KAUNAS UNIVERSITY OF TECHNOLOGY

MECHANICAL ENGINEERING AND DESIGN FACULTY

Venkatbalaji Kamalakannan

DEVELOPMENT OF THE CLOSED TYPE ALGAE GROW BIO-REACTOR

Final project for Master degree

Supervisor
Assoc. Prof. Dr. **Kazimeras Juzenas**

KAUNAS, 2015

KAUNAS UNIVERSITY OF TECHNOLOGY

MECHANICAL ENGINEERING AND DESIGN FACULTY

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Head of Department
Assoc. Prof. Dr. Kazimieras Juzėnas

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Industrial Engineering and Management (621H77003)

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Reviewer
Assoc. Prof. Dr.Gudzinskas Juozas

Project made by
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KAUNAS, 2015

KAUNAS UNIVERSITY OF TECHNOLOGY

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(Title and code of study programme)

DEVELOPMENT OF THE CLOSED TYPE ALGAE GROW BIO REACTOR

DECLARATION OF ACADEMIC HONESTY

1 June 2015

Kaunas

I confirm that a final project by me, **Venkatbalaji Kamalakannan**, on the subject "Development of the closed type algae grow bio reactor" is written completely by myself; all provided data and research results are correct and obtained honestly. None of the parts of this thesis have been plagiarized from any printed or Internet sources, all direct and indirect quotations from other resources are indicated in literature references. No monetary amounts not provided for by law have been paid to anyone for this thesis.

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FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Approved:

Head of	_______________ (Signature, date)
Production engineering Department	_______________ (Name, Surname)

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Development of the closed type algae grow bio reactor

Approved by the Dean 2015 may 11 Order No. **ST17-F-11-2**

2. Aim of the project

To develop a design and technology of algae fast growing closed photo-bioreactor system with high productivity.

3. Structure of the project

Summary, Introduction, Forecast of algae and market analysis on companies problems and drawbacks and capital cost for the open and closed system, Review of existing technology such as open pond, closed pond- flat plat and tubular plate and vertical column, Analyses on algae growth production challenges and drawbacks such as water and nutrients, contaminations, physical problems etc. on the current technology, Development of design and technology on closed photo bioreactor for by using chemical absorption method and solar optical fiber lighting system and water flow system, Selection of components equipment's techniques that required for growing and capital cost for this system

4. Requirements and conditions

To prepare final project according to KTU regulations and requirements.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2015 June 1st.

Given to the student Venkatbalaji kamalakannan

Task Assignment received ___________________________ ______________________

(*Name, Surname of the Student*) (*Signature, date*)

Supervisor ____________________________ ______________________

(*Position, Name, Surname*) (*Signature, date*)

Kamalakannan, Venkatbalaji: Uždaro tipo dumblių auginimo bio reaktoriaus kūrimas

Pramonės inžinerijos magistro baigiamasis projektas / vadovas doc. dr. Kazimieras Juzėnas; Kauno technologijos universitetas, Mechanikos inžinerijos ir mechatronikos fakultetas, Gamybos inžinerijos katedra. Kaunas, 2015. 54 p.

SANTRAUKA

Šiame baigiamąjame darbe apibūdinama novatoriška uždara sistema naudojamą auginti dumblius biokuro gamybai. Jame apibūdinama bendra dizaino apžvalga susijusi su reaktoriaus, kuris naudojamas augimo mechanizme dideliame uždarame reaktoriuje. Pagrindiniai projektavmo aspektai apima šviesos (t.y fotozintezės), vandens suvartojimo ir anglies dvideginio suvartojimą, tinkamą maistinių medžiagų tiekimą ir pH, aplinkos temperatūrą. Atviri tvenkiniai yra seniausia ir papraščiausia sistema dumblių auginimui, bet yra sudėtinga kontroliuoti augimo sąlygas. Priešingai, yra nemažai uždarų reaktorių kuriais galima pakankamai kontroliuoti augimą, bet aukštas produktyvumas reikalauja didelių išlaidų. Pagrindinis magistro baigiamojo darbo tikslas yra sukurti biologinį reaktorių, kuris užtikrintų greitą ir ekonomiška dumblių auginimą. Dabartinis uždaro reaktoriaus tikslas yra, kaip padidinti reaktorių ir jo naudingumą atsižvelgiant į ekonominę pusę ir taip pat atikti rinkos tyrimus, apibendrinant šituos faktorius sukuriama optimali reaktoriaus konfiguraciją. Tam tikslui autorius sukurė uždaro ciklo bioreaktorių, su kuriuo galima kontroliuoti aplinką, tuo būdu padarant artimesnę aplinką biomasės dumblių greitesniam augimui, kuris leidžia didinti produktyvumą.

