Microalgae cultivation – An effective solution to air pollution

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Stage 1: Acclimatization of microalgae to desired stress

Duration: April 2017 to October 2017

Stage 2: Optimization and establishment of microalgae consortia capable of remediating air pollutants.

Duration: November 2017 to February 2018

Stage 3: Determining the change in growth pattern as well as morphological changes of the micro algal cells.

Duration: March 2018 to October 2018

Stage 4: Design an economical unit that would enable optimal survival and growth of the microalgae while mitigating aerial pollutants.

Duration: November 2018 to October 2019 (Extension for 5 months)

Introduction

Most of earth's population now lives in cities and the process of urbanization continues generating many problems deriving from the drift of the population towards them. These problems can be resolved by cities becoming efficient habitats, saving resources in a way that improves the quality and standard of living. The process however, faces a number of major challenges, related to reducing pollution, improving main transportation and infrastructure systems. New urban solutions are required to optimize the use of space and energy resources leading to improvements in the environment, i.e. reduction in air, water and soil pollution as well as efficient ways to deal with waste generation. These challenges contribute to the development of social and economic imbalances and require the development of new solutions. Air pollution is creating alarming situation day by day. Some air pollutants are poisonous. Inhaling them can increase the chances of health problems. People suffering from heart or lung diseases, older adults and children are at greater risks from air pollution. Air pollution isn't just outside – the air indoor is also polluted and affects health in more or less similar way. Various primary and secondary air pollutants like sulfur oxides (SOx), carbon monoxide, volatile organic compounds, chlorofluorocarbons (CFCs), ozone, nitrogen oxides (NOx) contribute to these increasing levels of air pollution **(S.S. Bagh, 2015)**. Each of these pollutants pose some or the other kind of threat to life on the planet.

In order to keep a check on these pollutants, various control technologies like cyclonic separation, hydrodynamic separators, different scrubbers, and methods like absorption, adsorption, bio filtration etc. have been employed **(The sustainable city IX:urban regeneration and sustainability-vol 2**). Some of the effective methods to control Air pollution are as follows: (a) Source Correction Methods (b Vegetation (e) Zoning.

a. Source Correction Methods:

Industries make a major contribution in increasing air pollution. Formation of pollutants can be prevented and their emission can be minimized at the source itself. These source correction methods are:

(i) Substitution of raw materials: If the use of a particular raw material results in air pollution, then it should be substituted by another purer grade raw material which reduces the formation of pollutants. Thus,

(a) Low sulphur fuel which has less pollution potential can be used as an alternative to high Sulphur fuels, and,

(b) Comparatively more refined liquid petroleum gas (LPG) or liquefied natural gas (LNG) can be used instead of traditional high contaminant fuels such as coal.

(ii) Modification of Existing Equipment & Process:

Air pollution can be considerably minimized by making suitable modifications in the existing equipment. The existing process may be changed by using modified techniques to control emission at source.

(a) For example, smoke, carbon-monoxide and fumes can be reduced if open hearth furnaces are replaced with controlled basic oxygen furnaces or electric furnaces.

(b) In petroleum refineries, loss of hydrocarbon vapors from storage tanks due to evaporation, temperature changes or displacement during filling etc. can be reduced by designing the storage tanks with floating roof covers.

(c) Pressurizing the storage tanks in the above case can also give similar results.

(d) If coal is washed before pulverization, then fly-ash emissions are considerably reduced.

(e) If air intake of boiler furnace is adjusted, then excess Fly-ash emissions at power plants can be reduced.

b. Vegetation:

Plants contribute towards controlling air-pollution by utilizing carbon dioxide and releasing oxygen in the process of photosynthesis. This purifies the air (removal of gaseous pollutant—CO_2) for the respiration of men and animals.

Gaseous pollutants like carbon monoxide are fixed by some plants, namely, *Coleus Blumeri, Ficus variegata* and *Phascolus Vulgaris.* Species of *Pinus, Quercus, Pyrus, Juniperus* and *Vitis* depollute the air by metabolizing nitrogen oxides. Plenty of trees should be planted especially around those areas which are declared as high-risk areas of pollution.

c. Zoning:

This method of controlling air pollution can be adopted at the planning stages of the city. Zoning advocates setting aside of separate areas for industries so that they are far removed from the residential areas. The heavy industries should not be located too close to each other.

New industries, as far as possible, should be established away from larger cities (this will also keep a check on increasing concentration of urban population in a few larger cities only) and the location decisions of large industries should be guided by regional planning. The industrial estate of Bangalore is divided into three zones namely light, medium and large industries. For example in Bangalore and Delhi very large industries are not permitted.

All these techniques have been employed in whole or part by many of the industries but due to various reasons these may or may not be feasible to all, therefore it is essential to bring a green solution that could tackle the growing concerns.

d. Green/Biological solutions

Tiny organisms known as microalgae could hold answers to majority of the pollution problems. Using the microalgae could halve the carbon dioxide in the flue gas. Simultaneously, the levels of nitrogen oxides could be drastically cut and that of sulfur oxides were considerably reduced when flue gas was bubbled through the medium in which the organism was growing (Raj, 2011). Microalgae, the microscopic, predominantly unicellular eukaryotes, are the most common inhabitants of Earth's water bodies. Due to their short generation time, they multiply exponentially under favorable environmental conditions. Efforts are constantly being made to comprehend the non-target effects of environmental pollutants toward cyanobacteria and microalgae because of their ubiquity in aquatic and terrestrial niche and their highly adaptive survival abilities under environmental and evolutionary pressure. Being photosynthetic, they act as massive carbon sinks. They also possess the capacity to take up metal ions from the

surrounding medium. Different microalgal species are distinct with respect to the biomolecules they accumulate. These biomolecules- pigments, lipids, and proteins- constitute high-value nutrients in human and animal diets. Considering these attributes of microalgae, their potential in bioremediation of toxic metal pollutants and minerals like nitrates and phosphates in water and the greenhouse gases (CO_2 and N_2O) in the flue gas emissions from fossil fuel consumption in transport vehicles and industries is being extensively explored. The microalgal biomass thus created during biosequestration of greenhouse gases and nutrient minerals can be a source of nutraceuticals for humans or animals and also probably a biofuel.

The need for clean and low-cost algae production demands for investigations on algae as pure culture and as consortia to determine its physiological response under different growth and climatic conditions.
Aim of this project is to employ and determine the efficiency microalgae in remediation of air pollution.

Microalgae systems can absorb up to 200 times more CO_2 than trees [6], current systems [7] – photobioreactors – (Figure 2) are used as a Sustainable method to generate through biomass value added products such as bio-fuels or foods, in fact, several scholars have recently pointed out Microalgae as the “food of the future” [8-9].

The Microalgae cultivation systems are categorized into open (ponds, lagoons or creeks that receive direct sunlight.) and closed systems (transparent vessels and containers that are kept outside under the sun or under artificial light).

Photobioreactors work under controlled conditions. Thus, problems of water evaporation and carbon dioxide absorption faced in open pond systems are taken care of. The growth of unwanted algae and molds can also be minimized through this type of system. However, contamination is not completely eliminated even with closed systems. The disadvantages of this system are that it is rather difficult to construct (compared to open systems) and they also incur greater maintenance costs.

Currently immobilized microalgae are used in metabolite production, culture collection handling, co-immobilized systems and production of energy and removal of undesired or valuable substances from media (nutrients, metals and different pollutant agents).

Technologies in use:

- **Microalgal purification system on highways.**

A French and Dutch design company has come up with an elegant and green solution to clear up the environment around highways: suspended algae farms. So far, they have implemented such a system over a small stretch of highway in Geneva, Switzerland. As a proof of concept, a closed system of transparent tubes, clinging onto the viaduct was used for the production of algae. These algae could be used to filter air, as combustible biomass or even as raw material for different cosmetic and alimentary products. A steel structure, supporting all the secondary equipment such as pumps, filters and solar panels, functions as a marker for the quickly passing traffic near a highway. Over time, the alga matures into what can be turned into any number of usable products. Most notably, the algae can be used as combustible biomass or in creams, lotions and other cosmetics.

