that is used in this project was chosen to make it a non-complicating factor [13].

This experiment was created to study the fluid flow within the tanks for this previously studied process. Understanding the fluid flow, and its interaction with the samples of *G. Vermiculophylla* can help understand better tank designs and processes within the tank to improve the cultivation process. It was observed that the flow of the water changes as the *G. Vermiculophylla* grows, so this research aims to study how the flow affects its growth. The hypothesis is the velocity of water perpendicular to the *G. Vermiculophylla* sample has a positive correlation with the growth rate of that sample.

1.2 Thesis Statement

This thesis develops upon a current laboratory process to understand the system's fluid mechanical behavior and whether velocity changes affect the red macroalga *G. Vermiculophylla* production.

2. Methods

2.1 Variables

	Description	Variable	Value	Units
Tank	Tank Length	l_t	135	cm
	Number of channels		2	
	Tank Width	$2w_t$	38	cm
	Channel Width	w_t	19	cm
	Liquid Depth	d_l	20	cm
	Cross Sectional Area	A_{cs}	0.39	cm^2
	Liquid Volume	V	100	L
Panels	Panel Width	w_p	7	cm
	Panel Height	h_p	7	cm
	Number of Panels	n_p	10	
	Panel Frame Width	w_{pf}	9	cm
	Panel Frame Height	h_{pf}	20	cm
	Panel Frame weight	m_{pf}	138	g
Equipment	Pump Power	P_p		
	Light Intesnity		450	$\mu M/m^2s$
	Light Timer		8	hr/day
	Temperature	T	14	°C
	Air Inlet	l_t	20	ft^3/hr (scfh)
	Heat Exchanger			
G. Vermiculophylla	Width G. Vermiculophylla	w_{gv}		cm
	Depth G. Vermiculophylla	d_{gv}	10	cm
	Area G. Vermiculophylla	A_{gv}		cm^2
Calculations	Initial Mass	m_i	2	g
	Final Mass	m_f		
	Velocity Measurement Length		5	cm
	Growth Rate	μ		%/day
	Reynolds Number	Re		
	Force of Drag	F_d		N
	Coefficient of Drag	C_d		

Table 1: Variables used in the experiment with their values and descriptions.

2.2 Setup Procedure

The experiment was prepared by first cleaning the raceway tank to remove any contaminants that were in the tank and its components. The filter materials and piping materials were covered in aluminum foil before insertion into an autoclave for cleaning. While the filters are being cleaned, the raceway tank is dismantled and filled with water and 10% acetic acid. The tank was scrubbed with this solution twice to ensure the removal of all contaminants. Once cleaned, the tank was then filled with 100L of water until a depth of 20cm was reached. A salt solution was added to the water at 35.87 g per liter of water to create the ratio of salt to water ideal for growing *G. Vermiculophylla*. The tank is completed with a divider in the center of the long side and topped with a three-piece lid. Figure 1 below shows the equipment and sample setup of the tank from two different angles