Kamalakannan, Venkatbalaji: Development of the closed type algae grow bio reactor.

Industrial Engineering and Management (621H77003) / supervisor Assoc. Prof. Dr. Kazimeras juzenas Kaunas University of Technology, Mechanical Engineering and Design faculty, production Engineering department.

Kaunas, 2015. 54 p.

SUMMARY

This thesis describes an innovative closed system used to cultivate algae for biofuel production. It describes general design consideration related to the reactor that uses the growth mechanism on large-scale closed reactor. Main design aspects include light (i.e. photosynthesis), water consumption and carbon-dioxide consumption, proper supply of nutrients and pH, ambient temperature. Open ponds are the oldest and simplest system for mass cultivation of microalgae but it is difficult to control the growth conditions. In contrast, there is different variety of closed reactors which offer considerable amount of control, but a few of them with the high level of productivity lead to high costs. The main aim of this project is to develop a bio reactor for algae to grow fast and its process for production is cost-effective. The current challenge in the closed system bioreactor is how to increase reactor size and productivity in terms of economy and also includes market research and it concludes with a discussion regarding the possible optimal reactor configuration. For this purpose the author has developed a closed-loop bioreactor which provides a controlled environment by bringing the required system closer to the biomass algae to grow faster and which enables high productivity.

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INTRODUCTION

Energy plays a vital role in the socio-economic development in any country which needs an improved standard of quality and living conditions of life. Currently biofuel research is of immense interest due to global economy and the increase of global energy demand, as well as to emerging economy and the rise in fuel price. A Green energy algae, a photosynthetic microorganisms have the ability to produce molecular hydrogen photo synthetically by using sunlight and water and CO_2 [1]. This is carbon neutral process that has the ability to sequestering carbon dioxide during the algae growth phase scrubs heavy metals from the flue gases. Algae can also absorb various nutrients found in wastewater and convert them into useful by products. Algae provide an efficient way to prevent waste and pollution by utilizing resources efficiently, keeping majority of resource in a closed loop cycle. Oil content in microalgae varies from 20%-50% and sometimes may reach up to 80% by weight of biomass compared to other best agricultural oil crops. A 1 hector (ha) of open algae farm can produce over 10 to 50 times more oil as compared to another known oil crop; the closed reactor can yield 100 times more than other oil crops but there is not much developed technology to provide high productivity in a closed reactor. Closed reactors face various problems which make their productivity lower, so the current challenge is to develop an innovative and cost-effective bioreactor and an effective production process.

Aim-

To develop a design and technology of algae fast growing closed photo-bioreactor system with high productivity.

Objectives of the Work

1. Forecast of algae and market analysis and capital cost of the systems
2. Review of existing technology and design of algae growing systems.
3. Analyses on algae growth production challenges and the drawbacks of the current technology.
4. Development of design and technology on closed photo bioreactor for algae to grow fast.
5. Selection of components equipment’s techniques and capital cost for this system.

1. FORECAST OF ALGAE AND MARKET ANALYSIS AND CAPITAL COST FOR THE SYSTEM

ABO (Algae Biomass Organization) 2015 industry survey was conducted in January and February, through an electronic questioner to more than 230 contacts. Forecast of algae by 2020 the survey response the algae-derived fuels are likely to be priced below € 1.20 per. liter by 2020, reaching 230.58 billion liters per year and market value of 1.3billion by 2020[2].The production will increase by 2020 with existing and new facilities and improved supportive federal policies would accelerate both the production plant development of algae, and algae based fuel, feed, other products as well as number of jobs across industry [3]. Current production cost is 3.66 € per liter with more advance technology and operations the production of algae based fuel cost will be reduced and by 2023 the price will be € 0.72 per liter and by 2026 the price will be € 0.36 per liter and by 2029 the price of the algae based fuel will be cheaper than the petroleum based products and diesel showing in the Figure [1.1].