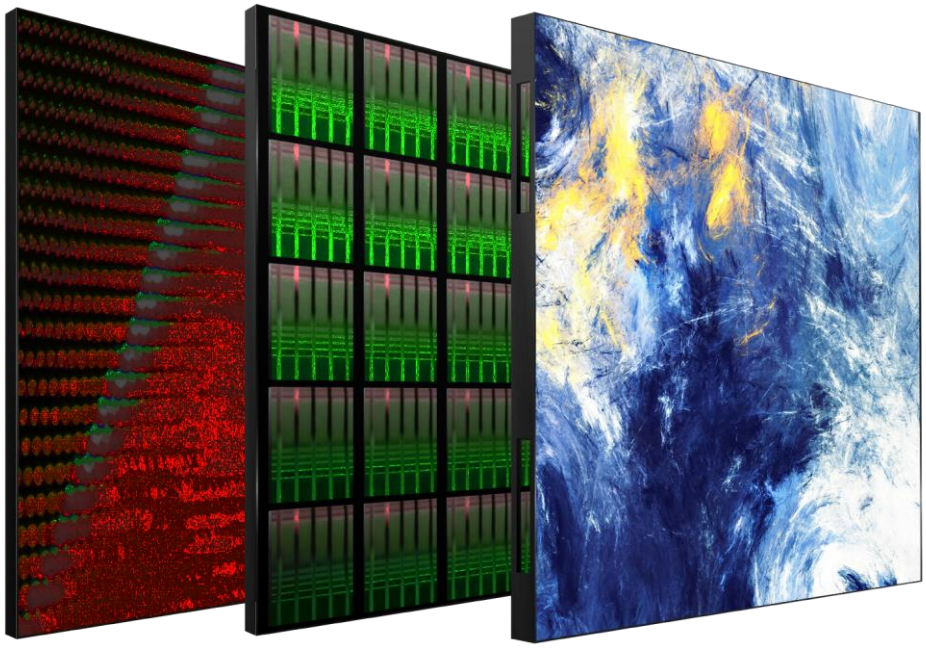
Figure description: Prototype installment done on a highway in Geneva, Switzerland

- **Artveoli**

A Delaware Corporation established in 2015 based in Silicon Valley pronounced to improve indoor air quality by: Creating fresh air and removing increased levels of localized CO_2 indoors.

The core technology constitutes a microfluidic high density photobioreactor that converts CO_2 into Oxygen with the help of three essential parts: An LED panel that acts like the Sun,

Microfluidic Bio-Chips panel that act like trees using photosynthesis to convert CO_2 to Oxygen and a customizable front panel in digital or printed art. (see image below)



- On similar lines we propose here, a scalable microalgal system for indoor areas which would enable growth of microalgae alongwith remediating majority of pollutants in the vicinity.

AIMS & OBJECTIVES

1. **Acclimatization of microalgae to desired stress**
    - **a.** Isolation, characterization & enrichment of microalgae
    - **b.** Exposure of the microalgae to outdoor pollutants vs. indoor pollutants
2. **Optimization and establishment of microalgae consortia capable of remediating air pollutants.**
    - **a.** Optimization and establishment of microalgae consortia
    - **b.** Acclimatization of the microalgae to stress
    - **c.** Remediating capacity of microalgal consortia.
3. **To study the changes in growth pattern as well as morphological changes of the microalgal cells pre and post exposure to naturally present pollutants in the environment.**
    - **a.** Growth pattern of the microalgae exposed to outdoor pollutants was determined over a period of two months wherein the chlorophyll content, growth in terms of chlorophyll a and biomass generated was observed.
    - **b.** The rate of evolution of oxygen was determined by setting up a micro unit of the system comprising of the microalgal consortia has been experimented and verified statistically.
    - **c.** Nutritional profile of the biomass obtained was analyzed for carbohydrate content, lipid content and protein content.
4. **The Design of an economical unit that would enable optimal survival and growth of the microalgae while mitigating aerial pollutants.**
    - **a.** Immobilization of microalgae on various matrices
    - **b.** Designing a microalgae bioreactor that would enable optimal survival and growth of the microalgae
    - **c.** Mitigation of pollutants by microalgae.

EXPERIMENTAL SETUP & RESULTS

1a. Isolation, characterization & enrichment of microalgae

Water sample from a local pond was collected and processed according to standard procedure to initiate microalgae growth *(A. Ilavarasi et. al)* (figure 1a, b). Two different growth mediums, blue green algae 11 (BG-11) and Chu's no.10 medium were tested as to ensure and determine optimal growth pattern as well as productivity. The microalgal consortium was enriched in BG11 medium with pH 8, photoperiod of 12:8 hours light: dark ratio, for desirable optimal growth and the temperature optima was determined to be 26 ±2°C.

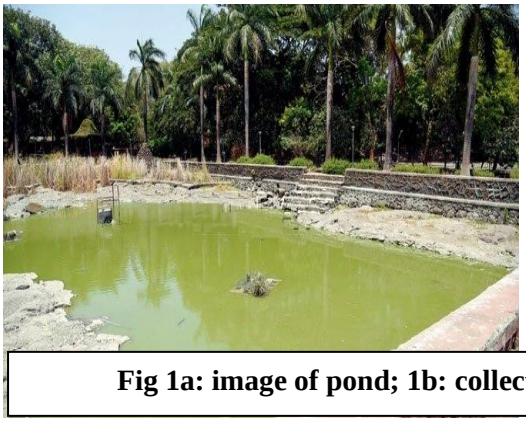
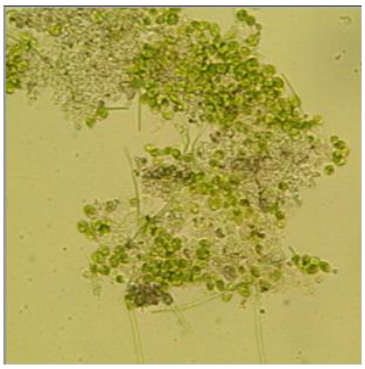


Fig 1a: image of pond; 1b: collected sample



***Microalgae growth.*(40X)**

1 b. Outdoor acclimatization of microalgal consortium:

In order to check the capability of the consortium to survive under natural environmental conditions, two sets of initial 400 ml culture medium one at two different locations were set up (fig 2a, 2b).Both the places were determined to be polluted residential areas according to NAQM data(http://airpollutionapi.com/aqi/india/maharashtra/mira-road-east,http://airpollutionapi.com/aqi/india/maharashtra/dombivli-east)

Fig 2a: Setup at Mira road

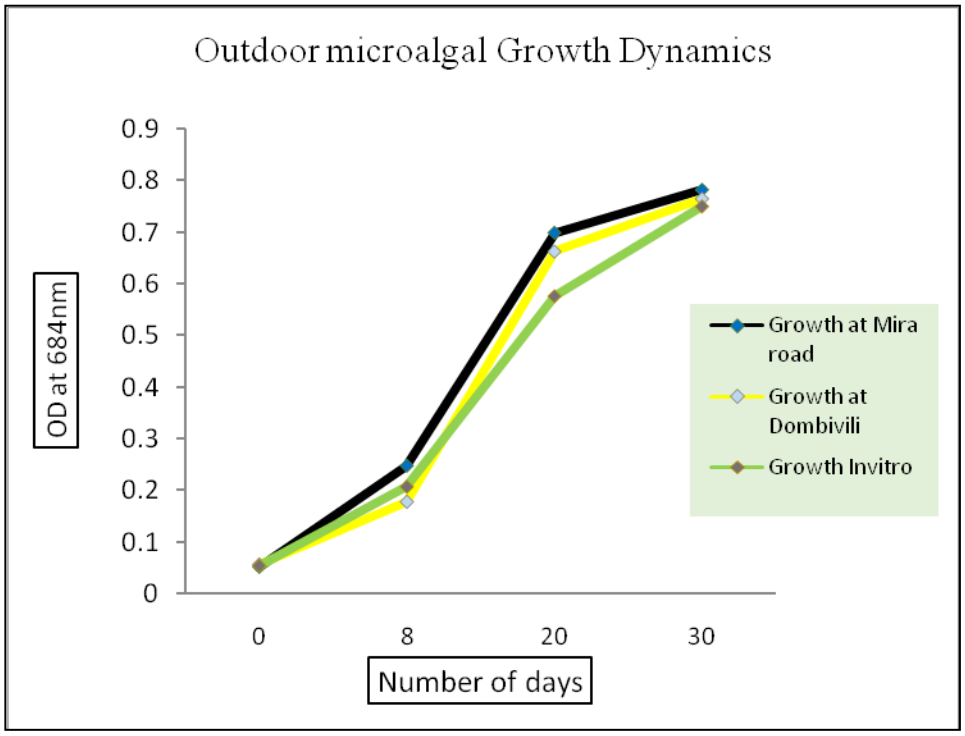
Fig 2b: Setup at Dombivili east

The growth observed was as shown in table 1:

Day	Consortium 1 location 1 growth @684nm	Consortium 2 Location1 growth @684nm	Consortium 1 location 2 growth @684nm	Consortium 2 location 2 growth @684nm
0	0.223	0.301	0.078	0.177
8	0.249	0.330	0.179	0.159
20	0.700	0.394	0.663	0.514
30	0.734	0.483	0.796	0.585

Key:

Consortium1: consists of Spirulina dominance
Consortium 2: consists of Chlorella species dominance
Location 1: set up at Mira road
Location 2: set up at Dombivili



Graph 1: Comparative growth analysis of Microalgae indoor vs. outdoor

2 a. Optimization and establishment of microalgal consortia

In the second phase, the diverse micro-algal species were screened for their inherent traits, nutrient requirements and growth complementarities. Three different nutritive mediums viz. Blue green algae medium (BG11), Bold Basal medium (BBM) and Chu's no. 10 medium were used for the culturing of the microalgal species obtained (Fig 3).