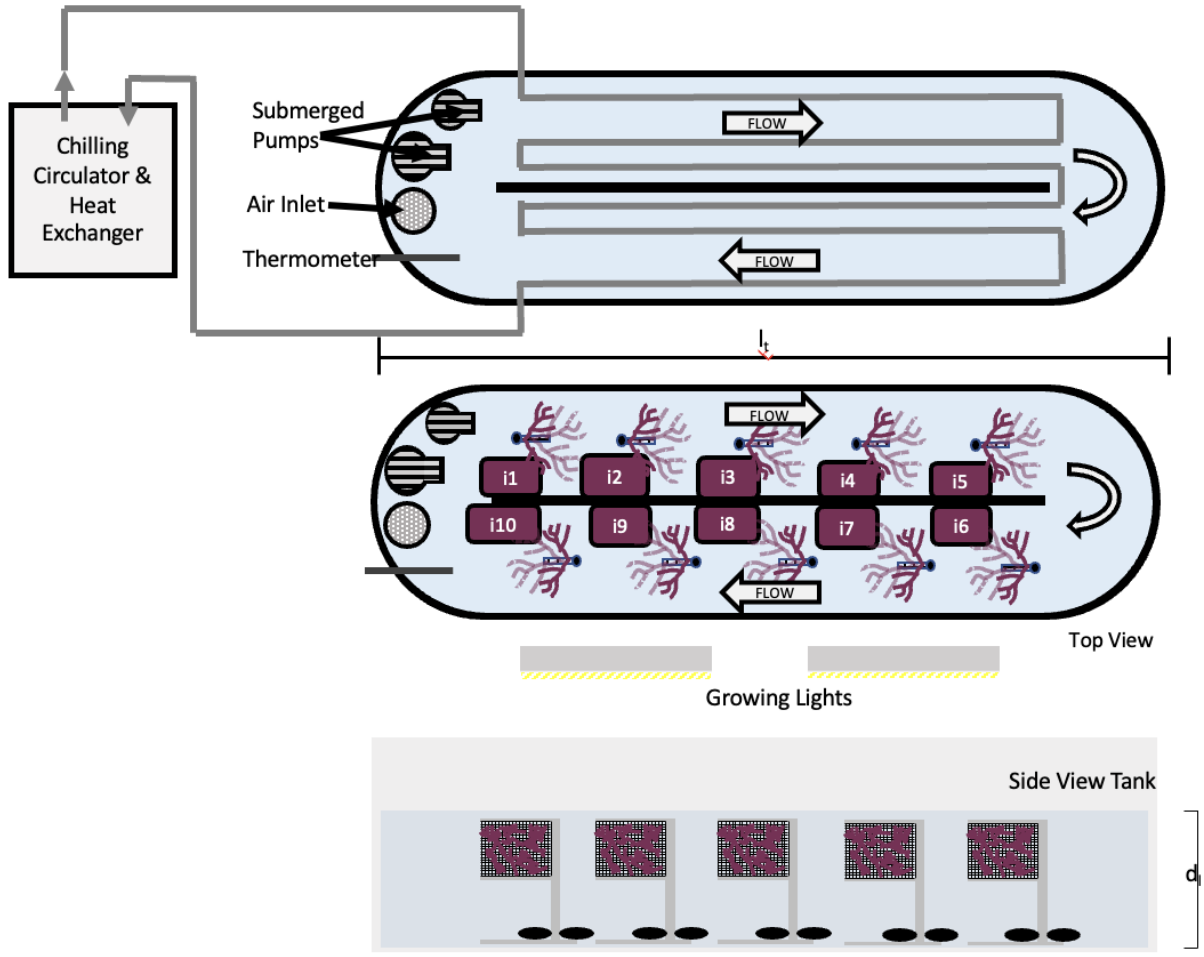

Figure 1: Views of the experimental setup, the top diagram contains all equipment needed from the top view, the middle diagram contains the experimental sample setup, and the bottom diagram shows the side view showing the lights.

With the tank clean, the equipment was added to the tank. The tank is outfitted with two different models of Jebao Propeller pumps, an SOW-20, and an SOW-8. The pumps are placed at the center depth of the seawater, 10 cm, on one turnaround of the track, pointing directly down the first long side. Air is then added at the specified rate of 20 SCFH via a tube that connects the air source and a stone diffuser placed below the pumps. The system was lit with a Viparspectra DS300 running on an 8-hour-per-day timer. Finally, the temperature, measured by an omega DP450 Thermo-coupler, was set at 14°C. These conditions were kept steady for the entire six-week growing period of the experiment. With the tank ready, the pumps were then turned on to run water through the system to avoid contaminant growth in the days leading up to the experiment.

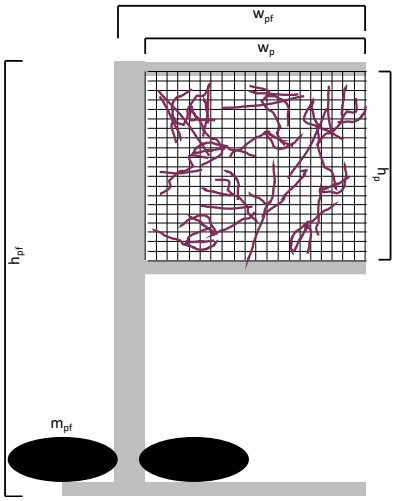

Figure 2: Panel Frame

Ten frames were constructed to hold mesh panels shown in Figure 2. The mesh panels were then weighed and labeled from one to ten, to denote the positions in the tank. Due to the fluid flow in the tanks, two 138g steel weights were added to each stand to hold them in place. The panels were set on the raceway tank parallel to the direction of fluid flow. This was set up as a control system before *G. Vermiculophylla* was introduced into the tank. The measurement process described below was taken for each cross-section to get this calculation.

