WATER HYACINTH AS A SUBSTRATE FOR PLANT-MICROBIAL FUEL CELL TO CLEAN WATER AND PRODUCE ELECTRICITY IN MARSHES

--N. Cherly Anto Frezina D.C.A, D.C.F, D.A.B.M, (M.Tech.), Department of Biotechnology and Genetic Engineering, Bharathidasan University, Tiruchirapalli-24.
cherlyanto@yahoo.com

ABSTRACT:

This paper tries to the draw the extent of trouble caused by Water Hyacinth in Tamil Nadu and has proposed a method to curb its menace with the help of a microbial fuel cell.

A novel microbial fuelcell has been designed to use Water Hyacinth and to convert its biomass into electricity. The bacterium Enterobactercloacae is used to degrade the complex Chitin into simpler sugars like Glucose and Fructose. This enterobactor also ferments the Sugars into Protons and Electrons releasing Carbon di oxide in the process. This process is carried out in the anode compartment of a microbial fuel cell. The entire setup is arranged in the form of a microbial fuel cell(MFC). The two compartments are separated by a membrane and the electrodes made of Graphite are connected in a circuit. The protons produced as a result of the microbial activity, passes through the membrane towards the Cathode because of its positive charge. Whereas, the electrons enter the circuit and travel to the cathode. In the Catholyte, the H+ ions combine with the electrons to form pure water. The circuit is further extended to an amplifier, which helps to amplify the electrical current which is stored in batteries before connecting to electrical appliances.This idea if implemented can bring about a great solution to the existing problem of Water Hyacinth menace and power scarcity prevalent in Tamil Nadu.

KEYWORDS:

Microbial Fuel Cell, Water Hyacinth, Bioelectricity

FULL PAPER:

Introduction

This paper tries to the draw the extent of trouble caused by Water Hyacinth in Tamil Nadu and has proposed a method to curb its menace with the help of a microbial fuel cell.

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The origin of Water hyacinth is believed to be Amazonia, Brazil, with natural spread throughout Brazil and to other Central and South American countries. It infests rivers, dams, lakes and irrigation channels on every continent except Antarctica. It devastates aquatic environments and costs billions of dollars every year in control costs and economic losses. It is perennial, herbaceous, aquatic plant of the family Pontederiaceae. The genus Eichhornia contains number of other species all of which are aquatic, but only Eichhorniacrassipes has become a serious weed. The leaves of water hyacinth are compressed of a smooth, glossy, circular to kidney shaped lamina and a swollen spongy petiole. It has been reported as a weed in 56 countries.

Water hyacinth possesses specialized growth habits physiological characteristics and reproductive strategies that allow for rapid growth and expansion in freshwater environments and has spread rapidly throughout the tropics and subtropics. Eichnoriacrassipes forms large free floating, mono-specific mats that complete with other aquatic species for light nutrient and oxygen. As biomass from mats decomposes, organic input to sediments increases dramatically. Eichorniacrassipes grows in shallow temporary ponds, wetlands and marshes, sluggish flowing waters and large lakes reservoirs and rivers plants can tolerate extreme of water level fluctuation and seasonal variations in flow velocity and extreme of nutrient availability, pH, temperature and toxic substances. It was introduced into many countries during late 19th and 20th centuries, where it spread and degraded aquatic ecosystems.

Eichhorniacrassipes remains the world’s most problematic water weed despite wide spreads and various approaches for its control.

DISTRIBUTION:

Water hyacinth has been widely introduced in North America, Asia, Australia, Africa and New Zealand. They can be found in large water areas such as Louisiana, or in the Kerala Backwaters in India. First introduced to North America in 1884, an estimated 50 kilograms per square metre of hyacinth once choked Florida's waterways, although the problem there has since been mitigated. Directly blamed for starving subsistence farmers in Papua New Guinea, water hyacinth remains a major problem where effective control programs are not in place. Eichhorniacrassipes, the Common water hyacinth, has become an invasive plant species on Lake Victoria in Africa after it was introduced into the area in the 1980s. Despite management and control efforts since then, a significant seed bank still remains across the region.

