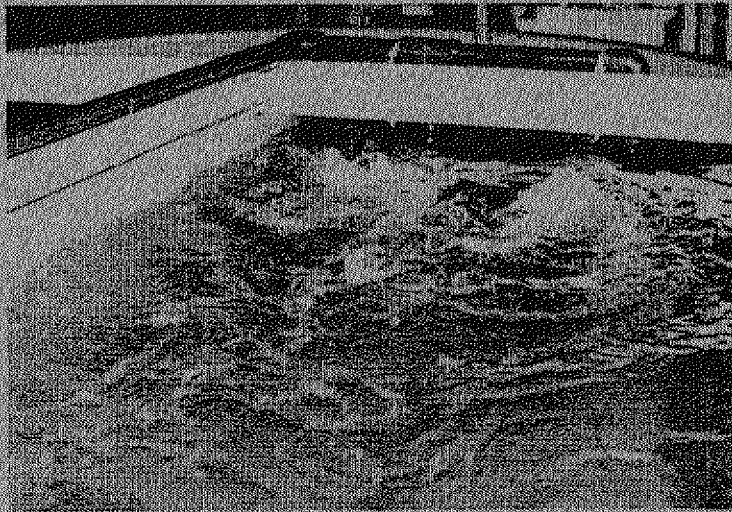


# DIRECTIONAL FLOW TANK

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## **ABSTRACT:**

A directional flow tank was developed to provide a small scale, moderately priced, functional tool for aquaculture research. The design represents a prototype of a system in operation at a large commercial aquaculture facility. Tank performance was evaluated by measuring flow velocities to determine the current generating capabilities of this system. Surface velocities measured in over a depth range of 60 cm. ranged from 5.1 cm/sec. at the surface to 2.0 cm/sec. near the bottom. The growth rates of a common fouling organism, the colonial tunicate, *Botrylloides* sp., was measured throughout a two week study in the tank system. We found consistent growth rates throughout the tank system with linear growth rates as high as 2 mm/day, which are consistent with limited data from field populations. These results suggest that this directional flow tank represents a successful and effective model for the culture of sessile marine organisms by combining a mechanically simple design that is flexible, compact, and cost efficient.

## **INTRODUCTION:**

### **Problem**

There is a growing need to culture marine organisms for a range of applications from commercial production to scientific research. The physical and physio-chemical requirements for marine organisms differ significantly from terrestrial organisms and profoundly effect their survival. These requirements include adequate water flow with sufficient dissolved oxygen concentration, and stable temperature and pH for establishing growth. The design of appropriate culture systems are critical to meet the particular growth requirements of marine organisms.

Features that are common to all facilities dedicated to the culture of marine organisms are tanks that control water flow in which most organisms live. These can include open and recirculating systems. Most tanks are designed to meet the needs of specific projects, and, thus are poor models for any other general purposes (Vogel, 1978). Therefore the specifications of this design are produced to minimize the potential problems and maximize performance.

The design and production of a directional flow tank is the main objective of this project. The goal is to produce a functional, small scale, moderately priced tank for a range aquaculture purposes. There are several issues affiliated with the design and production of directional flow tanks pertaining to the culture of marine organisms. First, the demand for an oxygenated water current is a 24 hour a day requirement. Second, the system must be versatile enough to allow the culture of several types of organisms. Third, an inexpensive design is critical to its appeal. Fourth, the tank must be practical

within the confines of limited space in research laboratories or production facilities.

Lastly, the true test is it must be able to approximately replicate the marine environment well enough to successfully achieve substantial growth of marine organisms.

Ideally, the design of the tank would be useful for the culture of many sessile aquaculture organisms including oysters, clams, sea urchins, scallops, and mussels. This design is targeted to these organisms due to the increasing demand for their culture for commercial and scientific goals. Aquaculture defined by the National Aquaculture Development Plan of 1996 is the farming of aquatic organisms including fish, mollusks, crustaceans, and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, and interest. The rising interest in commercial aquaculture is generally the result of overexploitation of wildstocks making hatchery culture cost effective.

Due to the limitations of tanks currently used for marine culture methods, we hope to establish this new design concept. This design will be explored by fabricating a functional system to investigate its utility for aquaculture in marine investigative laboratories. The goal of producing a functional, small scale, moderately priced tank for aquaculture purposes will be accomplished by developing a functional working unit that will achieve growth goals for the organisms of interest.

## **Development of the System**

The characteristics of many previous flow tank designs have incorporated rotating shafts connected to motors, water sprays, sump pumps, and oxygenators (Heinen, 1996). Many of these tanks are designed to generate uniform laminar flow or similar hydrodynamic regime for scientific research. However, these components of the tank's system are expensive and involve many moving parts which may malfunction, become fouled, or generally cost too much to repair. Unfortunately, this may result in slowed growth or mortality of organisms, incomplete data, or failed harvests.

Our design is a small scale prototype of a larger system designed by Great Bay Aquafarms ( Portsmouth, NH). Our design was created to minimize potential problems and maximize the performance on a much smaller scale. First, the flow of the recirculating water uses an airlift system in which rising air pushes water in an upward direction and is directed forward to produce the desired velocity. This approach eliminates the propeller, or moving parts within the tank, producing the current or directional flow. Second, our approach eliminates the mechanical agitation of traditional pump or propeller designs which may increase the water temperature at an appreciable rate, resulting in a financial loss of purchasing a cooling device to offset the heat(Vogel, 1978). Third, our approach also eliminates the need for protective screen coverings or housing units, which prevent any specimens entering the turbine area and may become fouled. Additionally, tanks that are designed for the production of laminar flow are not practical for growth of organisms. These tanks may include devices which will focus only on the effort of producing a unidirectional laminar flow, therefore reducing the amount of area for growing organisms. The rising air provides a source of

oxygenating the water, further eliminating water sprays or oxygen pumps to produce oxygenated bubbles.

An open system tank was chosen for practical and economical reasons. The practical reasons include the design of the marine laboratory in which the flow tank was located. Fresh seawater can be pumped directly into the tank and fouled water discharged back into the sea. The economical reasons include the elimination of a treatment process required in a closed water recirculating system. This treatment process also includes the control of pH and removal of metabolites such as feces, ammonia, and carbon dioxide, which may extensively increase the production cost of a closed system. Second, the external administration of food was not needed due to the sufficient nutrients and food pumped into the tank via fresh seawater. Third, a cooling or heating device was not needed due to the natural ambient temperature of the seawater, further lowering the cost. If temperature was used as a control in a particular experiment, the tank would further be characterized as an intermittent open system. Seawater could be used to manipulate the temperature. Standpipes will be placed in drain holes present in the tank and will allow for the continuous outflow of water and a consistent water height.

The mechanical power source generating the water current of the tank is an air pump. As a result, mechanical failure is only limited to this single component of the tank's design. Therefore the amount of air entering the tank directly relates to the flow of velocity within the tank. The control of water velocity within the tank can be manipulated by adjusting the amount of air entering the tank and the airlifter systems which are easily accessible. The tank is elliptical with dimensions of 10' x 6' x 2' thus, requiring only modest floor space. The tank's design creates versatility which will



accommodate other projects as well. Efforts were made throughout the construction process to produce a highly flexible system. Particular attention was paid to constructing removable and adjustable componentry to better facilitate the system.