Two robust species were selected for consortia development. The scale up of the process for desirable production of high quality biomass is being carried out. The capability of each microalga to survive in a consortium was analyzed and established by varying physical parameters like pH and temperature. It was observed that both the cultures were able to grow and reproduce synergistically at temperatures ranging from 25°C - 40°C, and pH from 7 to 11.

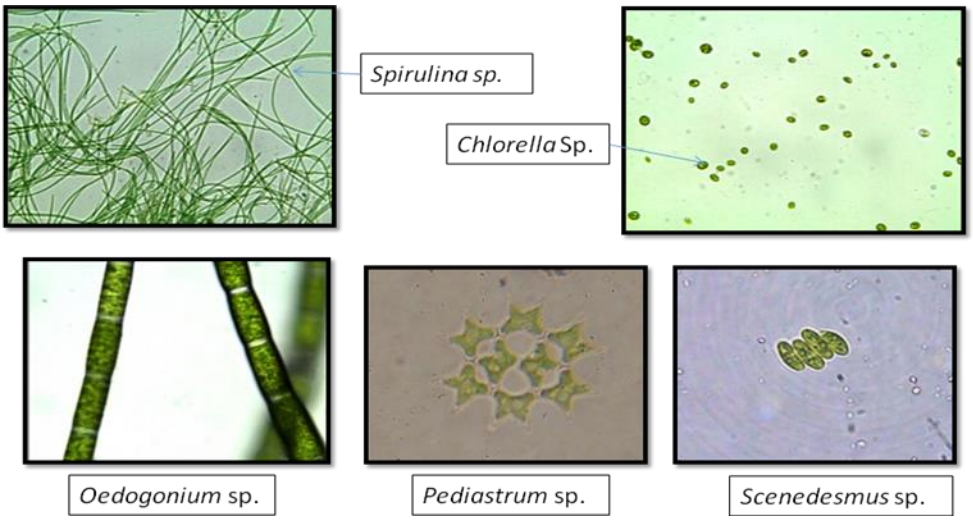


FIG.3 Microalgal isolates enriched, as observed under the Optical light microscope. Microalgae belonging to 5 different genera could be identified on morphological basis

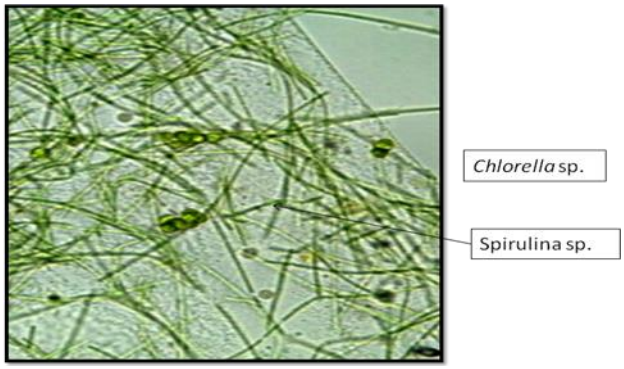


FIG 4: Microalgal consortium, microscopically characterized at 40 X magnification.

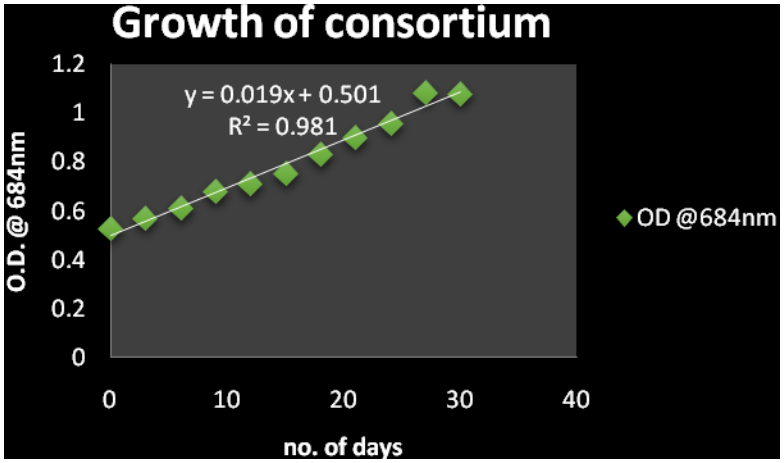
Results clearly indicated a fine compatibility between *Chlorella* species & *Spirulina* species as compared to other microalgae which were not able to survive in the consortia.

The Growth of the Consortium was monitored every 3 days until a period of 30 days. (Table no. 2, Graph 2)

Days	Temperature (max°C/ min°C)	pH	OD @684nm
0	36/23	7	0.531
3	35/22	7.5	0.572
6	36/23	7.9	0.613
9	35/22	8	0.678
12	33/22	8.5	0.711
15	33/20	9	0.756
18	33/19	10	0.833
21	35/22	10.5	0.902
24	32/18	11	0.960
27	35/20	11	1.086
30	35/18	11	1.081

Table 2: Monitoring growth parameters (temperature and pH) of the consortium

Graph2: Growth of Consortium for a period of 30 days



2 b. Acclimatization of microalgal consortium to stress

I. Sulfide stress as Hydrogen Sulphide:

Hydrogen sulfide was synthesized in the lab and bubbled through BG11 medium (Fig 5) in which the microalgae consortium was then inoculated.

The system was tested for 30 days where growth of culture, pH & conductivity of system and concentration of H_2S were periodically monitored. The initial concentration of sulfide in the medium was contributed by $MgSO_4$, $CuSO_4$ and $ZnSO_4$and determined to be around 8ppm

Fig 5. H_2S setup

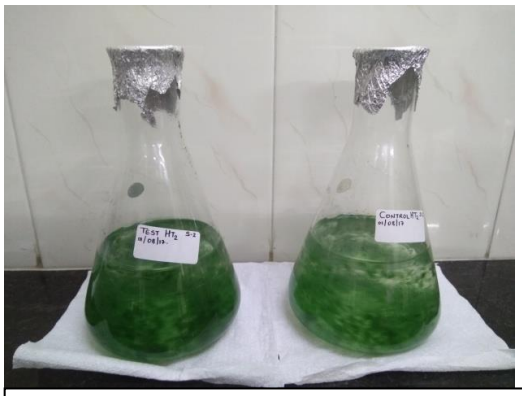


Fig 6. Microalgae control vs test H_2S

The system was tested for 30 days where growth of culture, pH & conductivity of system and concentration of H_2S were periodically monitored. The initial concentration of sulfide in the medium was contributed by $MgSO_4$, $CuSO_4$ and $ZnSO_4$ and determined to be around 8ppm.

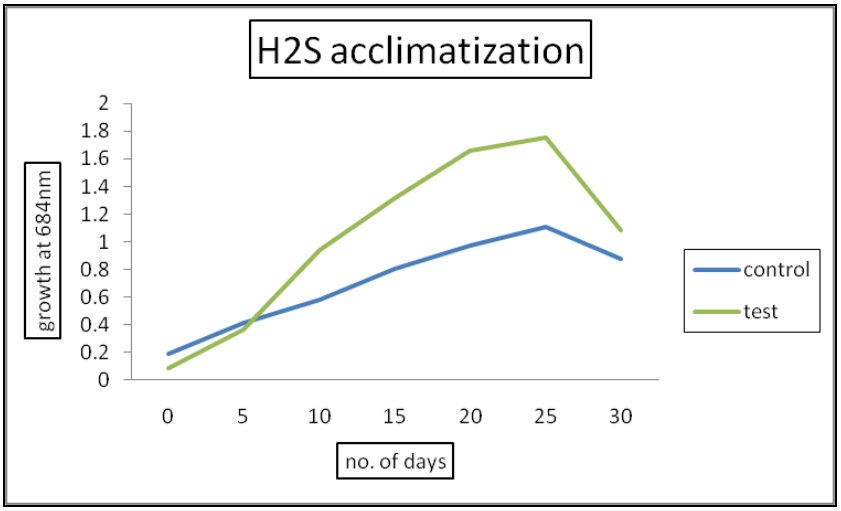
The following tables 3 & 4 show the survival and growth of the consortium to sulfide concentrations.