It is particularly suited to tropical and subtropical climates and has become a problem plant in areas of the southern USA, South America, East, West and Southern Africa, South and South East Asia and Australia. Its spread throughout the world has taken place over the last 100 years or so, although the actual course of its spread is poorly documented. In the last 10 years the rapid spread of the plant in many parts of Africa has led to great concern.

HABITAT

Water hyacinth grows in still or slow-flowing fresh water in tropical and temperate climates. Optimum growth occurs at temperatures of between 28°C and 30°C, and requires abundant nitrogen, phosphorus and potassium. Although this plant will tolerate a wide range of growth conditions and climatic extremes including frost, it is rapidly killed by sea strength salinity and will not grow in brackish water. Where water levels have receded, plants can survive on damp soil for several months.

IMPACT

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Water hyacinth is justifiably called the world's worst aquatic weed due to its ability to rapidly cover whole waterways. When not controlled, water hyacinth will cover lakes and ponds entirely; this dramatically impacts water flow, blocks sunlight from reaching native aquatic plants, and starves the water of oxygen, often killing fish. The plants also create a prime habitat for mosquitos, the classic vectors of disease, and a species of snail known to host a parasitic flatworm which causes schistosomiasis (snail fever). Water hyacinth is often problematic in man-made ponds if uncontrolled.

Water hyacinth invades bodies of water that have been impacted by human activities. For example, these plants can unbalance natural lifecycles in artificial reservoirs or in eutrophied lakes that receive large amounts of nutrients. Some of the problems associated with Water Hyacinth are elaborated below:

• *Hindrance to water transport*. Access to harbours and docking areas can be seriously hindered by mats of water hyacinth. Canals and freshwater rivers can become impassable as they clog up with densely intertwined carpets of the weed. It is also becoming a serious hazard to lake transport on Lake Victoria as large floating islands of water hyacinth form, while many of the inland waterways of South East Asia have been Clogging of intakes of irrigation, hydropower and water supply systems. Many large hydropower schemes are suffering from the effects of water hyacinth. The Owen Falls hydropower scheme at Jinja on

Lake Victoria is a victim of the weeds rapid reproduction rates and an increasing amount of time and money has to be invested in clearing the weed to prevent it entering the turbine and causing damage and power interruptions.

Water hyacinth is now a major problem in some of the world's major dams - the Kariba dam which straddles the Zambia-Zimbabwe border on the Zambezi River and feeds Harare has pronounced infestations of the weed.

• *Blockage of canals and rivers causing flooding.* Water hyacinth can grow so densely that a human being can walk on it. When it takes hold in rivers and canals it can become so dense that it forms a herbivorous barrage and can cause damaging and dangerous flooding.

• *Micro-habitat for a variety of disease vectors.* The diseases associated with the presence of aquatic weeds in tropical developing countries are among those that cause the major public health problems: malaria, schistosomiasis and lymphatic filariasis. Some species of mosquito larvae thrive on the environment created by the presence of aquatic weeds, while the link between schistosomiasis (bilharzia) and aquatic weed presence is well known. Although the statistical link is not well defined between the presence of aquatic weeds and malaria and schistosomiasis, it can be shown that the brughian type of filariasis (which is responsible for a minor share of lymphatic filariasis in South Asia) is entirely linked to the presence of aquatic weeds (Bos, 1996).

• *Increased evapotranspiration*. Various studies have been carried out to ascertain the relationship between aquatic plants and the rate of evapotranspiration compared with evaporation from an open-surfaced water body. Saelthun (1994) suggests that the rate of water loss due to evapotranspiration can be as much as 1.8 times that of evaporation from the same surface but free of plants. This has great implications where water is already scarce. It is estimated that the flow of water in the Nile could be reduced by up to one tenth due to increased losses in Lake Victoria from water hyacinth.

• *Problems related to fishing*. Water hyacinth can present many problems for the fisherman. Access to sites becomes difficult when weed infestation is present, loss of fishing equipment often results when nets or lines become tangled in the root systems of the weed and the result of these problems is more often than not a reduction in catch and subsequent loss of livelihood. In areas where fishermen eke a meagre living from their trade, this can present serious socio-economic problems. Fishermen on lake Victoria have also noted that, in areas where there is much water hyacinth infestation, the water is 'still and warm and the fish disappear'. They also complain that crocodiles and snakes have become more prevalent.