This tank would be appropriate for many sessile aquaculture organisms including oysters, clams, sea urchins, scallops, and mussels. A common feature to all these organisms is they exhibit the characteristic of being sessile feeding organisms. We have created an aquatic environment that allows adequate feeding and waste removal for a variety of sessile organisms. Therefore, the current created by the tank creates a healthy environment to maximize growth and survival of cultured organisms.

## **Goals/ Objectives**

The name of the project, Directional Flow Tank

- The goal of this project is to design and construct a functional, small scale, moderately priced, high directional flow tank for aquaculture purposes
- The finished product of an operating, functional unit to be developed within the guidelines of a working budget of \$2000.00
- The finished product will be 100% operational achieving substantial growth rates for experimental organism

## **Materials and Methods:**

### **Design Description**

The process of material selection for this project involved the utilization of our appropriated budget in the most efficient and cost effective manner. Our main focus throughout the selection process was to use the most effective and least expensive materials for all components of the tank system. The major considerations here that led to the selection of the final component group involved several key components; strength, rigidity, capacity, size, corrosion resistance and cost.

The existence of commercially available tank systems of similar design to this one aided in determining the type and style of tank that would best suit our needs. We talked extensively with representatives of the Great Bay Aquafarms (Portsmouth, NH) and concluded that a tank design similar to their setup would be the most appropriate for the needs of this project and would represent the most efficient way of dealing with space limitations at the marine lab. Our design resembles a scaled down version of their 30' x 18' x 6' oblong tank and includes the central baffle structure and air lifter assemblies that are incorporated into their system (see Figure 1).

We contacted several tank and plastic fabricators and through inquiry we found that material selection here became more of a cost comparison between the different types of available materials. The dimensions of our tank (10' x 6' x 2') were at a small enough scale that any of the major commercially available tank materials (PVC, polyethylene or fiberglass) could be used and be capable of providing the necessary strength and rigidity to support this volume of water. Le Gay Fiberglass in Waverly, N.S. Canada presented

the lowest price quote of \$832.00 + \$425.00 freight for delivery of the unit to the coastal marine lab.

The Sweetwater S-21 1/3 horsepower air blower represents the other major component of our tank system (see Picture 1). Purchased from Aquatic Ecosystems for \$398.00, the blower creates circulation and infuses dissolved oxygen into the system. The decision to incorporate this type of circulation / dissolved oxygen delivery system into our tank came at the recommendation of technical advisors at Aquatic Ecosystems. According to these specialists, incorporation of air lifters is seen as the most efficient way to create controllable flow and provide constant dissolved oxygen into small scale aquaculture systems today. The same technical advisors recommended the correct pump size for use in our system based on the tanks dimensions and depth specifications. The 4 manifold assemblies for the air lifter units and the bleeder valve (to redirect excess air output) for the S-21 blower were additional components of the air delivery system that were purchased from this company.

Arrival of the main components marked the beginning of the tank construction phase, which began with the selection of appropriate air lines to deliver air to the 4 air lifter assemblies. After consultation with technicians at Aquatic Ecosystems, 1" schedule 80 PVC pipe was purchased which provides increased strength and rigidity and is specialized for use in pressurized systems. Goulet Pipe in Gonic, NH supplied 60' of this pipe at a competitive price of \$0.32 /ft and also provided the necessary valves, elbows, T-fittings, PVC glue and hangers at reasonable cost (see budget analysis).

The construction of the air lifter assemblies, which house the individual manifolds was based on commercially available units presently in operation at the Great Bay

Aquaculture Co. Our design incorporates 4-20" tall arms of 4"PVC pipe with 4"PVC fitted 90 degree elbows connected to the top portion (see Figure 2). We determined that a total of 4 lifter assemblies (2 on each side of tank with each group facing opposite direction) would provide the necessary rate of flow and dissolved oxygen content and remain unobtrusive enough to allow maximum usage of all available square footage (see Picture 2). Since component failure exists as a possibility in most systems, this design allows for complete disassembly for replacement and cleaning purposes and presents a level of flexibility to the system setup by allowing height adjustment of the air lifter units for diffuser replacement and flow experimentation.

Upon completion of the air lifter componentry and connection of the air supply to these units, it was determined that additional structural support was required to firmly anchor the air supply and the air lifters. It was decided that a structural support system to brace the central baffle would be constructed with 2"x 4"boards to achieve additional stability. This design worked very well, was cheap (\$2.59/ 8'board) and remains sturdy.

While representing a design similar to the system at Great Bay Aquaculture Co. this setup does not utilize closed system recirculation technologies. Incorporating these levels of technology (bacterial toxin removal, feces collection and sand tower filtration) into this modular system was not feasible, nor was it necessary. This system represents an open system, fresh seawater continuously flows into the tank and stand pipes constructed over the two drain outlets keep the water level constant and allows outflow of water. The seawater input into the tank is provided by existing facilities at the Coastal Marine Lab and eliminated the need to purchase additional water pumps.

### **Tank Performance:**

Determining the capabilities and limitations of our tank system became our main focus upon completion of the final construction phase and obtaining data on flow velocities at different depths in the tank became the next objective. To test the velocity of moving water within the water column the dye blot release test was utilized since more advanced methods involving laser refraction technology could not be used with opaque walled fiberglass tanks. We obtained data by timing the travel of a dye blot in the water column for a given distance and translating these results into a centimeters/second scale using the equation:  $V = S/T$  (eq. 1-1)

where V=velocity , S = distance [cm] , T = time [sec]

To determine variations in velocity at different heights of the water column, measurements of flow were taken at various depths. Values for velocity were obtained at heights of 43, 33, 0 centimeters [cm] from the tank bottom (see Figure 3). In calculating flow values for Side A, measurements were taken at a height of 15 cm from the tank bottom since this level represents the plane of tunicate attachment and obtaining values of flow past this elevated region of growth could be an important variable in determining growth characteristics. Flow velocity on Side B was measured at depth 0 cm along the tank bottom since the average height of the cobblestones was less than one inch.

### **Organism Growth Rates:**

Completion of the design and construction phase of this system satisfied the main objective for this project and with some time still left before the project due date provided the opportunity to investigate this system more thoroughly. Development of the

secondary goal, analysis of the growth of colonial Tunicates, would test if this directional flow tank system functions effectively enough to mimic actual intertidal conditions. By measuring the growth of *Botrylloides* sp. (a colonial fouling species of tunicates) in the tank system we were able to determine if this system functions well enough to be considered a reliable and useful research tool for intertidal studies. Data collection involved setting up separate growth experiments on opposite sides of the baffle in the tank. Side A (see Figure 1) contained a PVC grid, elevated to 15 cm from tank bottom by supports, bearing 11 tiles with attached tunicates one colony per tile (see Picture 3). Side B also contained tunicates attached to four cobblestones lining the bottom of the tank (see Figure 1). All of these cobbles were of similar size and each had numerous tunicates (at least two) attached to its surface. Growth data were collected every other day by measuring the size of tunicates in millimeters along the X (the largest linear dimension) and Y axis (the linear dimension perpendicular to X) (see Picture 4). Growth was calculated as the difference between sizes at different points in time. Total growth was the difference between the measured size on day one and the last day of data collection. The total growth data for each individual tunicate colony were used as the dependent variable in subsequent analyses. Growth rates were compared between colonies on cobbles in the center vs. The edge of the tank, and between cobbles and tiles at the center of the tank using t-Tests (see Figure 1). Growth rates among colonies on tiles at the center, middle and edge of the tank were compared with analysis of variance (ANOVA). Tests of growth at different positions in the tank were used to assess the adequacy of flow conditions at different points within the system.