2.3 Experimental cultivation

The seaweed was introduced into the experiment by being immobilized in the mesh as shown in Figure 2. The panels were then carefully organized and weighed with the goal of 2 grams of *G. Vermiculophylla* on each panel. Clonal cultures were cut into pieces ranging from about five to ten centimeters. These pieces of *G. Vermiculophylla* were weaved into each mesh panel with a forceps tool. This process was repeated until about two grams of seaweed were held into each panel.

Finally, the stands were reconstructed with inoculated mesh panels and placed into the raceway tank. The pumps, lights, and air were initiated, and a second control measurement of the water was taken. The experimental setup required data specified in the measurement section once per week for six weeks of growth.

2.4 Velocity Measurements

Velocity measurements were taken thirty times for each set of data, there are five cross-sectional data points (j) for six locations in the raceway tank (i). As seen in Figure 3, the panels on the second half of the raceway tank are oriented in the same way. The data is collected via a vernier flow rate sensor that is positioned at each location for 10 seconds. This creates a data set that a mean and standard deviation can be taken to improve the accuracy of the data. This procedure is then repeated with the second pump turned on.

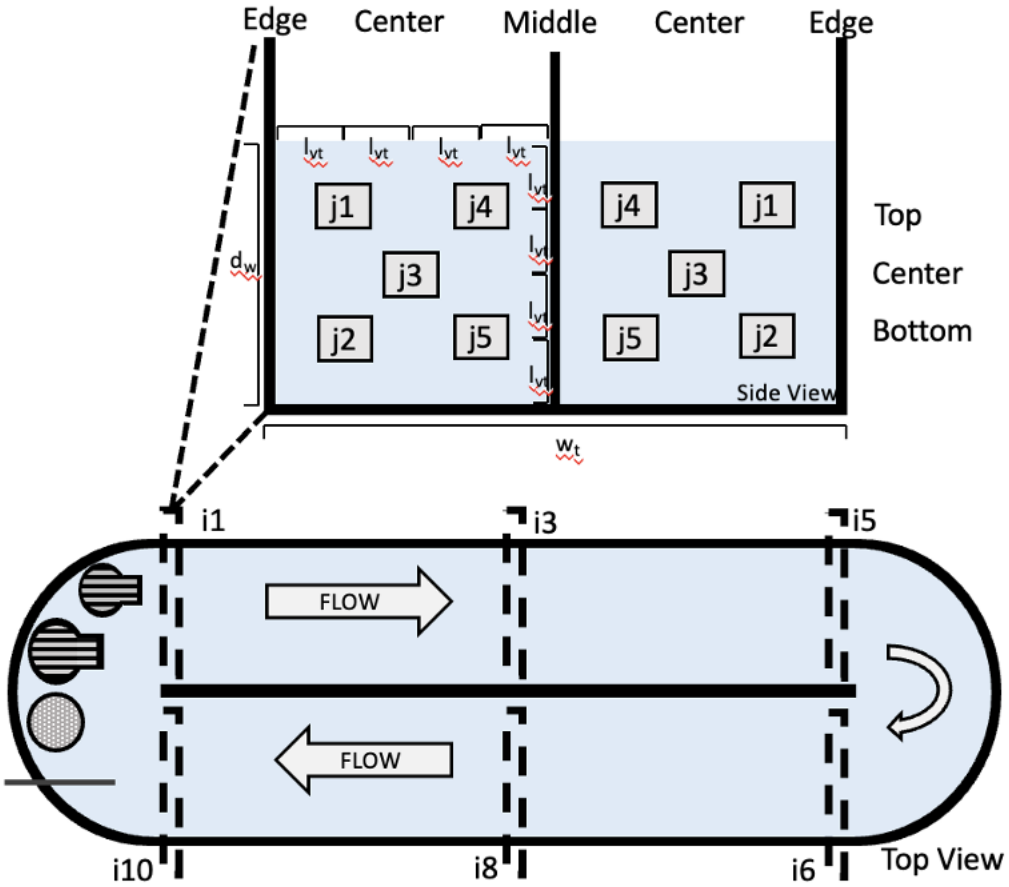

Figure 3: Top figure shows the cross-sectional view and locations (j) of the velocity measurements taken at each of the six tank locations (i)