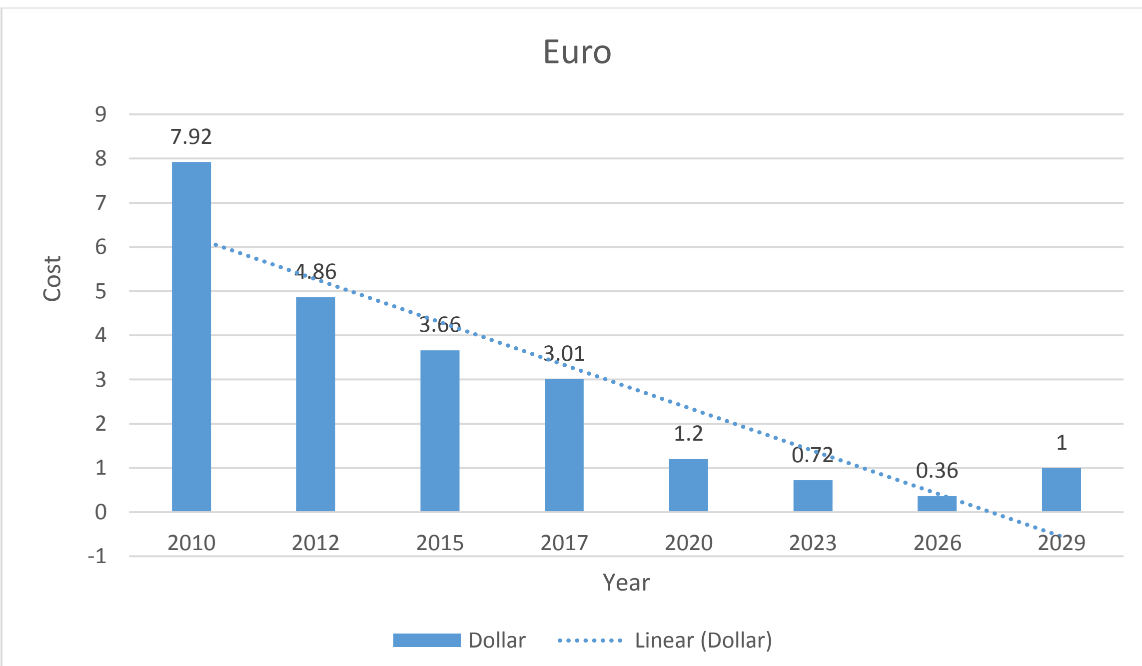

Figure 1.1 Algae production cost -15 years forecast

The World market for algae production has rapid growth and expansion over the next decade. Algae is attracting many companies to invest on it, and interest from aviation, and biofuels and Petroleum Company. During the survey of algae the study finds U.S and Europe cannot grow enough crops such as corn, soy or rapeseed to meet their biofuel target. In the year of 2010 there was just 23 companies all over the world for the algae production market but in 2015 its more than 200 companies are in the market. Algae an alternative sustainable fuel will find more demand for biofuels in Asia, Europe, US. Due to the raise of demand in oil, diesel and petroleum products in near future.

Algae is considered to be a future green energy because it is rich in oil and can grow in any type of land. But no company was able to make it commercial scale that can be grown and harvested in competitive price with petrol and diesel. Number of companies have formed to turn the algae in to a useful products such as biofuel, pharmaceutical products, cosmetics and animal feed.

Green Fuel Technologies Cambridge, USA one of the 1st company to enter into the algae biofuels business .They developed a system which uses recycled CO_2 to feed the algae and can capture up to 80% of CO_2 emitted from a power plant, during the day when sunlight is available and the company had their own patented technology for the growth on a 1 acer site and they yield about 48 tons of oil/acre/year but the company is now shutting down after running out of money. The financial situation at Green fuel Technologies had been degrading since last year, the reason behind this was from the beginning they had number of mistakes they were changing their methods often and manually harvesting the algae made that process too expensive, the employers complained the operation and finance was not managed properly[4].

Solazyme, USA developed a synthetic biological products, it’s a microalgae derived fuel and it’s the 1st successful renewable diesel to meet the American Society for Testing and Materials D-975 specifications. The fuel is chemically derived diesel and can burn cleaner than petroleum. Their process differ from other companies, their growing method by avoiding sunlight and it is claimed that is a better method to produce and has produced the biodiesel in superior cold weather climate. But there is no sign details available in amount of oil they produce per year. Solazyme uses their method to make liquid fuel and they target their market with initial customers in contract with US Navy and airlines that are testing its biofuel mixed with petroleum fuel and oils for nutrition and skin care products but they showed that is revenue has grown on sale of its oil for nutrition and skin care products but it had few loss of € 14.84 million on revenue of € 41.74 million few years ago and there is no sign of amount of oil they produce per year but one big challenges for them is producing at large scale and making it profit [2].