Table 3: Control system devoid of any external sulphide stress

Day	pH	Conductivity	Growth @684nm
0	7	6.12	0.191
5	7.5	6.14	0.411
10	8.5	6.45	0.58
15	10	5.67	0.805
20	10.3	5.53	0.97
25	10.5	5.67	1.104
30	10.5	5.44	0.87

Table 4: Test system with external sulphide stress

Day	Concentration of S^- (ppm)	pH	Conductivity	Growth @684nm
0	70.4	6	5.86	0.086
5	38.4	7.8	6.06	0.364
10	21.6	9	6.55	0.944
15	73.6 (100ml)	8	5.46	1.314
20	44.4	9	5.17	1.659
25	27	10	5.63	1.755
30	15.86	10.5	5.67	1.085



Graph 3: acclimatization of microalgae consortia to sulphide stress (growth dynamics)

The microalgae consortia comprising of *Chlorella Spp.* and *Spirulina spp.* was acclimatized to a maximum concentration of 70.4 ppm of sulphide wherein the growth pattern recorded showed an increase in presence of high concentrations of sulphide and a decline in the growth was observed when no external sulphide was provided.

The microalgae could survive, grow and replicate successfully under 73.6ppm sulfide stress.

II. **Acclimatization to Carbon-dioxide:**

Carbon-dioxide was synthesized in the lab and bubbled through BG11 medium (Fig 7) in which the microalgae consortium was then inoculated.

Fig 7. Carbon dioxide response

The system was tested for 15 days where growth of culture, pH & CO_2 of system were periodically monitored. The initial concentration of carbonate in the medium was 20ppm as determined using Himedia kit.

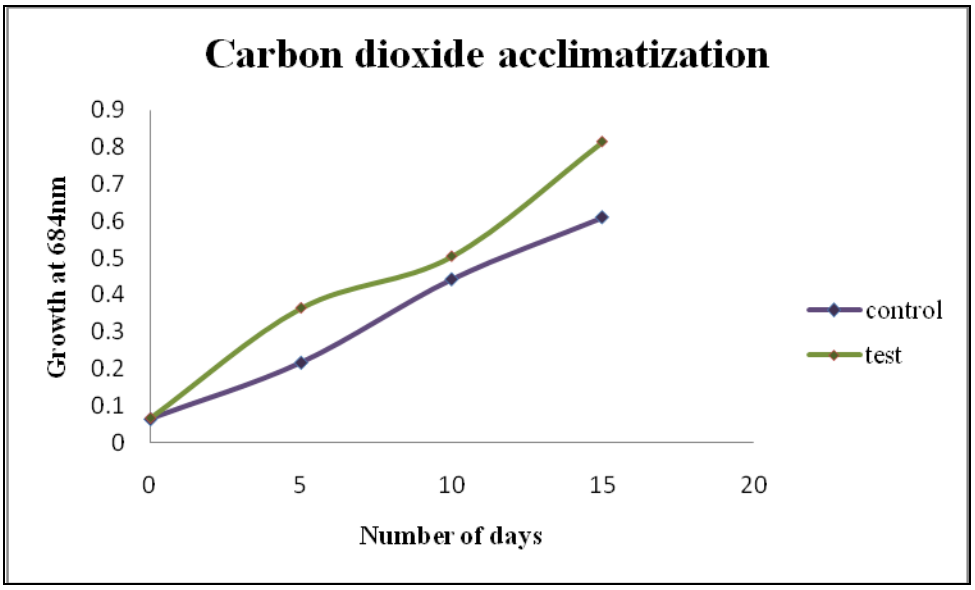
The following tables 5 & 6 show the survival and growth of the consortium to carbonate concentrations.

Table 5: Control set devoid of any external carbon-dioxide stress

Day	**Concentration of CO_2 (ppm)**	**pH**	**Growth @684nm**
0	20	6.7	0.063
5	10	7	0.216
10	4	7.4	0.442
15	2	8	0.610

Table 6: Test system with external carbonate stress

Day	Concentration of CO_2 (ppm)	pH	Growth @684nm
0	80	5.5	0.066
5	20	6.6	0.364
10	10	7.2	0.504
15	4	7.6	0.814



Graph 4: acclimatization of microalgae consortia to Carbon-dioxide stress (growth dynamics)

Studies showed that the microalgae were able to utilize 60ppm of carbon dioxide in a span of 5 days with simultaneous increase in growth in terms of chlorophyll a content from 0.066 to 0.814 measured at 684nm.

3 a. Experiment for determining morphological changes

System was setup for a period of one month. Test samples were placed in locations Mira road, Thane and a control was maintained in the laboratory under controlled conditions.

Growth was monitored every 5 days and Morphological changes were observed over a period of time.

The following are the images of control (fig 8) and test flasks (figs. 9-12) over a month's period.

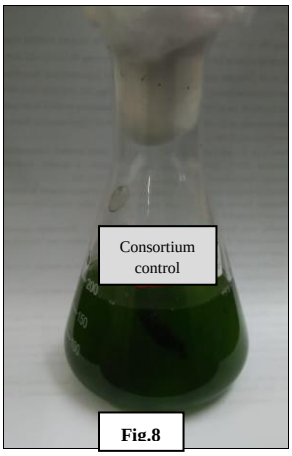


Fig.8

Control Day 30

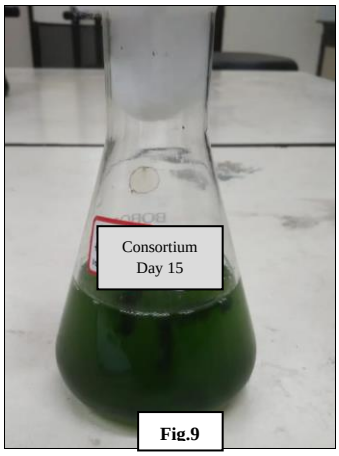


Fig.9

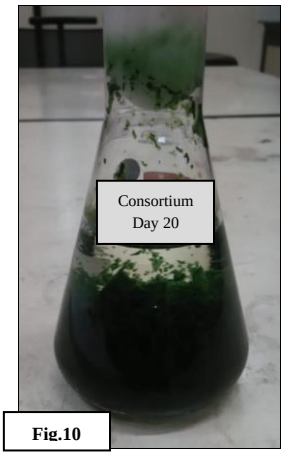


Fig.10

In Test flask, Clumping was observed from Day 20 onwards

Fig.11

Day 25

Fig.12

Day 30

- Microscopic Images (under 40X magnification) of the test flask during various stages were as follows:

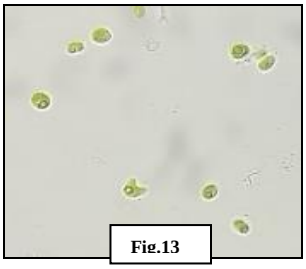


Fig.13

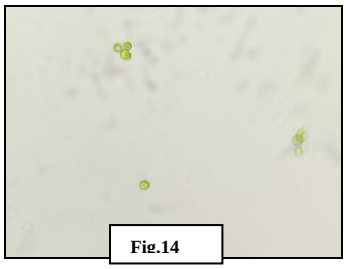


Fig.14

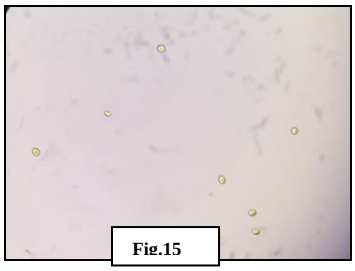


Fig.15

- Control flask (Fig 13) showed uniformity in the morphology of cells from day1 to day 30
- During initial stages (day 1 – day 14) well dispersed cells were observed but with smaller as compared to those observed in the control (Figures 14&15).

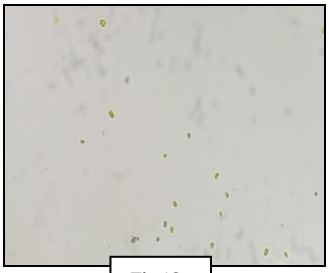


Fig.16

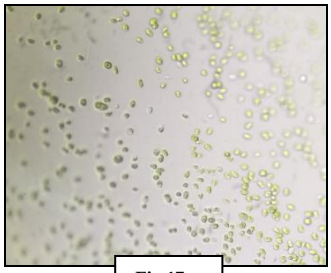


Fig.17

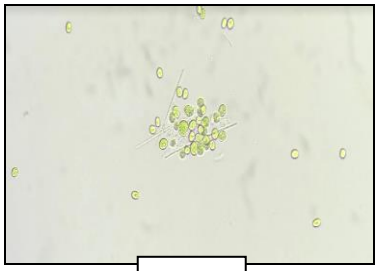


Fig.18

- During intermediate stages (Day15- Day 20) aggregation of the cells alongwith presence of *cyanobacteria* was observed. (Figures 16-18)