2.5 Areas of Analysis

This process was developed around the idea that three-dimensional velocity data could improve the analysis of how the water moved around the tank. The five different cross-sectional positions show fluid behavior in specific locations of the tank. The cross-sectional distribution of velocities was compared against the tank position to show how the velocity of the tank changed with tank location. The cross-sectional distribution was also compared with the time to show how the growth of *G. Vermiculophylla* affected the fluid mechanics of the system. The average velocity at

each panel was analyzed compared to the growth rate. Finally, the fluid dynamics analysis showed the values for the drag and Reynolds numbers. This specific measurement setup contributed to the project's success because of the three-dimensional data collected about fluid behavior.

2.6 Equations

Growth Rate

- $\mu = \frac{\ln\left(\frac{m_f}{m_i}\right)}{\Delta t} * 100\% \ (\frac{\%}{day})$
- $m_f = Final\ Mass\ (g)$
- $m_i = Initial\ Mass\ (g)$
- $\Delta t = 42 = Experiment\ Length\ (days)$

Reynolds Number (Open Flow)

- $Re = \frac{\rho V(A_{cs} - A_{gv})}{P_w * \mu}$
- $A_{cs} = w_t * d_w = Cross\ Sectional\ Channel\ Area\ (m^2)$
- $A_{gv} = w_{gv} * h_{gv} = Cross\ Sectional\ Sample\ Area\ (m^2)$
- $P_w = w_t + 2d_w = Wetted\ Perimeter\ of\ Channel\ (m)$
- $\mu = 1.013 = fluid\ viscosity\ (\frac{g}{cm^3})$

Drag

- $F_d = \frac{1}{2} * C_d * V^2 * A_{gv}$
- $F_d =$ Force of Drag (N)
- $C_d = Coeffienct\ of\ Drag\ (.47)$
- $V = Fluid\ Velocity\ \left(\frac{m}{s}\right)$

3. Results

3.1 Data and Analysis

Figure 4 shows the comparison between tank location (i) and the velocity recorded at every cross-sectional position (j). Each value is an average of every cross-sectional velocity reading (j) during the experiment. The water out of the pumps was centered on the first *G. Vermiculophylla* sample, which caused the center and top positions to read the highest velocities while the bottom positions are consistent with the readings from the rest of the tank. Position i10 showed higher than average velocities with the smallest variation because the pumps draw water causing a more consistent and easily measurable flow. Cross-sectional location j3 had the lowest velocity measurement for most tank locations (i) because of the drag caused by the *G. Vermiculophylla* samples. Additionally, edge locations j1 and j2 are the most consistent measurements because the wall of the tank guided the water streamlines along the turn when compared to other cross-sectional areas of the tank.