Aquaflow, New Zealand based company conducted a laboratory and field development work in the Marlborough region. Their target is to become the first company in the world to produce fuel form wild algae harvesting technology in open air environment. Aquaflow disclosed few years ago that is was seeking € 4.55million to continue improving the refining process and their technology gained interest from investors from Europe, U.S.A, Asia, and Australia. Aquaflow is currently working with Boeing to develop algae-based jet fuel. Aquaflow targeting more on commercial scale production [6].Scaling from pilot studies to commercial products are always risky. Company faces difficulties in controlling conditions like right amount of nutrients, large amount of water supply and controlled temperature and consistent amount of CO_2 supply for algae to grow quickly and they are prone to succumbing to invasive species and they are dying in masses due to overcrowding [6].

Algenol Florida, U.S.A and India’s Reliance Industries Ltd., a joint venture started India’s first algae production platform. The project is designed and developed and several production cycle of demonstration has been completed and the process is designed to product 545 liters of oils and converting them into ethanol, gasoline, diesel and jet fuels. But production process requires large amount of water supply which is a drawback for Algenol. [5]

Joule Unlimited one of the successful company has raised € 36.42 million in private equity and venture debt funding as they decide to produce in large scale commercialization, also the company said that its fuel meets America and European specification to obtain government approval for commercialization of its fuel. Joule unlimited has developed technology to produce renewable fuels. The company partnered with Audi automakers to test out the fuel. They have their own patented technology and reverse combustion process. The company has planned to build a 1000 – acer’s plant in 2017 that has potential to produce 94.5 million liters of ethanol or 56.7 million liters of diesel per year. They expect if they proceed in the right way of production for few years they could gain revenue of € 91 million minimum. [5].

Seambiotic, an Israeli-based a leading company in developing reactor and production of microalgae for biofuels and nutrition and pharmaceutical. Company established a joint venture with Yantai Hairong Electric Technology Ltd. And Penglai Weiyuan Science & Trading Ltd. Companies associated China for the commercial cultivation of microalgae in China. Seambiotic had a unique technology of open pond system for cultivation of microalgae. The first commercial farm of 12 hectares and expected to cost € 9.1 million. The company is currently in transition from pilot plant stage to commercial scale algae cultivation and production, their current markets are biofuels, nutrients and pharmaceutical feedstock for animals. Rosetta Green a Company and Seambiotic signed a collaboration agreement to develop the process. Rosetta will be responsible for the development of strains of algae and Seambiotic will be in charge of large scale production [5] [6].

The analysis of the Companies market and their production process, there are lot of challenges for companies in the algae production, some company survive by using proper technology and operation and some company divestiture. Company had to invest more, since there are not much developed technology on the production process this leads to the company to shut down. Company that are still in the market due to their joint venture with other companies they help each other with the technology and operation they owned. Collaboration of leading companies from complementary fields, is the only way to success to meet the challenges that lie ahead for them to stay in the market for the next 5 years till the advanced production technology are in to this field.

Table 1.1 Capital cost for the open pond system [1]:

Land and Ponds roads and drainage	1.214 ha	41,000€
Water distribution	1.092	18,200€
Nutrition Cost	metric tons/ha	6400€
Electricity distribution/supply	metric tons/ha	1887€
Machinery's		1370€
Nutrition and CO_2 supply	metric tons/ha	4100€
Total Cost		72,957€

Table 1.2 Capital cost for the closed pond system [7]:

Land and Building cost and	1.214 ha	992,970€
Algae tube system and Fitting cost and CO_2 supply	1.092 ha	728,336€
Water distribution	metric tons/ha	6830€
Electricity distribution/supply	metric tons/ha	1370 €
Nutrition Cost	metric tons/ha	7280€
Equipment and Machinery's		546,250€
Total Cost		2,283,036€

2. REVIEW OF EXISTING TECHNOLOGY OF ALGAE GROWING SYSTEMS

Microalgae have the highest oil yield among various oil plants. It can produce up to 201,000 liters oil per hector (ha) year, whereas palm, coconut, castor and sunflower produce up to 5950, 2689, 1413 and 952 liters per hector(ha) year, respectively [8].Many algae are extremely rich in oil, the oil content of some microalgae exceeds 80% of the dry weight of algae biomass[9][10], and according to Oilgae , some have about 15–40% oil (dry weight), whereas palm kernel has about 50%, copra has about 60%, sunflower has about 55%. Oil content itself can be estimated to be 64.4% of the total lipid component [11] [15]. Energy conversion reactions of biomass can be classified into biochemical, thermochemical and direct combustion [8].