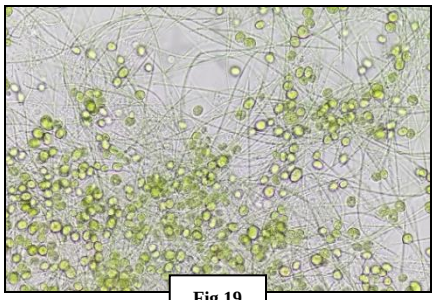
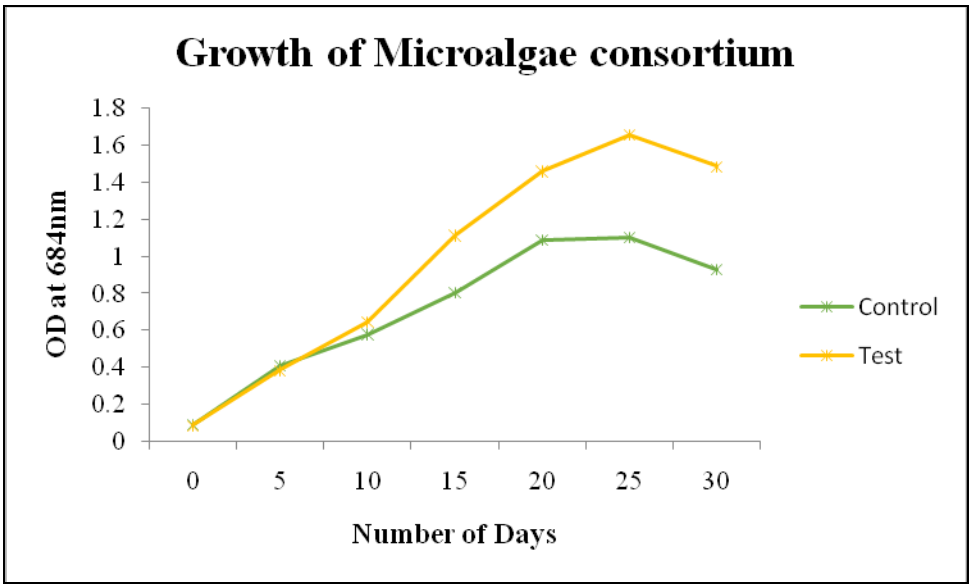


Fig.19

During the end of the experimental study close aggregation of *Chlorella* and *cyanobacteria* was observed (Fig19).

- **Growth pattern of the consortium**

The growth pattern of the microalgal consortium was tested by exposing the microalgae consortium to outdoor pollutants where in a test flask and a control flask with equivalent initial concentration of microalgae were observed for a period of 30 days. The experiments were performed in triplicates.



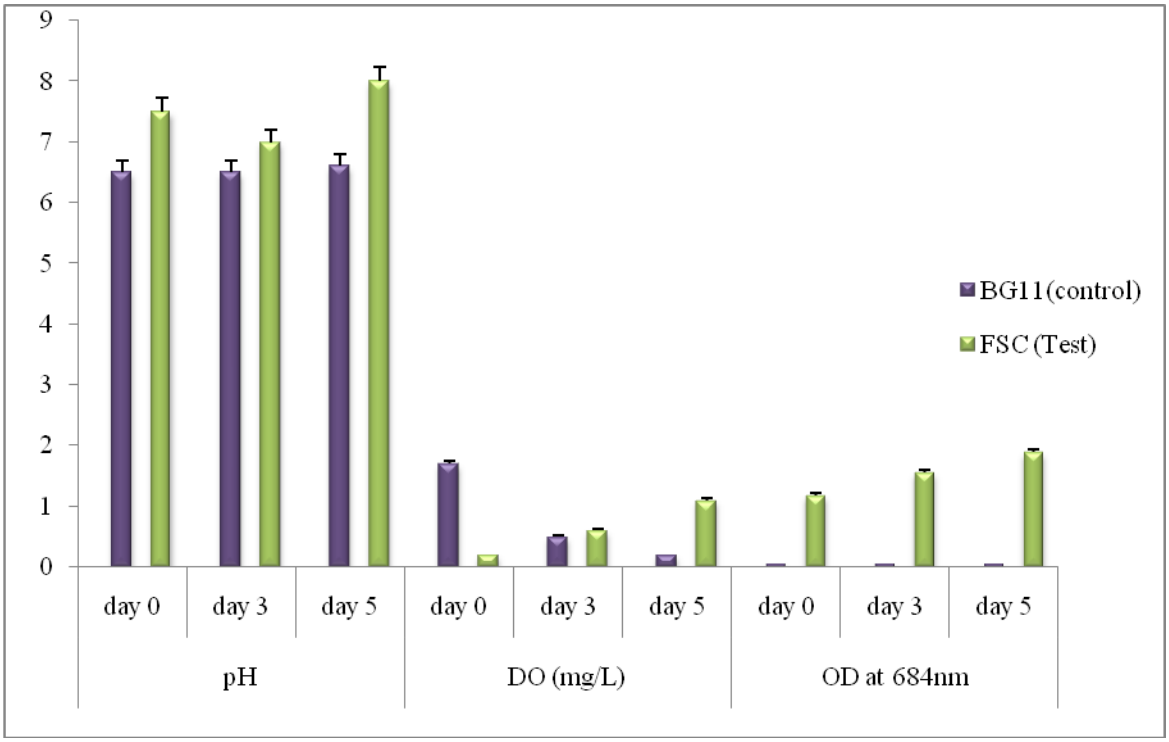
Graph 5: Growth dynamics of microalgae consortia outdoor vs. indoor

3 b. Experiment to monitor evolution of oxygen

A laboratory system was set up in order to determine the rate of evolution of oxygen due to microalgae and a system with BG11 was used as control.

The parameters monitored were growth in terms of chlorophyll a, dissolved oxygen & pH

- Graph 6: The following graph displays the results obtained.



3 c Nutritional Profile of Biomass Obtained:

Post harvesting **1.036 ± 0.023 g/L** dried biomass in test while **0.8642 ± 0.04 g/L** in control systems respectively. The nutritional profile of the microalgae was analyzed (Fig. 20, 21)

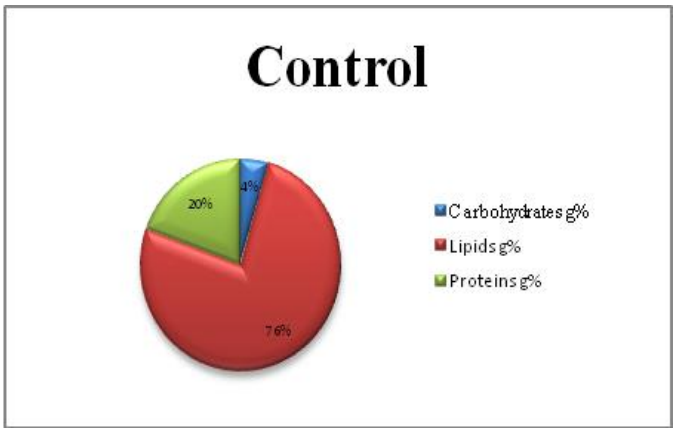


Fig.20

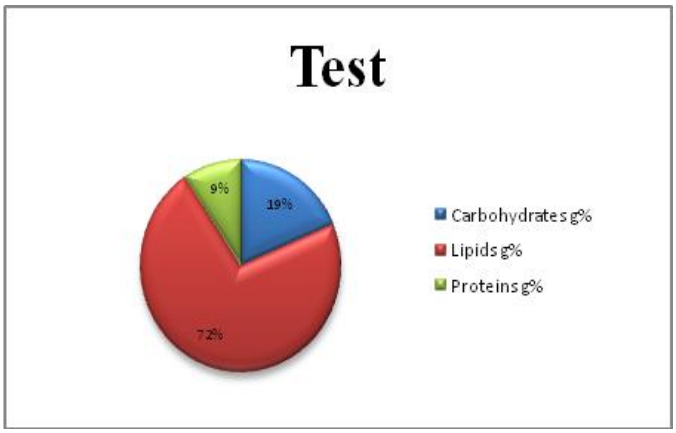


Fig.21

4 a. Immobilization of microalgae

In order to immobilize the microalgae consortia, various matrices were used

I. **Aquarium filter**: Fig 3.1 shows the initial setup for immobilization. The filter sponge was cut 10cm * 20cm and placed in the container as shown in the image. The sponge was partially submerged in 40ml of 20 % v/v inoculum and 320ml of BG11 medium.

Figure 22a shows the initial setup of immobilization while fig. 22b shows the immobilization of microalgae consortium on the filter.

Fig 22 a: setup of 13*11cm cut filter submerged in 320ml BG11 and 40ml inoculum

Fig 22 b: Immobilization of microalgae observed on the matrix

II. **Calcium alginate**: To 5 mL of green algae culture 2.5 mL of 2% sodium alginate solution was added and mixed. The algae mixture is then gently and uniformly dropped in cold calcium chloride solution, to make immobilized algae bead. Figure 23 shows the microalgae incorporated in the calcium alginate beads.