In addition to all this they also

- block irrigation channels and rivers
- restrict livestock access to water
- destroy natural wetlands
- eliminate native aquatic plants
- reduce infiltration of sunlight
- change the temperature, pH and oxygen levels of water
- reduce gas exchange at the water surface
- increase water loss through transpiration (greater than evaporation from an open water body)
- alter the habitats of aquatic organisms
- restrict recreational use of waterways
- a serious threat to biodiversity
- reduce aesthetic values of waterways
- reduce water quality from decomposing plants
- destroy fences, roads and other infrastructure when large floating rafts become mobile during flood events, and
- destroy pastures and crops when large floating rafts settle over paddocks after flood events.

Water hyacinth can rapidly take over an entire waterway. Under favourable conditions it can double its mass every 5 days, forming new plants on the ends of stolons. It also grows from seed which can remain viable for 20 years or longer. This enormous reproductive capacity causes annual reinfestation from seed and rapid coverage of previously treated areas, making ongoing control necessary.

With these characteristics, the water hyacinth has become a major ecological and economic problem in this century in the tropics and subtropics.

METHOD OF SPREAD:

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Water hyacinth infestations increase most rapidly by the production of new daughter plants. During high water flows and flooding, infestations can break up and be moved to new locations. Most spread can be attributed to human activity such as the deliberate planting of water hyacinth in ornamental ponds or dams. Unwanted aquarium plants that are discarded into waterways are a major form of spread. Water hyacinth can also be spread by contaminated boating equipment.

Seeds are the main source of new infestations and are carried in water, mud (e.g. on machinery or boots) and by birds.

CONTROL MEASURES IN USE:

Water hyacinth is difficult to control in all freshwater aquatic environments. When access is limited by the presence of the weed itself, control becomes more difficult. Early detection and rapid response offer the greatest likelihood of successful control and the opportunity for eradication. It is essential that any new infestations are controlled as soon as possible. If allowed to become established, the seed bank rapidly expands, increasing costs and massively increasing the duration of the control program.

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Some of the control methods employed till date have been listed below:

Physical removal

Early control attempts concentrated on removing plants from the water with pitchforks, dumping the accumulated mass on land to die. Manually removing plants from small areas of water such as farm dams and drains is an effective form of controlling water hyacinth, but only when the rate of removal is faster than the rate of regrowth. On a larger scale, manual removal is less likely to achieve control of water hyacinth.

There are instances where mechanical harvesting of large infestations has been effective, although costly. As a guide, it takes between 600 and 900 hours to harvest one hectare of dense water hyacinth – which should be undertaken prior to flowering and seed set. Fifty million tonnes of water hyacinth are removed from the White Nile annually, and the Panama Canal is kept clear of the weed by mechanical harvesting.

Chemical control

The most commonly used technique for applying herbicides to water hyacinth is high volume spraying with hose and handgun power sprays either from a boat or from the banks. In some situations large infestations have been aerially sprayed.

Various kinds of herbicides such as 24-D, Dalapon, Diquat, and others have been used in some places. The ecological problems created by these herbicides were obvious. The water could not be used for irrigation or human consumption for long periods of time, and the fauna in the eco-system were seriously affected.

Spraying an entire heavy infestation can cause the weed mat to sink and rot resulting in deoxygenation of the water, potentially killing fish. This can be avoided by spraying one third of the infestation at a time, or by physically removing as much of the weed as possible prior to spraying.

Biological control

Four insects from South America have been released by CSIRO since 1975 and are well established across the world. There are two weevil species, Neochetinaeichhorniae and Neochetinabruchi, and two moth species, Niphograptaalbiguttalis and Xubidainfusellus.

Biological control of the hyacinth was studied with several kinds of animal viruses, bacteria, and fungi, as well as with manatees, insects, herbivorous fish such as grass carp and tilapia,, ducks, geese, turtles, snails, and other animals. However, the results were disappointing, perhaps because of defense mechanisms in the plants. For example, the larger plants form 2.5 or more leaves for each one destroyed by pathogen attack.