## Results:

### Flow Velocity:

Flow velocities measured using the dye blot release test showed qualitatively different rates of flow between Side A and Side B. Velocities at the three heights within the water column on each side showed a consistent decrease with depth and average values for velocity at these points were calculated (see Figure 3A). Average velocities of Side A (with tiled grid) ranged from 5.14 cm/sec near the surface (43 cm from bottom) to 2.06 cm/sec (33 cm from the bottom). Velocity measurements of Side B (with cobbles) ranged from 3.67cm/sec near the surface (43 cm from bottom) to 2.00cm/sec (33 cm from the bottom) ( see Figure 3B).

### Organism Growth:

Growth rates for *Botrylloides* sp. on tiles showed consistent growth near the center of tank. Mean size on day 1 for center region was 3.035 cm<sup>2</sup>, on day14, with a mean growth of 2.11 cm<sup>2</sup>. Mean growth of center region was 2.11 cm<sup>2</sup> compared with a limited mean growth of .467 cm<sup>2</sup> for middle, and negligible mean growth of -1.39 cm<sup>2</sup> for the edge region ( see Figure 7).

Growth rate for *Botrylloide* sp. on cobbles showed consistent growth for both center and edge regions. The mean size on day 1 for center region was 1.8 cm<sup>2</sup>, with mean growth reaching 4.66 cm<sup>2</sup>. Mean growth of the edge region was .68 cm<sup>2</sup> with an overall mean growth of 1.55cm<sup>2</sup> (see figure 8) .

The relationship between average mean growth and location in tank (center, middle, edge) on the tiled grid was significantly different with ANOVA, with a p-value of .005 and a F - value of 10.5 (see Table 2). The statistical analysis, t -test, of the relationship between average mean growth of center and edge regions on cobblestones suggested no significant differences between the growth of two regions exists, p-value of .376 and critical t value of 2.30 ( see Table 1). The relationship of the average mean growth between the center regions of the tiled grid and cobbles was not significant, p value of .176 and critical t value of 2.18 (see Table3).



## **Discussion:**

The goal of this project was to design and construct a functional, small scale, moderately priced, directional flow tank for aquacultural purposes. This goal was accomplished successfully within the appropriated budget of \$2000.00 and is now 100% operational. The early completion of our primary goal enabled us to further investigate various features of the tank including flow characteristics throughout the system and the effectiveness of the tank's capability as a research tool.

The collection of flow velocity data from different depths of the tank allowed us to better analyze the capabilities or limitations the system may impose as a investigative tool for intertidal research. The dye blot release test proved to be an efficient method for testing velocities throughout the water column and allowed for precise determination of ambient flow velocity throughout the system. This test showed conclusively that the velocity of flow decreased as the depth from the surface region increased, resulting in an inversely proportional relationship between depth and flow velocity(see Figure 3).

These results were not unexpected since the air lifters discharge into the surface of the tank, subsequently increasing the velocity of flow to much greater extent at this region. An interesting observation was made when testing the flow velocity along the bottom of the tank on side A (with grid) with the dye blot release test. The support structure for the tiled grid consists of stacked bricks which cause an observable obstruction to normal flow past this unit which was easily observed when using the dye blot test. This tank system creates a very active water column especially at the region of the air lifters and, though highly directional, this is considered a turbulent environment since it strays from the

characteristics associated with laminar flow (see Picture 5). The development of a turbulent environment with high inputs of dissolved oxygen is seen as a benefit to the culture of marine organisms since these conditions more closely mimic actual intertidal and subtidal water movements.

To determine the reliability and usefulness of this tank design marine organisms, *Botrylloides* sp., were placed in the tank and growth data was recorded. Successive analysis of this data over a two week period allowed for the application of statistical testing to determine if growth data was significant compared to known growth data for these organisms, a relationship that would suggest that the tank system represents a successful model of an actual intertidal / subtidal environment. The comparison of growth data between the tiled grid and cobblestones showed varied positive growth in all individuals. From the results of the statistical analysis on the growth data, it was determined that there was no significant difference between the growth on the different substrates (tiled rack, cobbles) ( see Table 3 and Figure 6). The congruence of growth data from both growing areas suggested an interesting relationship in which certain areas of the tank appear to provide more optimum regions for growth. This data suggested that the center regions, near the baffle, provided a better growing environment (see Table 3). Decreased water velocity in the center region of the tank, as compared to the edge and middle regions, may have played a significant role in causing this variation in growth among the tunicates. Increased flow velocities may be a limiting factor that could inhibit food gathering capabilities of these organisms or impact their abilities to anchor and grow on the substrate surfaces, which would explain the increased growth recorded in the center region. It was also observed that an appreciable amount of sediment present in the

tank from placing cobblestones into the system tended to circulate around the edge region of the tank. The continuous presence of this sediment and sand could have resulted in some degree of fouling of the organisms present in this region and contributed to the observed data. Though the growth data of *Botrylloides* sp. on cobblestones appeared to reflect this relationship and the statistical analysis performed between the center and edge data suggest that this difference is not significant (see Table 1 and Figure 4). The comparison of growth data between the organisms growing on the tiled grid similarly reflected this relationship and appeared to suggest that location in the tank can significantly impact growth characteristics. Using an analysis of variance test it was determined that growth rates at different locations here were not statistically different (see Table 2 and Figure 5). These results suggest both methods of growing this organism within this system are capable of generating similar positive growth results.

A discussion of experimental error is necessary at this point as it can play a large role in effecting the overall scientific value of research data obtained through experimentation. In this growth experiment, much energy was put into collecting and recording data in a competent manner to ensure that the data collection process would not be a direct cause of possible error. However, regardless of the competency level of data collection, other factors can just as easily cause error to be a factor in the experiment. In the final data collection days of this experiment, 2 individual *Botrylloides* sp. colonies died. The resulting effects of this occurrence can easily be observed following the trend of the plotted line for the edge category ( see Figure 5). Though suggesting significance, the graph of this comparison appears partially skewed as a result of this experimental error.

The data collected in this growth experiment represent results that are consistent with observed growth rates in the field (Grosholtz, unpublished data 1998) and therefore suggest that this directional flow tank system represents an effective and viable laboratory research tool for the culture of intertidal / subtidal organisms like *Botrylloides* sp.