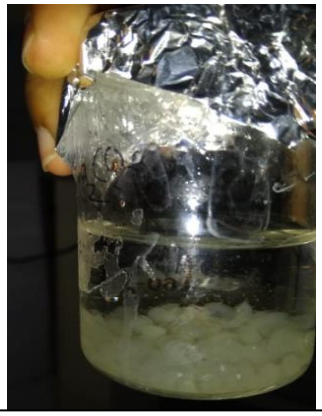


Fig 23: Microalgae trapped in calcium alginate

III. **Hydrogel beads:** fig 24a - 24d is a stage wise observation of immobilization taking place on hydrogel beads. These are inert, non- toxic beads that swell up when put in liquid. Here they were immersed in BG11 medium until they reached a medium size approx. 0.7-0.8cm in diameter. After which these were pricked with a surface sterile needle before adding the microalgae inoculum.

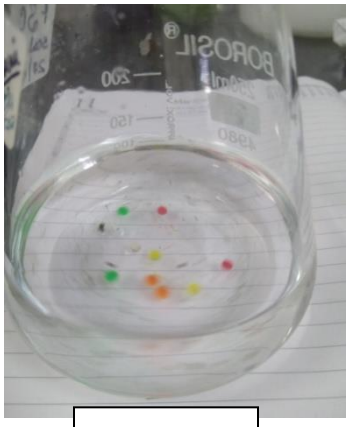


Fig 24 a

Fig 24 b

Fig 24 c

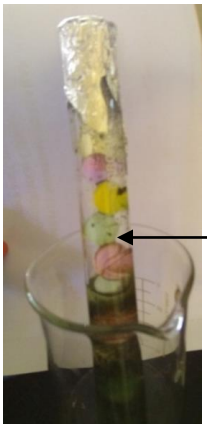
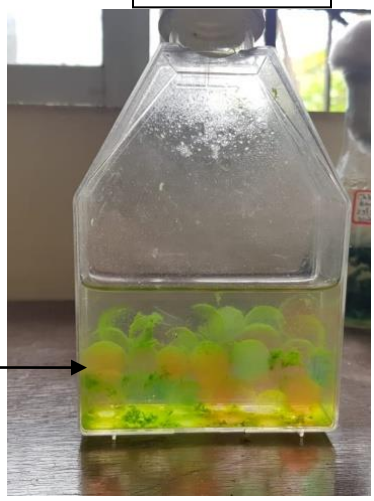


Fig 24d : Surface immobilized algae



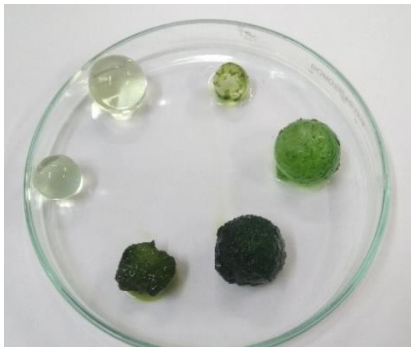


Fig 24 e: stepwise immobilization on hydrogel beads.

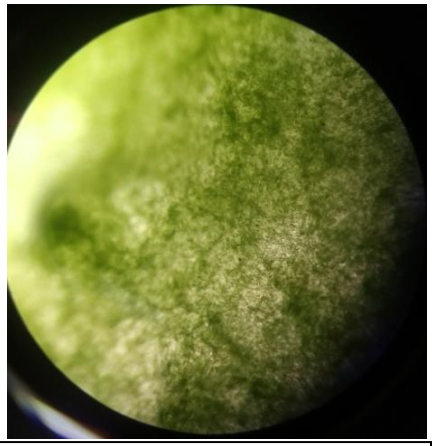


FIG 24 f, g: Microscopic view of immobilized algae biomass on hydrogel (40X)

IV. **Zeolite:** These are aluminosilicate members of the family of microporous solids known as "molecular sieves", and mainly consist of Si, Al, O, and metals including Ti, Sn, Zn, and so on.

Fig 25 a: Zeolite as purchased

Fig 25 b: Zeolite & algae inoculated in 2 ml BG11

Fig 25 c: Film like immobilization observed

4 b. The fact that microalgae remediate environmental pollutants is quite evident. 1 gram of algae consumes 1.83gm of CO_2, retains 0.5gm of carbon and releases 1.33gm of Oxygen per day *(Benemann JR, Van Olst JC, Massingill MJ, Weissman JC, Brune DE,2003)*. Considering these facts, the designing of the algal photobioreactor was carried out.

- **Design 1:**

Proposed Design for Bio Filter 1 where in Bio-filtration is out stationed

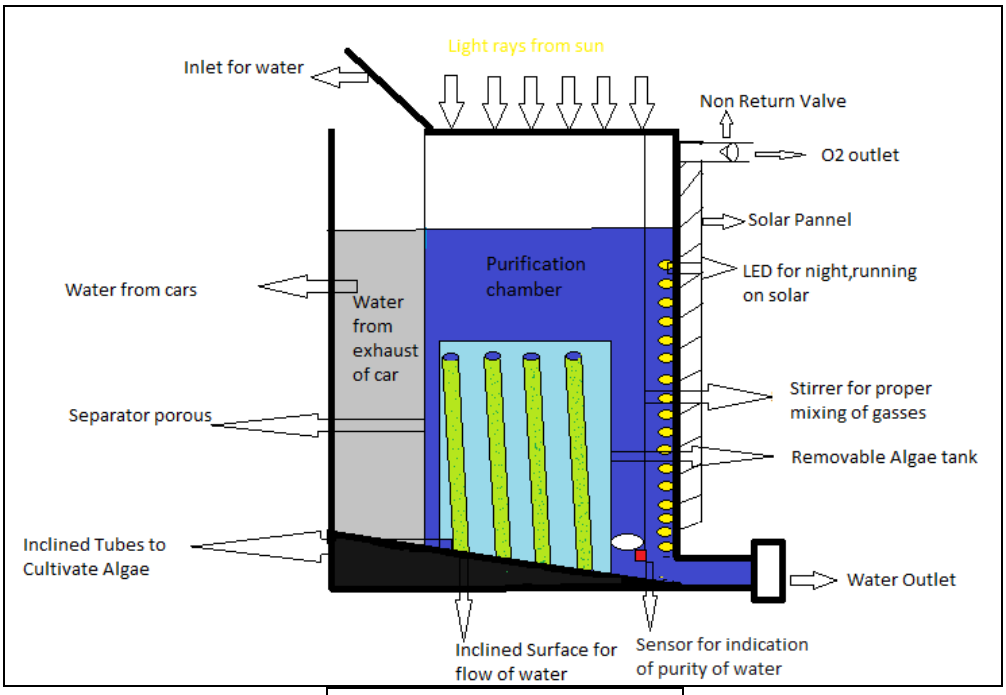


Fig 26: Biofilter Design 1

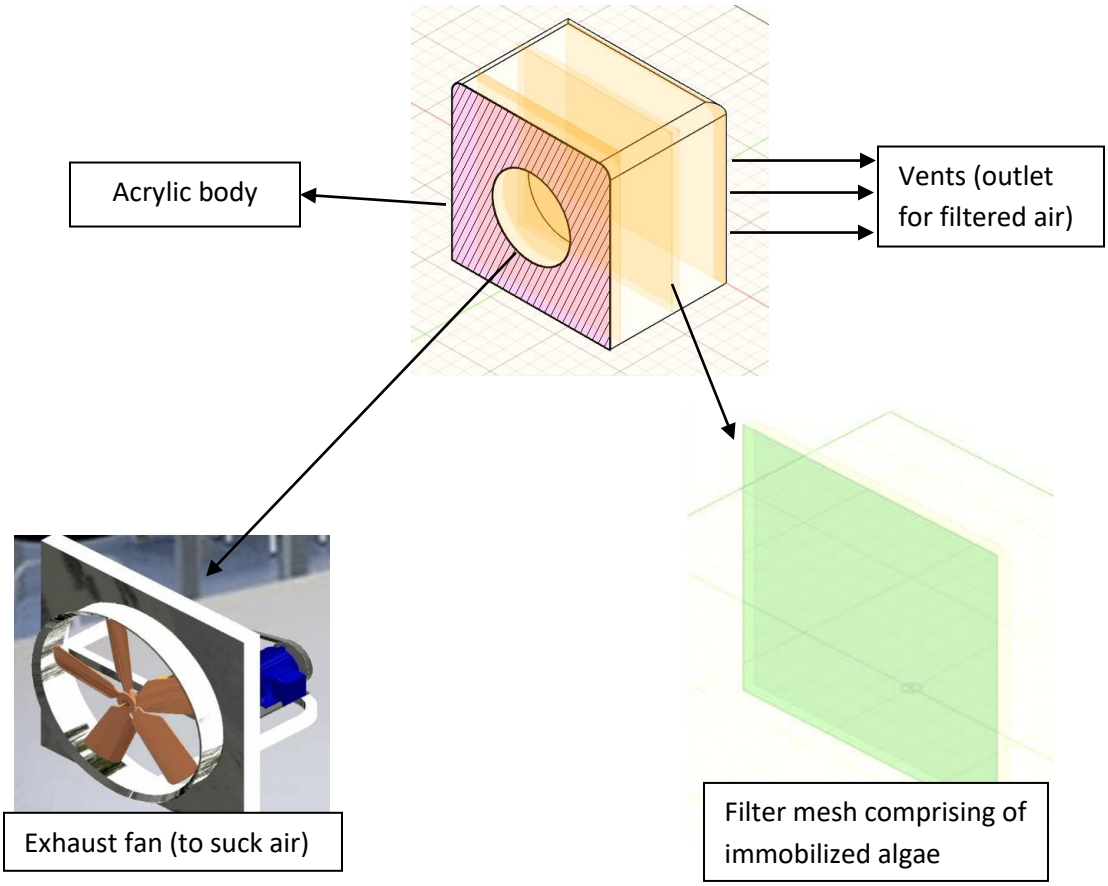
Description:

Water bottle having 3 liter capacity may be connected at exhaust bypass of automobiles. Exhaust gases will dissolve into water. This will then be purified with the help of algae biofilter unit as shown in figure 26. Purification chamber can have a capacity of ≥ 200 liters.