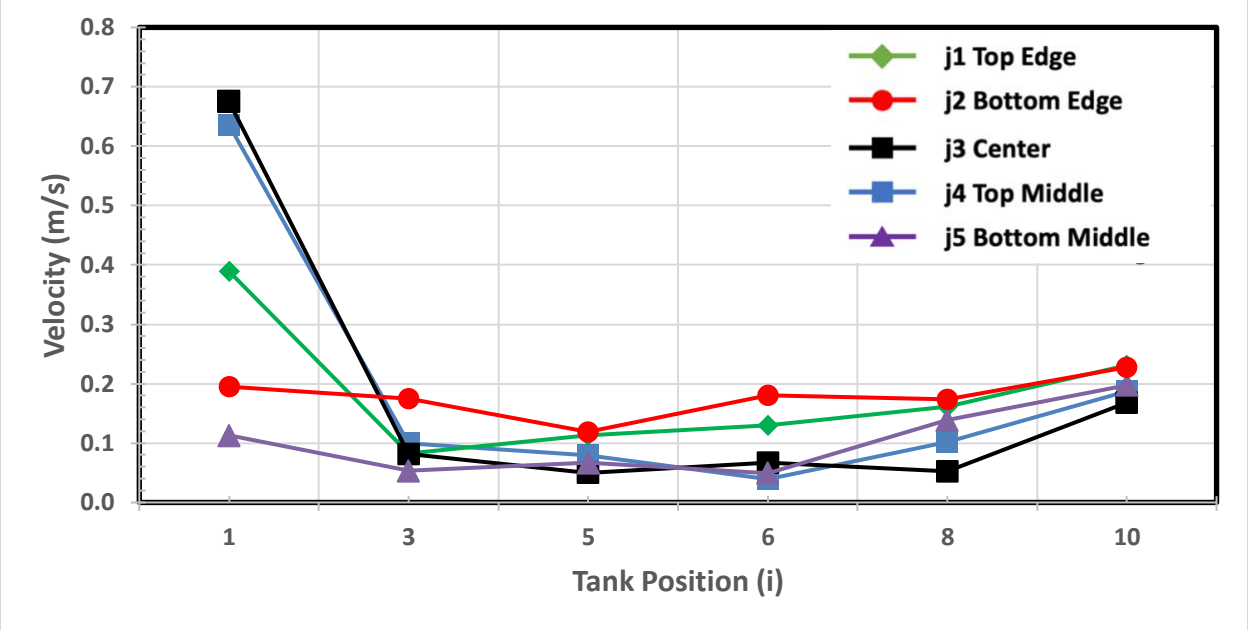

Figure 4: Velocity vs Tank Position (i) and Cross-Sectional Position (j)

Figure 5 shows the change in velocity over the course of the experiment. Each value is an average over all the tank locations (i) for that day. This graph's most visible macro trend is that the average velocity steadily decreases as the Vermiculophylla grows and blocks parts of the tank. The velocity decreased with growth because of the erratic flow caused by the seaweed blocking the easiest path for the water to pass around the tank.

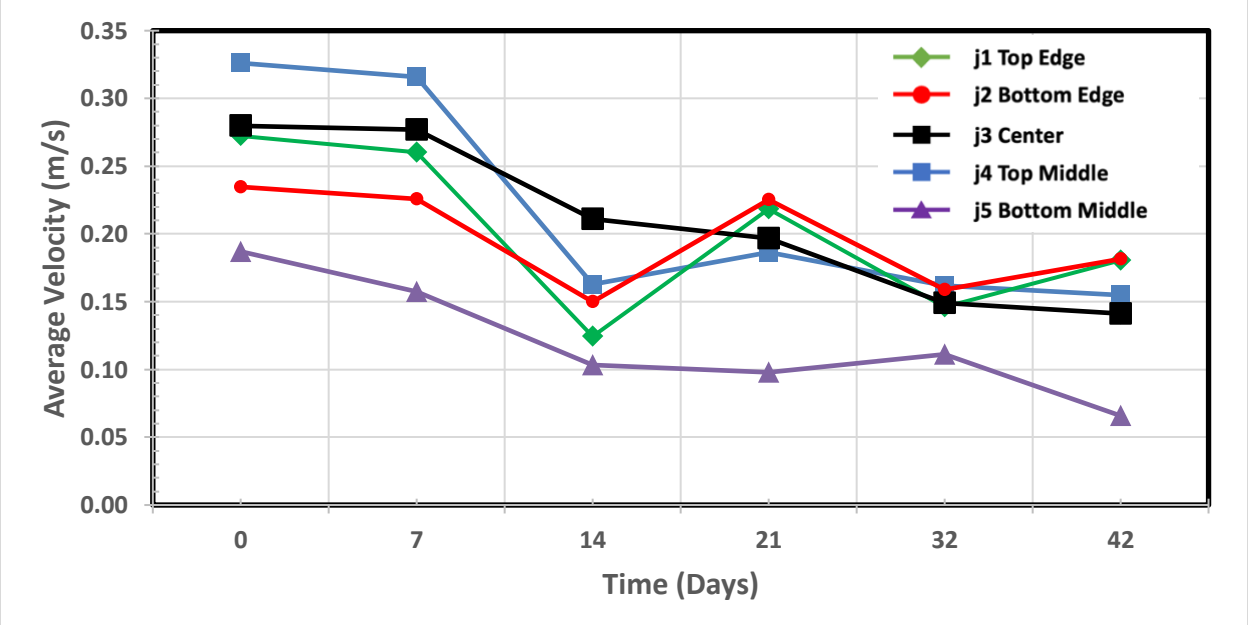

Figure 5: The average velocity of each tank position compared to the growth of the G. Vermiculophylla over time.