## **Budget Analysis**

The High Directional Flow Tank project was allotted a \$2000.00 budget. All the funds were utilized in purchasing the main components and materials for the construction and testing of this tank system. The majority of these funds (\$1500.00) were spent on the purchase of the tank and airblower. The remaining \$500.00 was allocated toward the purchasing of PVC piping, manifold structures, diffusers, and various construction materials (see Project Budget).

## Project Budget

1. Fiberglass tank (10' x 6' x 2')	\$832.00
LeGay Fiberglass, Weaverly, N.S., Canada	
2. Freight	\$425.00
3. Tank Divider	\$24.75
Struct - Glass 4' x 8'	
4. Air Blower	\$398.00
Sweetwater S-21 Aquatic Ecosystems	
5. Diffusers	\$45.00
10 - 3 in.	
6. 4" PVC uplifts	\$10.72
per 10 ft	
7. 4" PVC 90 deg. Joints	\$40.00
per 8	
8. 1" PVC airline	\$9.60
per 150 ft	
9. 1' PVC glue	\$10.00
10. Fiberglass resin	\$14.85
11. Fiberglass cloth	\$7.80
12. Miscellaneous (brushes, sandpaper, hardware, masks)	\$172.00
<b>TOTAL</b>	<b>\$1989.72</b>

## **Conclusion:**

At this point in time, the Directional Flow Tank project is 100% complete and additional tests beyond the original scope of this project have been carried out to determine the actual effectiveness of this system for use as a viable laboratory research tool. Comparison of the data from these tests with actual observed data from the field suggest that this tank system can be used as a functional model of the intertidal / subtidal environment. Its success as a viable marine research tool is anticipated as the design is versatile enough to incorporate a wide variety of organisms in an area of square footage large enough to stage many different types of investigation research including, but not limited to diet experiments, spatial distribution studies, feeding observations and breeding interactions. This tank system will provide the coastal marine lab researchers with an additional research tool to augment their investigative abilities involving culture and direct observation of marine organisms and species interaction and behavior.

The moderate cost involved in producing a directional flow tank combined with the projected longevity of the componentry incorporated into the system and the apparent successes associated with its operation suggests that systems similar to this one will continue to gain in popularity in the field of marine research.

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Table 1:  
**t- Test Between Cobblestone Regions of Growth**

df	8
P(T<=t) two-tail	0.37637684
t Critical two-tail	2.30600563

Table 1 **t-Test Between Cobblestone Growth Regions**, Displays that Growth between the two regions is not statistically different, p- value of .37 and a critical T value of 2.3

Table 2:  
**Analysis of Variance of Growth Between Center, Middle, Edge Regions of Tiled Grid**

ANOVA					
Source of Variation	SS	df	MS	F	P-value
Between Groups	24.490422	2	12.24521	10.56516	0.005688
Within Groups	9.27214167	8	1.159018		
Total	33.7625636	10			

Table 2 **Analysis of Variance of Growth Between Center, Middle, Edge Regions of Tiled Grid**, displays significant differences present between groups of p - value .005 and F - value of 10.5

Table 3:  
**t- Test Between Center Regions of Growth of Cobblestone and Tiled Grid**

df	12
P(T<=t) two-tail	0.17609134
t Critical two-tail	2.17881279

Table 3 **t- Test Comparison Between Center Regions of Growth of Cobblestones and Tiled Grid**, shows the regions of growth are not statistically different, p - value of 0.176 and critical t value of 2.17.

# Directional Flow Tank

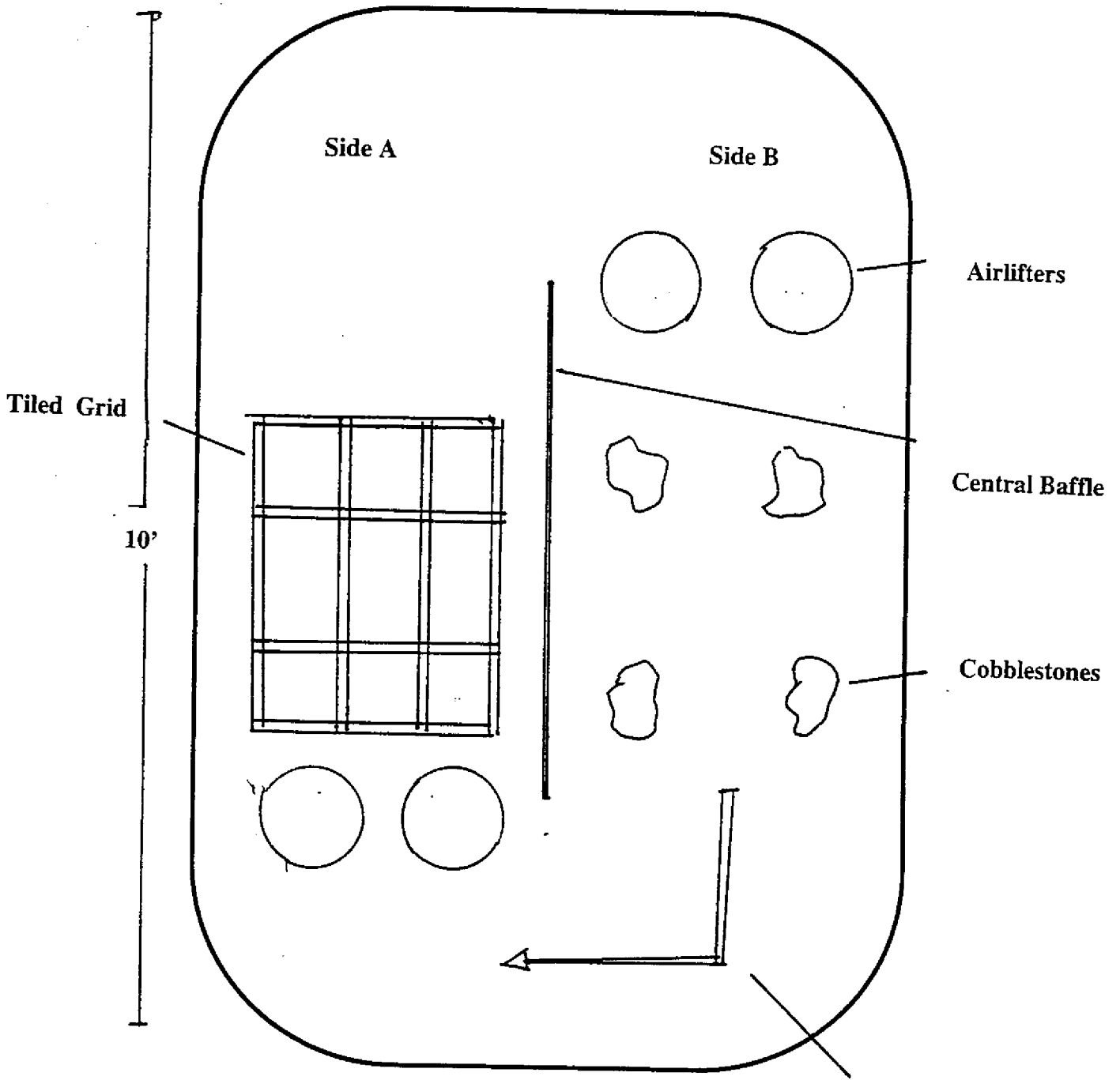


Figure 1: Directional Flow Tank

Direction of Flow

6'