The Neochetinaeichhorniae weevil has been successful in destroying large water hyacinth infestations in tropical northern areas of Australia. The adult is black, 5 mm long, and feeds on leaves, making small scars. Eggs are laid in the bulbous leaf stalks and the larvae tunnel through the plant tissue, which is then attacked by bacteria and fungi. This causes the plant to become waterlogged and death can occur under heavy attack. These weevils are inactive during winter.

In Australia, the Neochetinabruchi weevil is more active through the winter and is now well established from northern Queensland to Sydney, although both weevils are much less effective in subtropical and cooler areas. The moth Niphograptaalbiguttalis is well established in northern NSW and Queensland. Its larvae tunnel into the leaf stalks and buds, as do the larvae of Xubidainfusellus. Both species are very damaging to young plants and luxuriant weed growth but their impact is often temporary and patchy.

Unfortunately biological control cannot be solely relied upon for effective control of water hyacinth. It will provide some reduction in flowering and growth rates of the plant and occasionally mat sinkage has occurred as a result of insect damage. Control programs in should view bio control as a useful addition to the other available control techniques. It is possible that some infestations exist which do not have biological control agents present.

Cultural control

As part of a control program, nutrient run-off into infested waterways should be minimised. Drainage or reduction of water levels can also reduce the area of water hyacinth plants, but it is important to note that seeds will remain viable in the soil and will germinate when the area refills with water. In some situations salty water is able to be retained or naturally introduced to infested waterways.

Managing flood-stranded infestations

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Vast areas of land can become covered in stranded water hyacinth when floating mats become mobile during flood events. This creates major problems if the weed settles over roads, crops or pastures.

Earthmoving equipment can be used to remove hyacinth from roads and verges. While crops will be damaged by the weed mass, pasture recovery can be enhanced by the use of windrowing or mulching as the plant mass can take up to 12 months to break down naturally.

Situation in Tamil Nadu

Most rivers in Tamil Nadu have been covered by the green carpet of Water Hyacinth because of the pollutants dumped by the industries on their banks. Many textile processing units in Tamilnadu use a number of unclassified chemicals that are likely to be from the Red List Group which is said to be harmful and unhealthy.

The Public Works Department (Water Resources Organisation) launched a massive campaign in April 2012 along a stretch of 400 m near the mouth of Mannaraianicut to weed out water hyacinth along River Noyyal course as the plant is blocking free flow of water into the supply channels that feed irrigation tanks.

Following directions from the Coimbatore Mayor R. Venkatachalam and Corporation Commissioner, P. Muthuveeran, the officials have deployed three earthmovers to clear Singanallur tank from three different angles and using a motorised instrument, a net is being spread over the water hyacinth in the water spread area and using a motor the plants are being removed. Corporation sources show that the work estimated to cost close to Rs. 5 lakh would take nearly a month.

In Namakkal district, increased complaints are received from the farmers stating the Water Hyacinth menace due to the sewage from Kumarapalayam and Pallipalayam municipalities and untreated effluents from dyeing units, let into the Cauvery.

In February 2013, a major effort to clean up water Hyacinth clogging up the lakes in the Coimbatore district was given up. After spending Rs 8.10 lakh to remove water hyacinths from the Valankulam Lake, the city corporation claimed that the project was a success. They even replicated the work at Ukkadam Main Tank. But the euphoria was short-lived and the deadly weed is back in both water bodies choking aquatic flora and fauna. Expectedly, the return of water hyacinths in Valankulam has made the authorities wary of cleaning up the other major lakes in the city. Six months earlier the state government had allocated Rs 39.9 lakh to the corporation to clear water hyacinth from eight major water bodies in the city. Valankulam, one of the biggest water bodies within corporation limits, got the maximum allotment. "We have decided to put the entire operation on hold because of the negative results in Valankulam and Ukkadam. Manual removing the plant species is not a permanent solution. We are probing other options which can offer lasting solutions," said a senior officer of the corporation. About Four Lakh rupees were spent to clear up one acre of wetland. And each wetland area in the city spreads over 200 acres.

The weed, which grows into a thick bed of waxy leaves and multiplies with astounding rapidity, has turned out to be a major problem for the farming community and the power generation barrages of Tamil Nadu Generation and Distribution Corporation (TANGEDCO).