Benefits:

- Automobile companies get credit for every gram of Carbon dioxide filtered. (1 gm of algae consumes 1.83gm of CO_2, retains 0.5gm of carbon and releases 1.33gm of Oxygen per day)
- Industry will get matured algae from automobile users to make bio fuel from Algae (1 kg of algae gives 20ml of biofuel.
- 10% of CO_2 will be filtered by Algae and oxygen will be supplied back to atmosphere.

- **Design 2: Portable air purifier (Fig 27):**



Description:

This design is a portable table top air purifier which will purify the air to prevent dust; pollen; and other allergens. This is done with the help of microalgae balls inside the unit (Filter mesh). It also humidifies the air which makes it better for your skin. The exhaust fan sucks in air which then passes through the algae mesh. The algae will remediate the air by using carbon dioxide and other pollutants rendering a better quality of air to the user. Number of algae filters can be increased as per demand and efficiency according to the requirement.

- **Air quality monitoring device – Ambee (Fig 28)**

  Product Specifications:

- Measures particulate matter (PM2.5), along with TVOC (Total Volatile organic compounds), CO_2 (Carbon dioxide) and HCHO (Formaldehyde)
- **Real-time monitoring**: Ambee uses tested EPA bench-marked sensors which are carefully selected based on their response time, life and quality to provide accurate real-time data
- **Analytics**: Use our mobile companion app to get all the air quality data, with unique recommendations and suggestions to help improve indoor air quality so you can take action to improve your health
- **Easy to use**: with a portable design to display the air quality level in your home, office, car or even outdoors.
- Android app compatible with Android 6.0 and above. Requires 2.4 Ghz Wi-Fi.

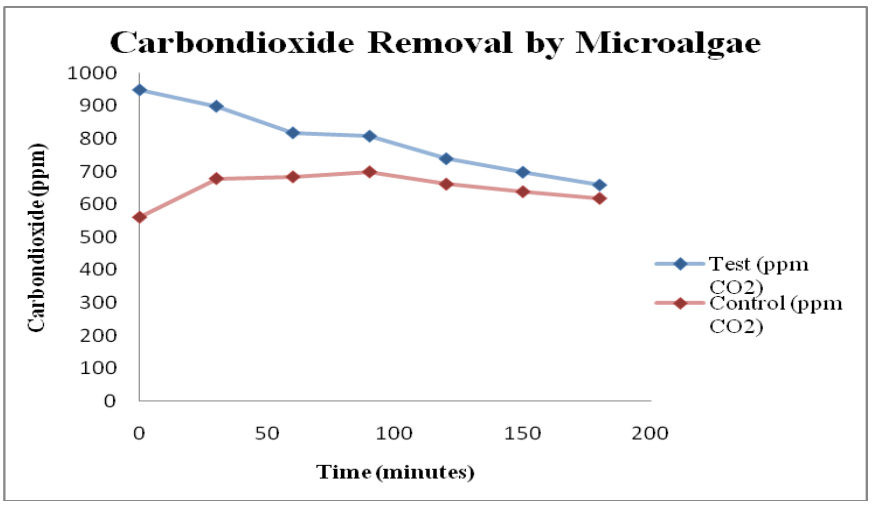
Parameter	Range	Accuracy
PM2.5 sensor	0-999ug/m3	0.01 ug/m^3
HCHO	0-1.5mg/m3	0.001 ug/m^3
CO2	0-5000 ppm	1 ppm

Figure 28: Images of Ambee air quality monitor

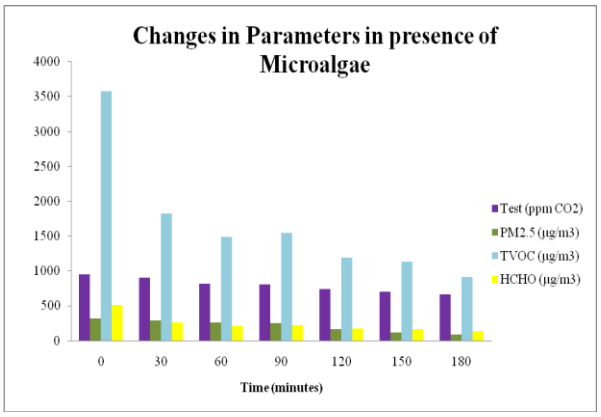
Testing of prototype:

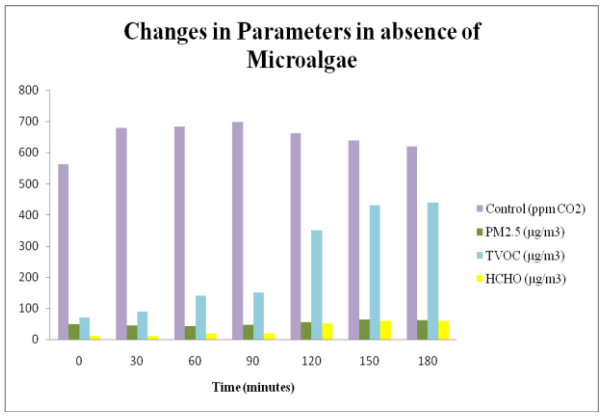
- The area of the selected room was 64 sq ft
- 30g immobilized beads, each with 1 g algal biomass were added in the unit. Max capacity of the unit is 50gms.
- Thickness of the algal bed is 12mm
- The unit was assembled and powered on. An AQI monitor (ambee) was placed near the outlet.
- After 30 minutes the CO_2 levels in the selected room dropped from 949 ppm to 899 ppm.
- There was 13.8% reduction in the levels of carbon dioxide in the first 60 minutes.

Graph 7: Testing of prototype for reduction in CO_2 levels.



Graph 8: Testing of prototype for reduction in other parameters





- **Efficiency of the Portable microalgae filter:**

As cited in literature about 100 CFM is required for each 250 square feet of space. For a small table top air purifier, for example, about 100 CFM would be essential. The right CFM value is important so that there is proper airflow in the room and ideal turnover of air.*(Engineering ToolBox, (2005). Air Change Rates in typical Rooms and Buildings.)*

- Volume of the room selected for testing = 512 cu.ft

Size of the fan = **4.75 inch**

Amount of algal biomass = 30g

- CFM of the filter = **278.87**

As per below formula:

CFM = Length x Width x Height x (Air Changes per Hour) / 60 min.

∴ For 6 air changes per hour

Required CFM = 8*8*8*6 / 60

- Required CFM = 51.2

The filter with 30g of algae biomass provides 278.87 CFM

- This therefore concludes to = 32 air changes per hour.

Now for purification efficiency of the air purifier we use the formula:

CFM of filter / Vol of room *100

278.87 / 512*100 = **54.46 %**

Hence the said air filter has a purification rate of **54.46 %.**

The capacity of the unit is sufficient to purify an area of 12*12 Ft^2 or 18.40 sq. mts with 6 air changes per hour.

Table 7: Efficiency of the designed portable biofilter unit.

Unit	Efficiency
Maximum Holding Capacity	50g
CO_2 capturing ability	54.9 g /day
Oxygen production	39.9 g /day

Other parameter	Percent Reduction
Total VOC	58.37 % / hour / sq meter
PM 2.5	18.26 % / hour / sq meter
Formaldehyde	58.85 % / hour / sq meter

- No harmful chemicals were used while designing or functioning of the unit hence making it safe and ecofriendly.
- Cost of the unit sums up to Rs. 3000/-
- Cost of replacement of filter columns will be Rs. 50/-

Waste disposal technology

Considering the current scenario of waste disposal which has been neglected by most of the industries, this unit is designed as a **zero waste technology**. The biological entity-microalgae is entirely biodegradable and useful as an agricultural and industrial product.