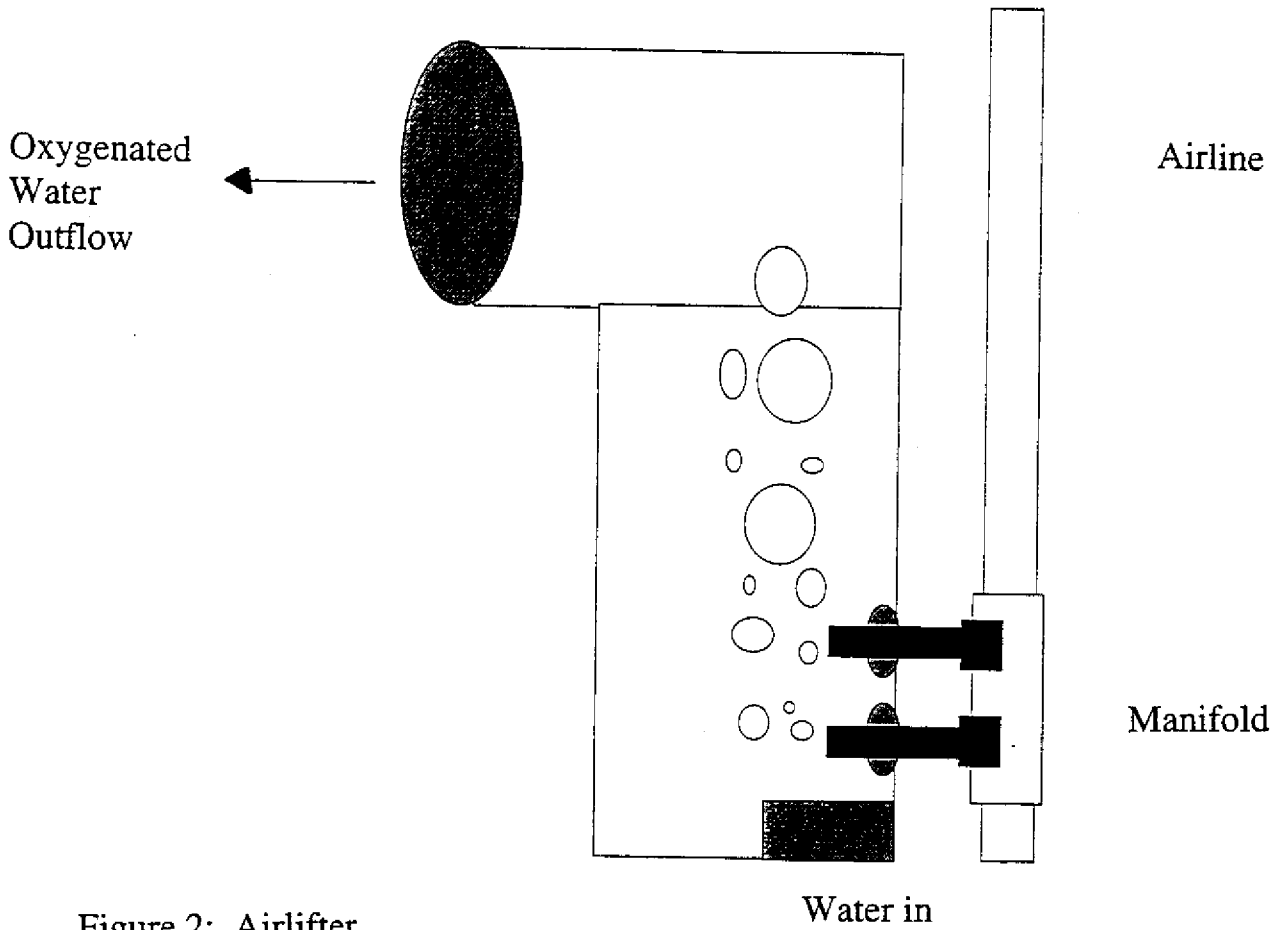
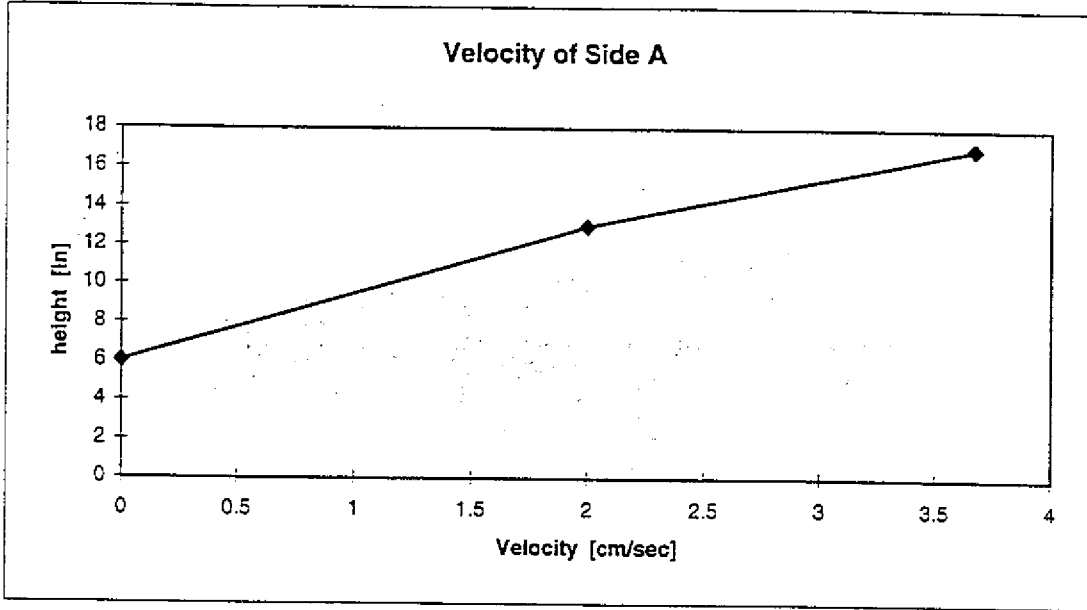


Figure 2: Airlifter

Figure 3:

A



B

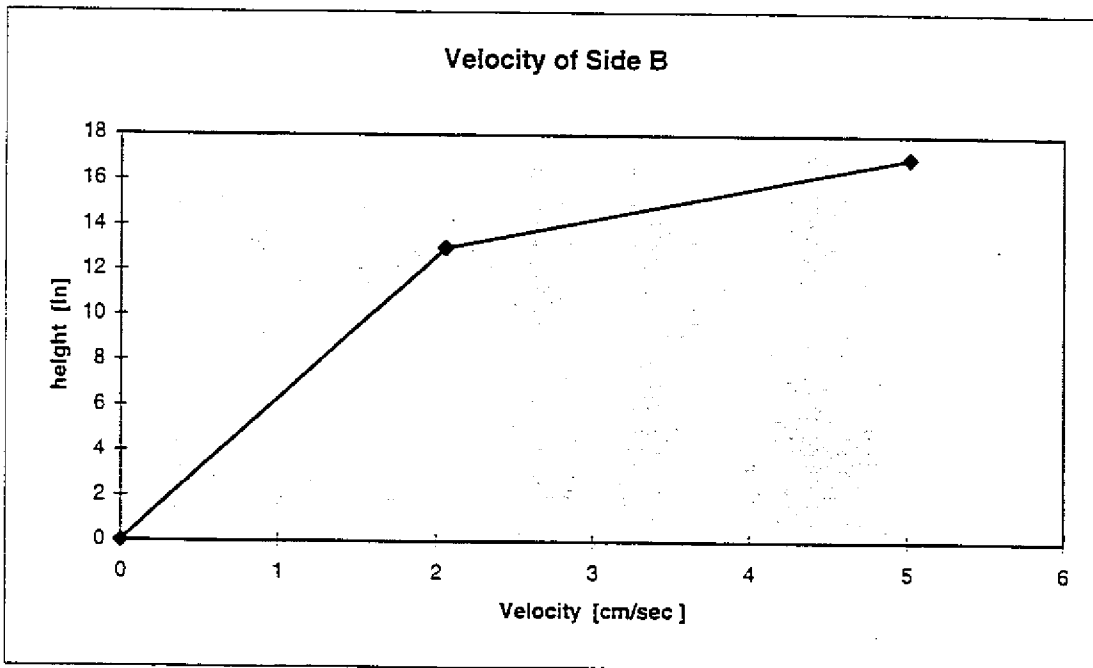


Figure 3 Comparing the two graphs, **Velocity of Side A** and **Velocity of Side B**, both exhibit an inverse relationship between the velocities and heights. There is a decrease in velocity at Side A. This decrease is due to the grid acting as an obstruction in Side A

Figure 4:

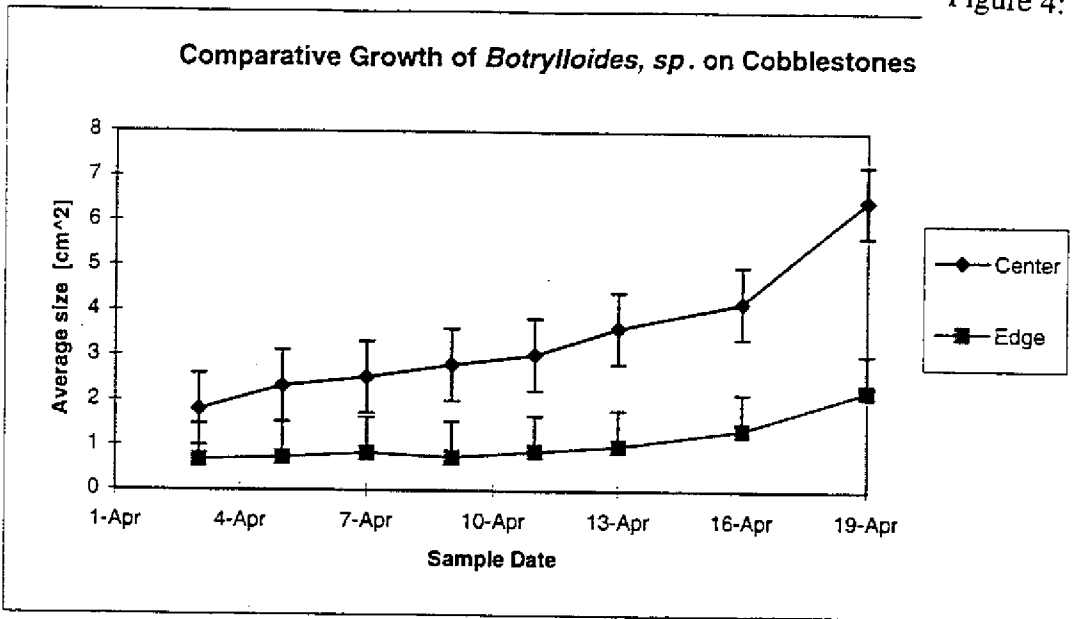


Figure 4 : "Comparative Growth of *Botrylloides, sp.* on Cobblestones," displays linear relationship growth patterns between two groups over a period of time. The tunicates in the center region displays a faster growth rate compared to the edge region.

Figure 5:

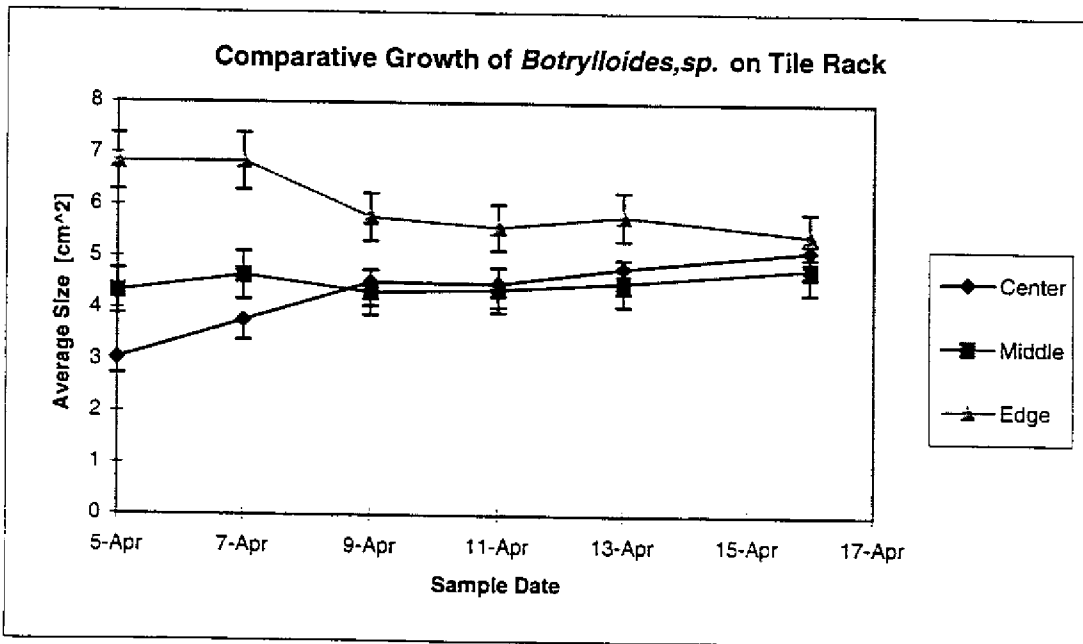


Figure 5 Comparative Growth of *Botrylloides, sp.* on the Tiled Rack," displays the growth patterns between three different groups over a period of time. The center region clearly shows a faster growth rate over a period of time compared to the edge and middle regions. The middle region also displays a faster growth rate compared to the edge region.