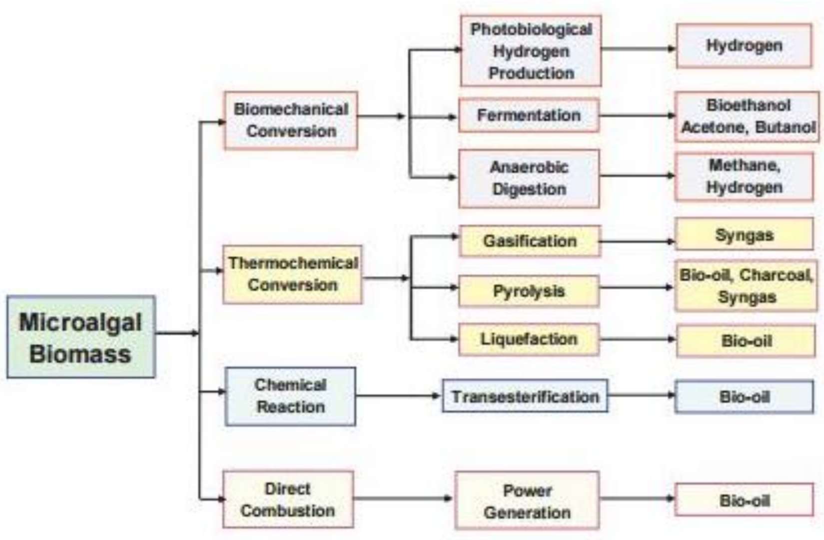

Figure 2.1 Energy conversion process from microalgae [12]

Biochemical conversion can be further subdivided into fermentation, anaerobic digestion, bio-electrochemical fuel cells and other fuel producing processes utilizing the metabolism of organisms. Thermochemical conversion can be subdivided into gasification, pyrolysis and liquefaction. Figure. 2.1 shows the energy conversion processes from microalgae. Biomass can also be converted into three main products: two of them related to energy product and a chemical feedstock. It is well known that microalgae have high water content (80– 90%) [14][15]**;** therefore, not all energy conversion processes of biomass can be applied to microalgae. For example, direct combustion of microalgae is feasible only for biomass with moisture content.

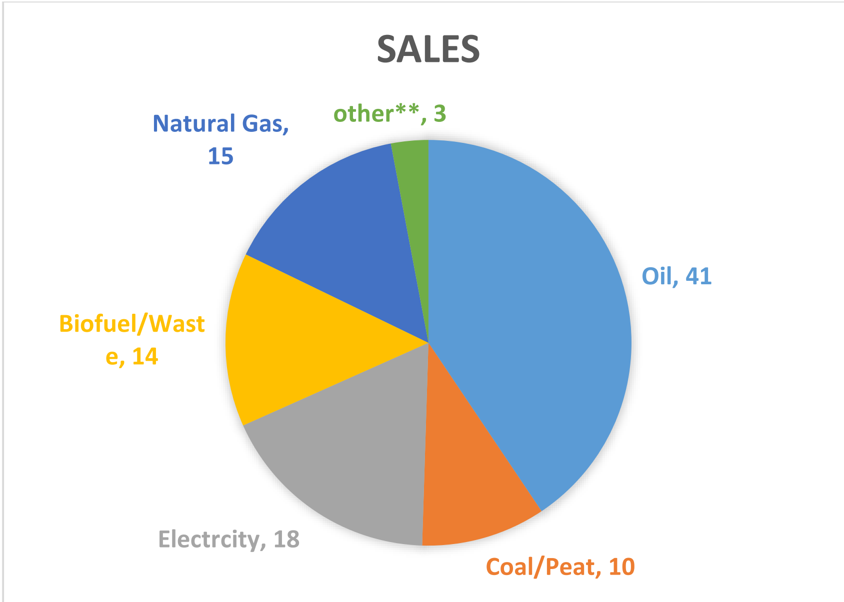

Figure 2.2 Percentage of sources of energy in 2010.Adapted from IEA [14]

The algae biomass production is carried out in two types of reactors, one is an open type and another is a closed type; the efficient reactor depends on its ability to provide sunlight to the growing algae, proper absorption of carbon dioxide, water, nutrients by growing algae, and temperature conditions. Generally, some industrial open-type production of algae is used for large scale production, which is more feasible. In the closed type the algae growth can be controlled, it is an ergonomic feature but both reactors have some major problems which are discussed below.