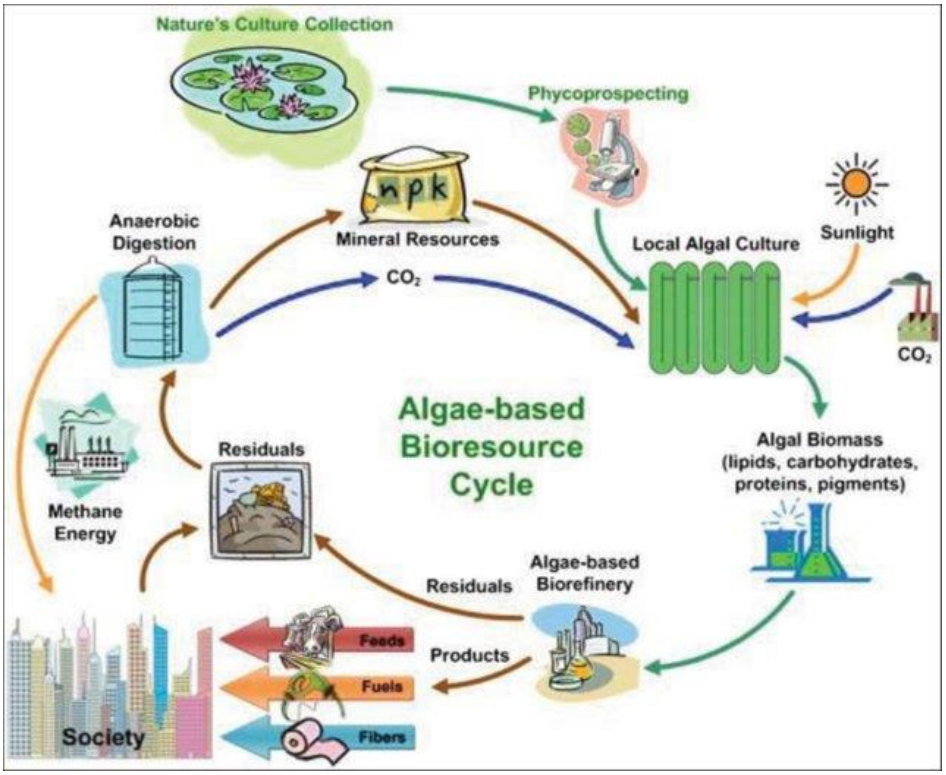


Fig 29: Resulting microalgae biomass processed into consumable products.

(https://www.researchgate.net/publication/303913929)

Fig 30: A display of the items produced by the project proponent as a part of the prototype presented at the sub-committee meeting held on 24th October 2019.

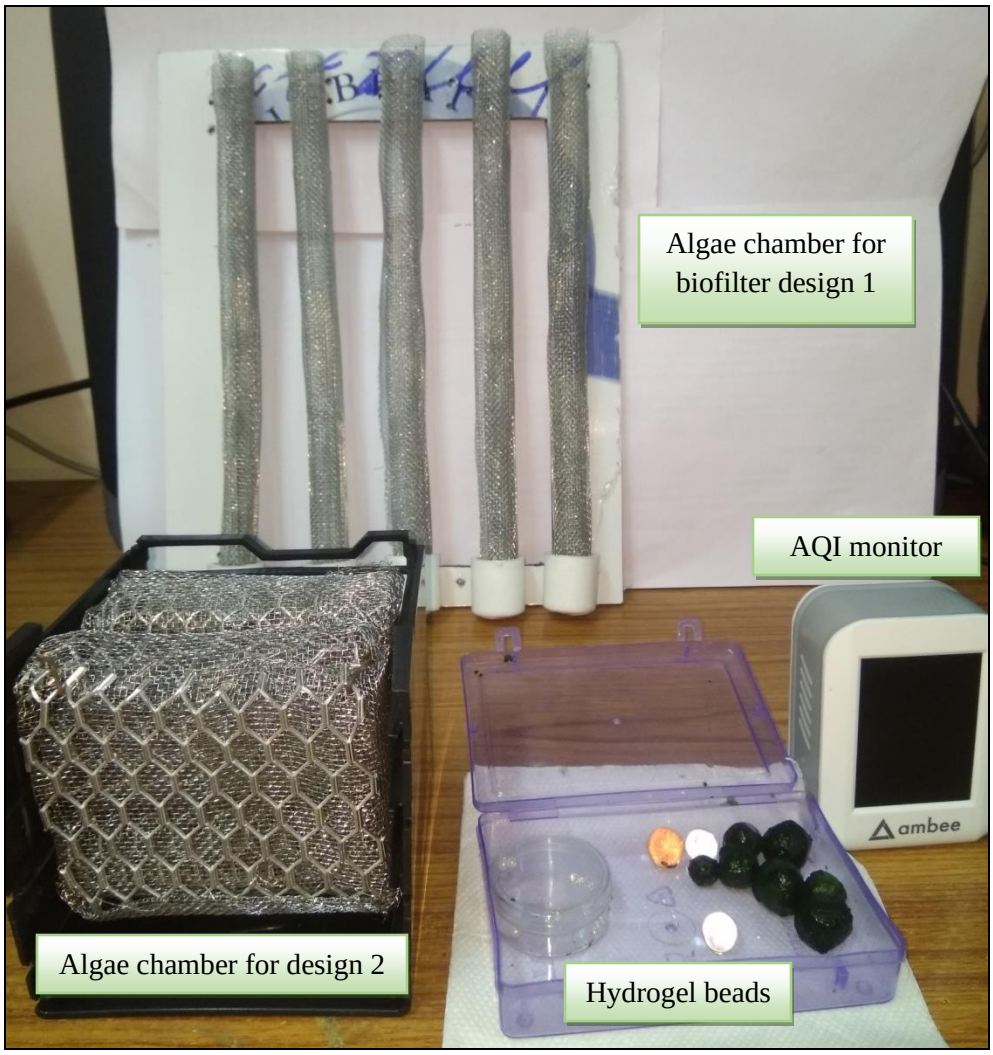


Fig 30: Presented Prototype Parts

CONCLUSION:

1. Microalgal consortia comprising of *Spirulina sp.* and *Chlorella sp.* was optimized and established to remediate the inorganic air pollutants
2. The microalgae could survive, grow and replicate successfully under 73.6 ppm sulfide stresses which is way above the PEL of H_2S according to OSHA.
3. Experimental studies showed that the microalgae were able to utilize 60 ppm of pure carbon dioxide in a span of 5 days with simultaneous increase in growth and biomass.
4. Microalgae consortium was able to grow in outdoor environment in similar growth pattern as compared to the growth pattern under controlled conditions in lab.
5. Morphological changes as per variation in size of the cells with varying time points were observed and showed little effect of the outdoor pollutants on the microalgae without rendering any detrimental effects as evident by the increasing chlorophyll content.
6. Nutritional profile of the biomass showed competitive results in test as well as control.
7. Aggregation of microalgal cells was observed which poses the possible potential of this consortium to entrap particulate pollutants present in the environment.
8. Dissolved oxygen was monitored which indicated the growth of microalgae is directly proportional to rate of evolution of oxygen.
9. Designing an economical unit that would enable optimal survival and growth of the microalgae while mitigating aerial pollutants demanded immobilization of the microalgae on a non-hazardous, biodegradable, economical matrix.
10. Four different matrices i.e. aquarium filter, hydrogel beads, sodium alginate and zeolite were put to test in order to choose the best matrix.
11. Among the above, the fastest and maximum immobilization was observed in the hydrogel beads. Each ball that swelled with a diameter of 1.2cm was able to hold approximately 1±0.2 gm of algal biomass and was found to be stable until 3- 4 months.
12. Looking at the ease of accessibility, low cost, stability and efficiency of immobilization, hydrogel beads were proposed to be the most suitable while designing a microalgae bioreactor for air pollution remediation.
13. The designed portable unit was tested for its capability to remediate air pollutants. The confirmation of which was done using a commercially available AQI monitor: AMBEE.

14. The design 2 was able to reduce carbon dioxide concentration from 949 ppm to 659 ppm within 180 minutes as recorded by Ambee AQI monitor. The filtration efficiency of the unit was found to be 54.46%
15. Percent reduction efficiency for various parameters was calculated as 13.8 % CO_2, 18% $PM_{2.5}$, 58.37% TVOC and 58.82% HCHO per hour.
16. This portable indoor Biofilter design is based on a zero waste technology wherein no hazardous waste will be generated on use of the unit. Also the biomass generated is completely useful as a fertilizer, animal feed component, and can be used for biofuel generation.
17. With this the aim of this project was successfully attained.

Improvement in air quality is thus assured with the help of the microalgae consortia established and optimized so as to remediate pollutants in the environment alongwith evolution of oxygen and generation of biomass rich in lipids and carbohydrates that could be processed for further industrial/ domestic/ agricultural use.

Further possibility of improvisation in terms of technology using inbuilt sensors for air quality and algae growth in the unit are possible.

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