Figure 6 shows the mean and variance of the growth rate compared to the average cross-sectional velocity (j) found at each tank location (i). i1 had the greatest variance in cross-sectional velocities, average velocity, and growth rate. i10 had the second-greatest velocity, but a growth rate that was comparable with the rest of the samples. The rest of the samples are clustered together with similar velocities and a small variance in growth rates. However, the range of growth rates is small; from 7.095% to 8.00% (i6, i1).

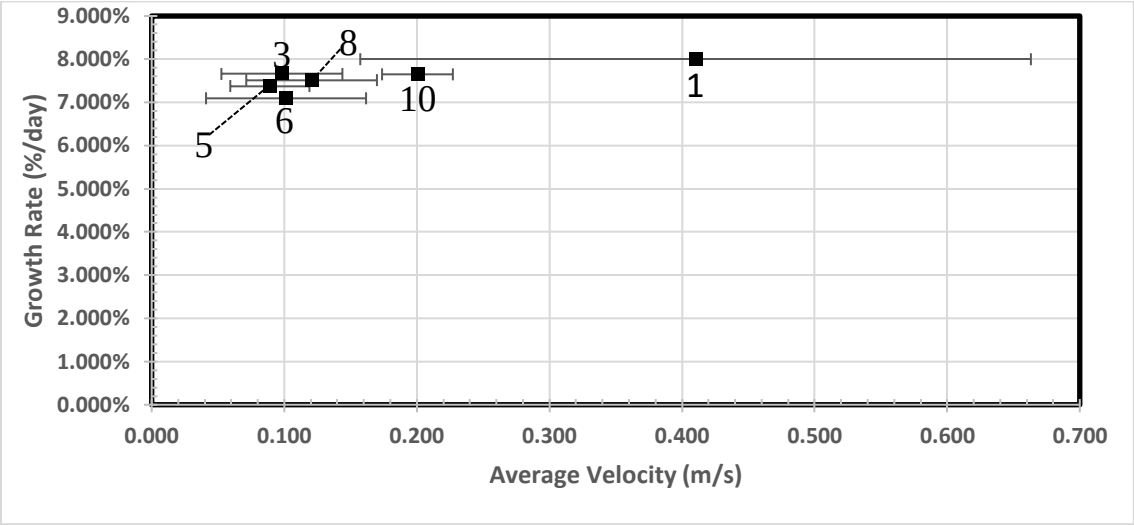

Figure 6: The average velocity and its variance of six samples compared to the growth rate of the sample.

Figure 7 shows a linear regression of the growth rate when compared to the velocity. The R^2 value of 0.6292 describes that there is a moderate positive correlation between average velocity and growth rate. However, because there is little variance between all growth rates meaning the fluid velocity probably only has a minimal impact on the growth rate of G. Vermiculophylla.

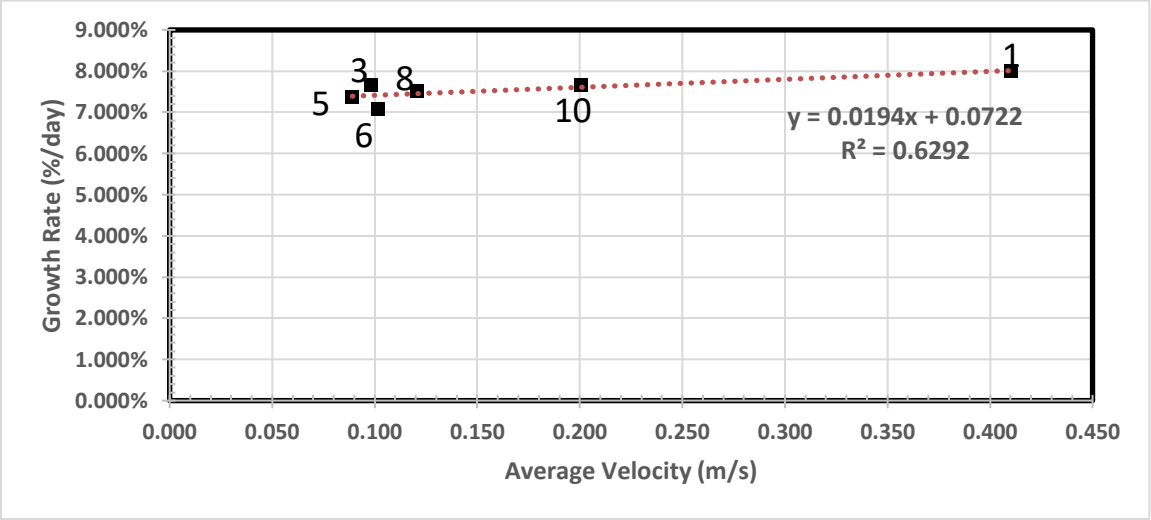

Figure 7: Linear regression of the average velocity of six samples compared to the growth rate.