The leaves clog bridges in the rivers. When water is released from the reservoirs, the leaves also enter into the irrigation canals and clog the regulation structures. The leaves also

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choke the power generation barrages of the TANGEDCO, affecting the generation activities. The Corporation employs fishermen to remove the water hyacinth near its barrages. The weed, according to officials in the Public Works Department, grows rapidly in places where sewage is discharged into the water courses.

In the city of Chennai, Velachery Lake, the boundary of pallikarani drainage swamp, a portion of AdyarRiver, Buckingham canal and Otterinullah have turned eutrophic due to Eichhorniacrassipes. This is also the case with water bodies around Trichy, Madurai, Tirunelveli, Coimbatore, Salem and other districts. Eichhorniacrassipes is the first order among water weeds causing menace only second to Ipomoea aquatica. In Tamilnadu almost 80% of 39000 tanks are already infested with this weed. Even very big lakes like Chembarakkamlake, Dusi- Mamandur lake, Kavaripakkam lake, Veeranam lake, etc. are affected by Water Hyacinth (Varshney et al 2008).

A programme for spraying Chemicals to prevent the Water Hyacinth, on a trial basis got under way in Velachery Lake, Chennai from May 19, 2012. The chemical was sprayed in the presence Mayor SaidaiS.Duraisamy. The agency in charge of the programme claimed that the chemical would prevent the growth of the weed for a period of five years after spraying. The chemical would not affect any other forms of life in the water body, an official has said.

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INITIATIVES IN NEIGHBOURING STATES:

ANDHRA PRADESH:

KondalaRuthala, a non-resident Indian from Andhra Pradesh has proposed the use of biogas produced from water hyacinth to be used for generating electricity, heating and industrial purposes.

The aim is to provide efficient energy solution that is reliable, scalable and cost effective. Chairman of Bengaluru-based Benaka Biotechnologies Pvt. Ltd., Mr.Ruthala has submitted the proposal to Krishna district Collector seeking permission to set up a biogas plant at Nandigamalanka in the district.

A citizen of USA and equipped with 17 years of experience in crude oil/gas exploration, high-tech electronics, medical and silk industries in the US and in India, he proposes to use indigenous technology developed by VillageVision Biotechnologies, IIT/GBES and National Environmental Engineering Research Institute (NEERI) to set up the gas plant.

The Collector has entrusted the task of looking into the proposal to the RDO and has directed District Manager NREDCAP (Non-conventional Renewable Energy Development Corporation of Andhra Pradesh) Limited G. Satyanarayana to offer his comments.

Besides the fact that farmers will benefit from the project, the Irrigation Department which spends between Rs.10 lakh and Rs.15 lakh every year on removal of water hyacinth, will have a reason to rejoice.

Listing out the many benefits of the project, Mr.Ruthala's proposes to produce 10,000 cubic metres of raw gas and 50 tonnes of manure every day, besides reducing green house gas effects, odours and pathogens and zero discharge and carbon negative. The other benefits, he says, include availability of road access from Gudivada, Kaikaluru and Eluru to the proposed site, availability of electricity next to the site and adequate water hyacinth in canals around the year. The proposed site is only 100 metres away from Chandrayya and Budameru canals and accessible to manpower. Mr.Ruthala has proposed to develop the plant in a phased manner.

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KERALA:

The Kottapuram Integrated Development Society (KIDS), a non-governmental organisation, in collaboration with the India-Canada Environmental Facility, is utilising water hyacinth for producing biogas. The project has been running successfully, according to Sunny George, a scientist who is associated with the project.

Water hyacinth has more than 85 per cent water. It is homogenised using a special machine. Special mechanisms are provided for maintaining constant temperature and pressure in a digester. Variations in the temperature are avoided by heating the inside of the digester through a hot water circulating system.

Biogas is collected in a conventional biogas plant. The slurry is ejected out of the digester once every fortnight.

A tank that is fed with 700 litres of homogenised water hyacinth yields 3,600 litres of biogas (i.e. 150 litres an hour). The entire requirement of cooking in the college canteen of KIDS is met by biogas from the water hyacinth project, according to Mr.George. The slurry generated from this processes is extensively used for organic farming among the self-help groups, according to P.Johnson, Director of KIDS.