Figure 6:

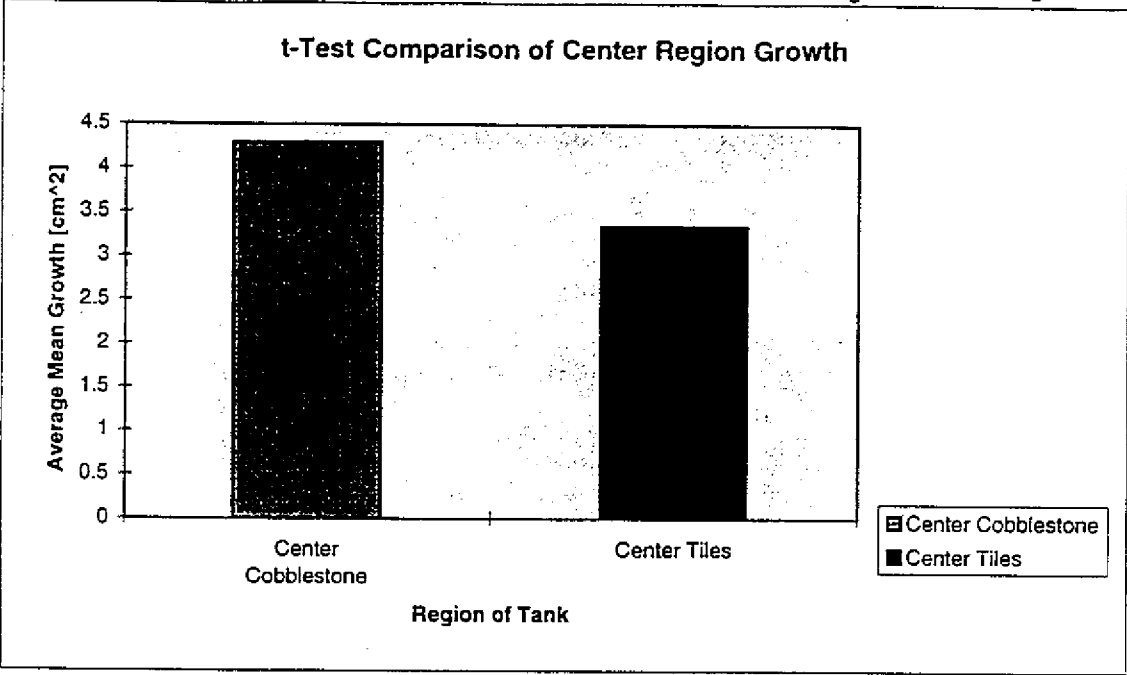


Figure 6: t- Test Comparison of Center Region Growth, shows the apparent difference in average mean growth is not significant between similar locations on different substrates tested.

Figure 7

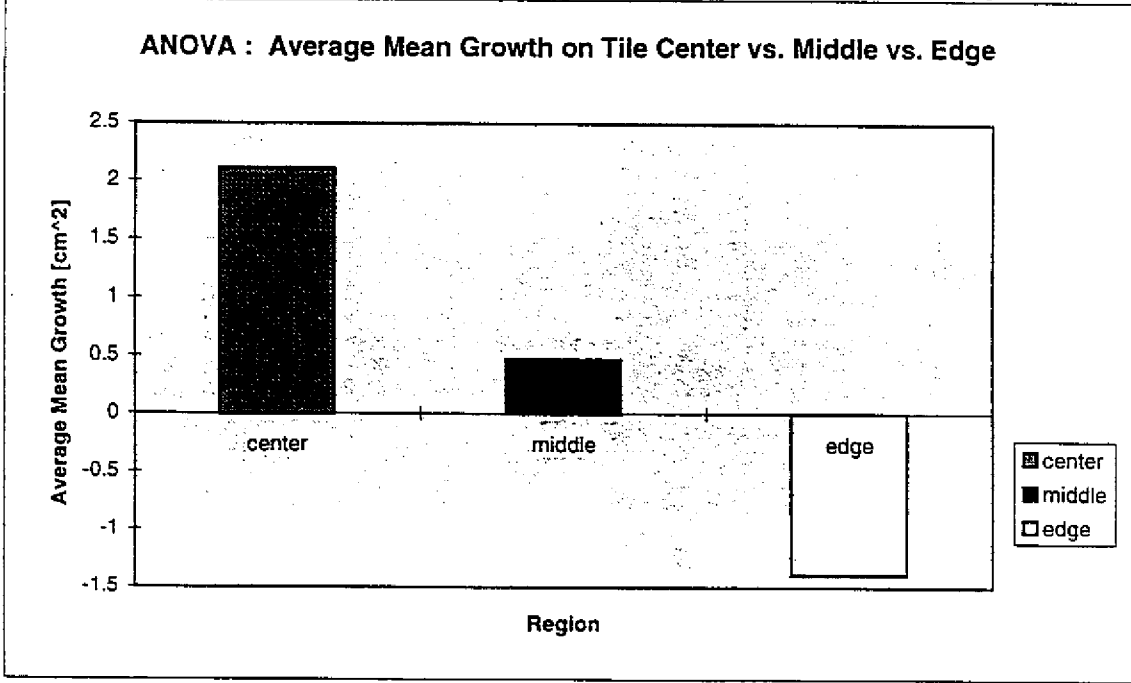


Figure 7 : Anova : Average Mean Growth Between Tiles Center vs. Middle vs Edge, displays the significant difference between the regions of the tiled grid.