Figure 8 shows the Reynolds number for open-channel flow. A Reynolds number above 12,500 for turbulent open-channel flow is considered turbulent flow, shown as the grey line. The only sample of G. Vermiculophylla in turbulent flow is the first sample that is directly after the pumps. The Reynolds number varies linearly with the velocity and is predictive of fluid patterns within the tank.

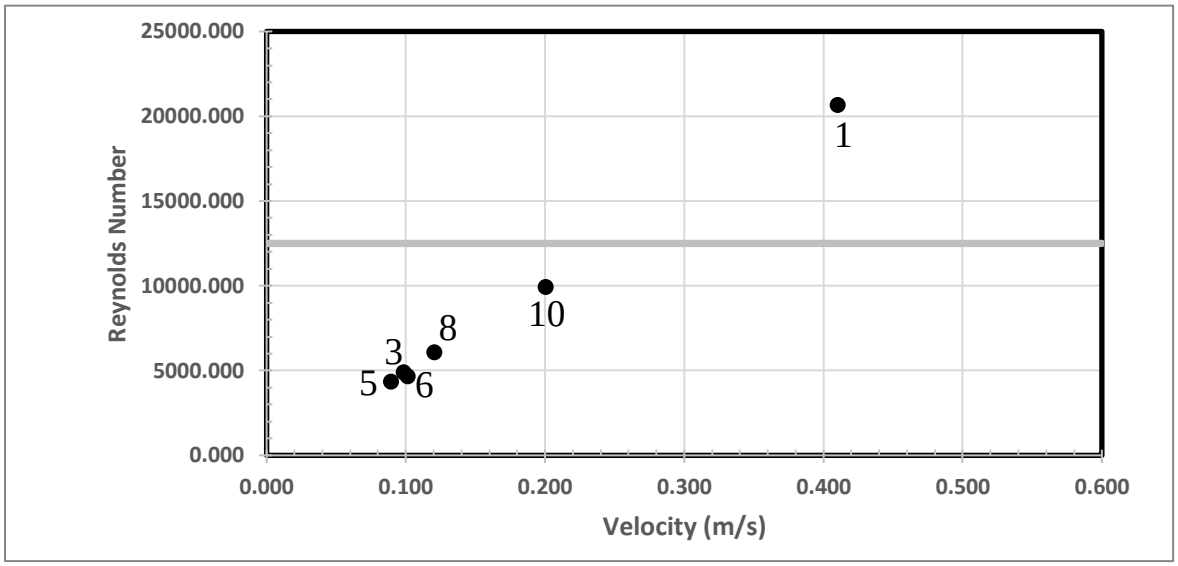

Figure 8: Velocity compared to the open-channel Reynolds number of the fluid; the numbers denote the location of each measurement.

Figure 9 shows the relationship between the velocity and the drag force for each measured sample. The values for drag were determined by a measurement of the cross-sectional area of each sample and an averaged velocity of the samples collected on day 42. As shown in Figures 5 and 6, there is a moderate correlation of a small effect the velocity has on the growth rate This means the drag caused by *G. Vermiculophylla* possibly has a small effect on its growth rate.