Another project of KIDS involves production of vermi-compost from water hyacinth. The process involves several steps. The water hyacinth is chopped manually. Cowdung is used to absorb excess water from water hyacinth. A layer of coconut husk is prepared at the bottom of the vermi-compost tank followed by a layer of cowdung. Then, the chopped water hyacinth is spread over it, after which worms are put into the tank.

Each worm is expected to eat one gram of water hyacinth per day and excretes one gm. About 2 kg of worms are introduced into each tank.

PROPOSED SOLUTION:

Mere clearing of the weed has always led to negative results due to the fast regrowth of theWater Hyacinth. Hence, the best way to solve this problem is to make the best out of it and find apt ways to use Water Hyacinth for Social Wellbeing. Some ways in which this plant can be used have been given below. But the choice of the solution lies in the size of the water body, area of Water Hyacinth growth, lifestyle of people living around it, need for employment, etc.

PROJECT OUTLINE:

A novel microbial fuelcell has been designed to use Water Hyacinth and to convert its biomass into electricity. The bacterium Enterobactercloacae is used to degrade the complex Chitin into simpler sugars like Glucose and Fructose. This enterobactor also ferments the Sugars into Protons and Electrons releasing Carbon di oxide in the process. This process is carried out in the anode compartment of a microbial fuel cell. The entire setup is arranged in the form of a microbial fuel cell(MFC). The two compartments are separated by a membrane and the electrodes made of Graphite are connected in a circuit. The protons produced as a result of the microbial activity, passes through the membrane towards the Cathode because of its positive charge. Whereas, the electrons enter the circuit and travel to the cathode. In the Catholyte, the H+ ions combine with the electrons to form pure water. The circuit is further extended to an amplifier, which helps to amplify the electrical current which is stored in batteries before connecting to electrical appliances.

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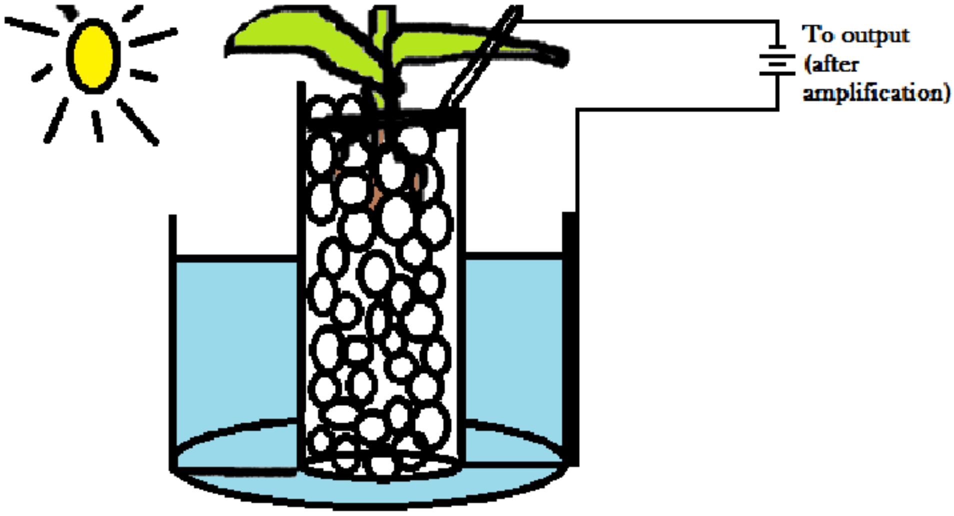