Figure 8

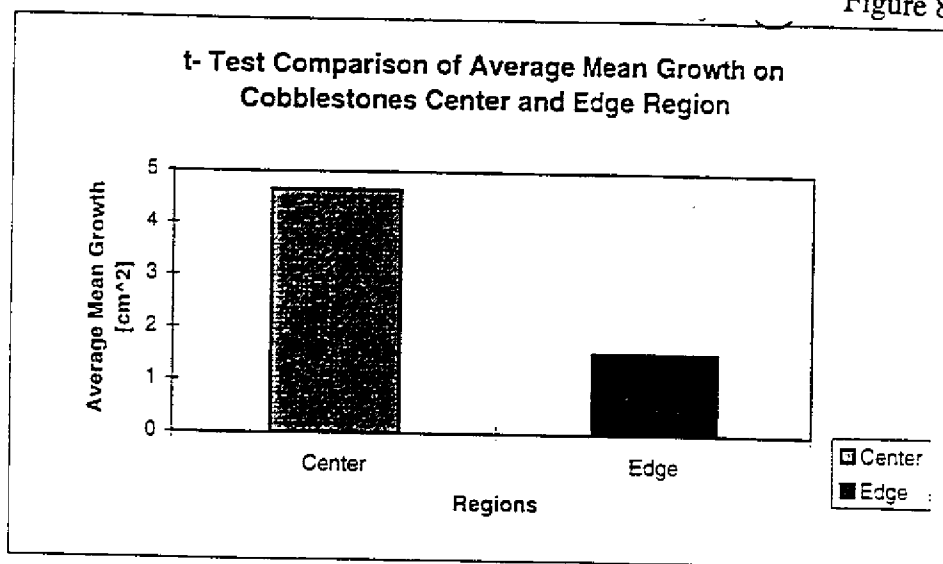
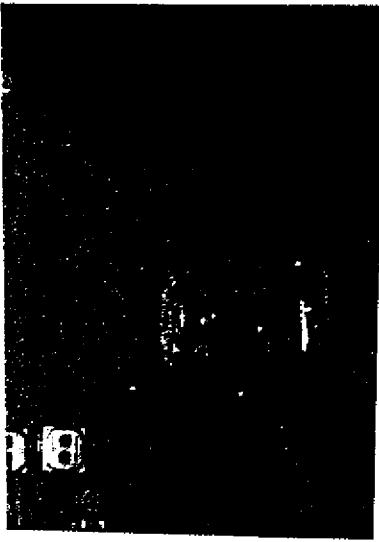
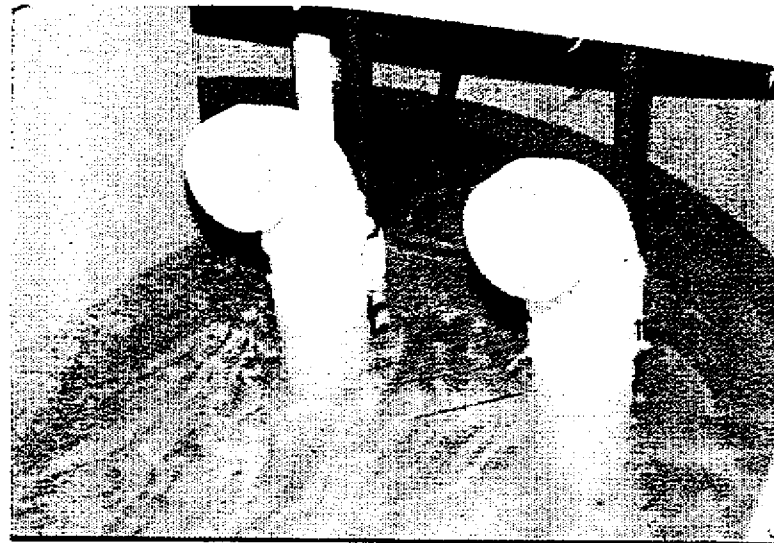


Figure 8: t - Test Comparison of Average Mean Growth on Cobblestones Center and Edge Regions, shows the average mean growth is not significant between the two regions of the cobblestones

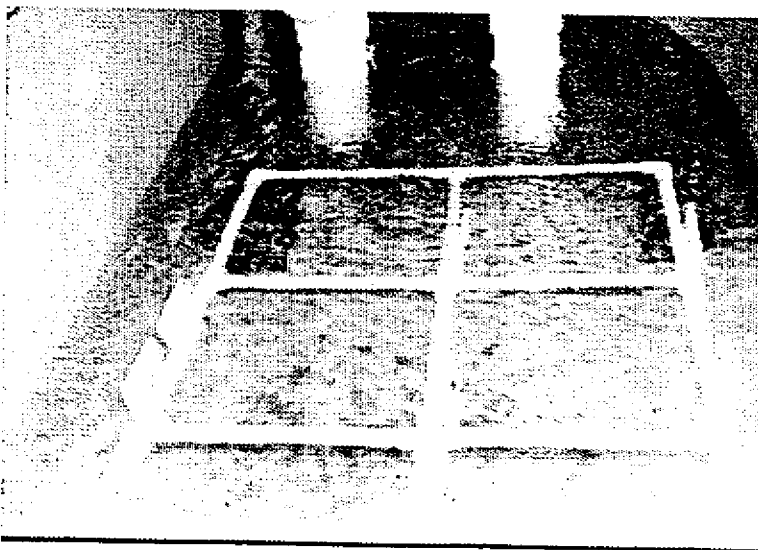




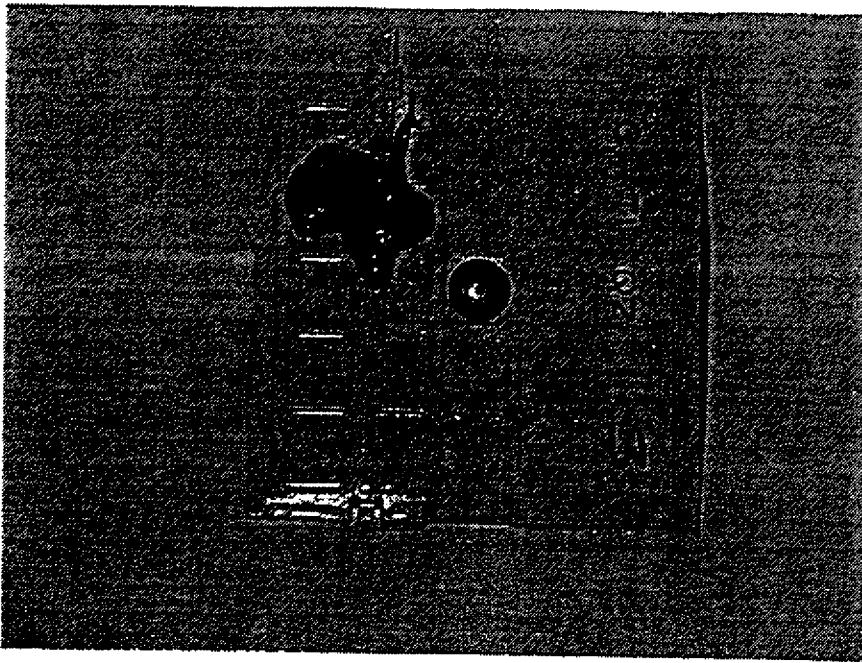
Picture 1: Sweetwater S - 21 Airblower mounted on wall at Coastal Marine Lab



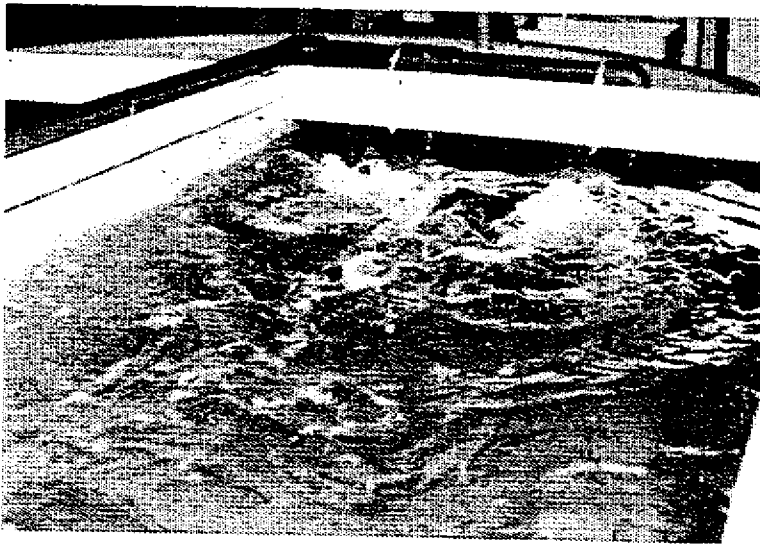
Picture 2: Airlifter units attached to manifolds



Picture 3: Tiled Grid Layout on Side A



Picture 4: Individual *Botryllodes, sp.*, colonies on tile



Picture 5: Airlifter units creating turbulent flow