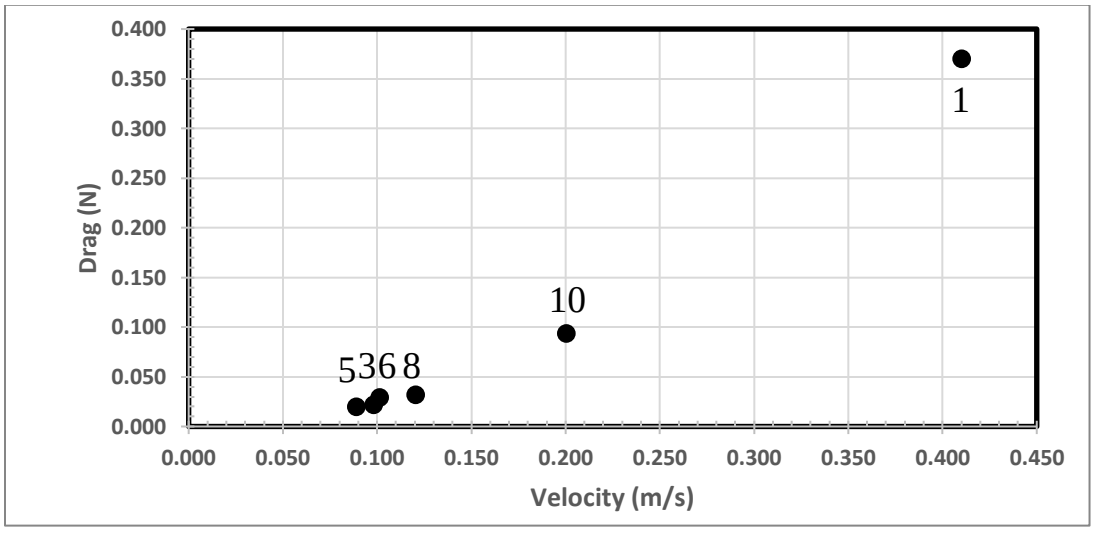

Figure 9: Velocity compared to the drag caused by the G. Vermiculophylla of the fluid; the numbers denote the location of each measurement.

3.2 Discussion

This experiment tested how changes in velocity affected the growth rate of *G. Vermiculophylla* in laboratory growth. Figure 4 shows that there are changes and variances in the velocity in multiple places. The velocity recording at tank position one had the greatest deviation because of its proximity to the pumps, while in the other positions, the calculated fluid flow was much slower and more uniform. Figure 5 shows that the velocity of the water generally decreased as the *G. Vermiculophylla* samples grew. The losses in velocity could be caused by a difference in the pump output or the pressure drop of the system, or the added friction of the *Gracilaria* growth. More testing is needed to determine the factors that led to the decreased velocity. Figures 6 and 7 show that there is a moderate positive correlation in the growth rate for higher velocities. However, there is only a small difference in growth rate between the samples exposed to the fastest and slowest water. Figures 8 and 9 show the Reynolds Number and drag created by *G. Vermiculophylla,* with only the first tank location experiencing turbulent flow. Because both drag and the Reynolds Number is a function of velocity, these graphs show more insight into different factors that could contribute to a difference in fluid speed and growth rate. The results show that the experiential hypothesis can be true, but there is not enough data to prove a strong positive correlation between fluid velocity and the growth rate of *G. Vermiculophylla*. A moderately positive correlation was found, but only between small differences in growth rates between the slowest and fastest velocity samples.

The velocity was measured with a Vernier flow rate sensor. This sensor used a rotating blade that read the water velocity by evaluating a propellor's angular velocity. The blade worked the best to capture velocity values in one direction because complex three-dimensional flow would inhibit the propellor from moving at the speed of the water. This caused an error in every data point, and better analysis techniques would have given a more accurate analysis of the velocity within the tanks. Additionally, the SOW-20 Pump also had some limitations, even though the pump was set at the same setting, the changes in the system as with the growth of the biomass may have affected the power that enters the system via the pump. The project lacked a measurement system that revealed the power input in the system, which shows that the pump could have been working at any area of the pump curve. Future studies into this project need to use better equipment to track more of the variables within the fluid flow of the system.

3.3 Suggested Future Work

- Add a pump on both turnarounds
- Improve the velocity measurement tool
- Use a positive displacement pump
- Move the samples in the water rather than the water around the samples
- Change the tank shape to decrease frictional losses
- Using a flow straightener for uniform flow

4. Conclusion

This experiment demonstrated how the fluid mechanical properties affected the cultivation of the macrophytic red alga, *G. Vermiculophylla*. By measuring the velocity of the water at six locations, six times over a 42-day-long experiment, the outcomes included how the velocity possibly affects the growth rate. These methods show that there are ways to improve the high-density onshore cultivation of clonal red microalgae. Future efforts to this study include changing pump placement and tank designs to allow for better movement of water within the raceway tank. This project improves upon previous research by highlighting how the tank fluid mechanically affects the cultivation of different microalgae.

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