Figure 1: A model MFC proposed to get electricity from Water Hyacinth

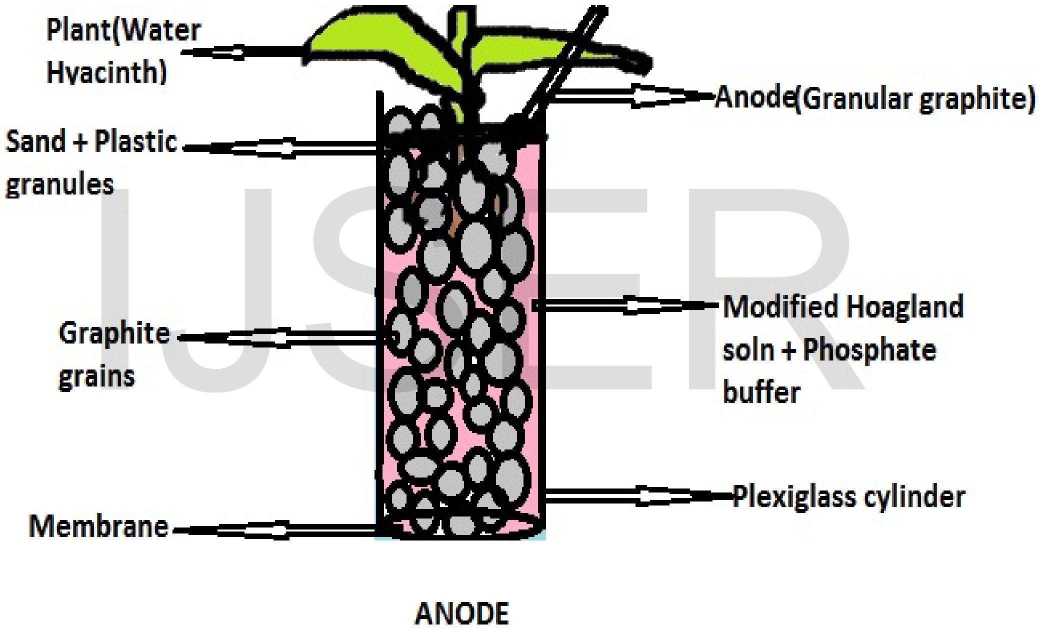

Figure 2: A figure of the Anode of the Microbial Fuel Cell.

MICROBES USED:

Past workers have worked with a number of microbes like Rhodoferax, Shewanella, Pseudomonas, Aeromonas, Geobacter, Geopsychrobacter, Desulfuromonas, Desulfobulbus, Clostridium, Geothrix, Ochrobactrum, and Rhodopseudomonas. These bacteria are known to convert cellulosic biomass into simpler sugars. Further, Clostridium cellulolyticumexoelectrogen and Geobactersulfurreducens have been used previously to ferment the sugar materials into carbon di oxide, electrons and protons.

A new bacterium that serves both the purpose of degrading the cellulose content into simple carbohydrates and further decomposing it into Carbon di oxide, protons and electrons is required.Enterobacter cloacae has been found to exhibit such desired qualities in previous studies. Hence it has been selected as the required stain.

ANODE:

A Plexiglass cylinder filled coated inside with Graphite and filled with graphite grains is used.A granular Graphite rod coated with ammonia is used as the Anode. Ammonia is coated to facilitate greater attachment of the microbes to the anode. Further, Silica and Plastic granules are used to cover the surface to prevent algal contamination.

Anolyte-Modified Hoagland Solution is used along with 20mM Phosphate buffer(KH2PO4 / K2HPO4) is used as the anolyte. The pH is maintained at 7. An Iron complex of Dithylenetraiminepenta acetic acid ferric sodium complex dissolved in D-Fe-II/ DTPA-Fe is added as an additive.

CATHODE:

Graphite felt in the used to cover the base of the container with a Gold or Carbon wire stitched in it that acts as the Cathode.

Catholyte - 20mM Phosphate buffer-K_2HPO_4 / $KH_2PO_4$with a pH of7 is used as an electrolyte in the Cathode.

CONDITIONS:

1. Natural Sunlight or Artificial Metal Halogen Lamp is needed for a period of 14 hours per day.
2. The temperature should be maintained at 25°C - 27°C which is favourable for both the Water hyacinth and the Microbe used.
3. The humidity of about 75% is required for the Hyacinth which is the normal condition in Tamil Nadu.
4. A light intensity of 596+/-161u mol/m^2/s is required.

CONCLUSION:

This idea if implemented can bring about a great solution to the existing problem of Water Hyacinth menace and power scarcity. An approximate power supply of 67 mWper $m^2$of anode surface is anticipated as an outcome of this project. It will lead to an estimated potential electricity production of 21 GJ ha-1 year-1(5800 kWh ha-1 year-1).

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