2.1 Open ponds

Open Ponds are the oldest and simplest system for mass cultivation of microalgae. The pond is designed in a raceway configuration, in which a paddlewheel circulates and mixes the algal cells and nutrients. The raceways are typically made from poured concrete or they are simply dug into the earth and lined with a plastic liner to prevent the ground from soaking up the liquid. Baffles in the channel guide the flow around the bends in order to minimize space. The system is often operated in a continuous mode, i.e., the fresh feed is added in front of the paddlewheel, and the algal broth is harvested behind the paddlewheel after it has circulated through the loop [16].

Open-pond system are shallow ponds in which algae are cultivated. Nutrients can be provided through runoff water from nearby land areas or by channeling it around bends by baffles placed in the flow channel and raceways channel are built from concrete or compacted earth and may be lined with white plastics. During daylight the culture is fed continuously in front of the paddlewheel where the flow begins. Broth is harvested behind the paddlewheel on completion of the circulation loop. The paddlewheel operates all the time to prevent sedimentation.

Photosynthesis is the most important biochemical process in which plants, algae and some bacteria harness the energy of sunlight to produce food. Organisms that produce energy through photosynthesis are called photoautotrophs. Photosynthesis s a process in which green plants utilize the energy of sunlight to produce carbohydrates from carbon dioxide and water with chlorophyll content.

Raceways ponds for mass culture of microalgae have been used since the 1950s. The largest raceway-based biomass production facility occupies an area of 440,000m^2 [17]. Productivity is affected by contamination with unwanted algae and microorganism that feed on algae. Raceway ponds and other open culture systems for producing microalgae are further discussed [18] [Figure 2.3].

Figure 2.3 Design of open-pond algae production [18]

For large-scale biofuel production, which requires system of hundreds of hectors in scale, this would mean tens of thousands of such repeating units deployed at great capital and operation costs. Open ponds, specifically mixed raceway ponds are much cheaper to build and operate, they can be scaled up to several hectors for individual ponds and it is a way of choice for commercial microalgae production. However, such open ponds also suffer from various limitations, including more rapid (than closed systems) biological invasion by other algae, algae grazer's fungi and amoeba, etc., and temperature limitation in cold or hot humid climates.

Microalgae must be cultivated in coastal areas. The raceway pond system of biomass culture must be approved to achieve high and sustained growth rates and oil yields are essential to developing and algae-based biofuel industry [19].

Open pond system may be feasible and easy to maintain but they are highly prone to contamination and, moreover, water loss through evaporation. Million liters of water loss take place in the system, which increases salinity and a low rate of illumination, a lower mass transfer of carbon dioxide and inappropriate mixing. Open system using a monoculture are also vulnerable to viral infection. The energy that a high-oil strain invests in the production of oil is the energy that is not invested in the production of proteins or carbohydrates, usually resulting in the species being less hard or having a slower growth rate. Algae species with lower oil content, not having to divert their energies away from growth, have an easier time in the harsher conditions of an open system. This leads to the development of closed type reactors [22].

2.2 Closed system

Closed photo-bioreactor has been invented to overcome the contamination and evaporation problem encountered in open ponds [20]. These systems are made of transparent material and are generally placed outdoors for illumination by natural light. The cultivation vessels have a very large surface-area-to-volume ratio. The main problem in large-scale open doors cultivation of micro algae in an open pond leads to low productivity and evaporation of water and high contamination. To overcome these problems a closed system consisting of polyethylene sleeves was developed. In a study conducted outdoors the closed system was found to be superior to open ponds with respect to the growth and production in amount of microalgae. In both closed and open systems the growth and production under continuous operation were higher than in batch cultivation.

The Japanese, French and German governments have invested significantly R&D dollars on closed bioreactor designs for algae production. The main advantage of such closed systems is that they are not so much subjected to contamination with whatever organisms happen to be carried in the wind.

While developing a photo bioreactor, design parameters such as reactor dimension flowrate, light required, culture condition, algae species, reproducibility, and economic value need to be taken into consideration. Depending on the reactor dimensions and local climate, these parameters can determine the type of cultivation system needed (open versus closed). The reactor design should have good mixing properties, efficiency and reproducibility and be easy to maintain and sterilize. An efficient photo bioreactor does not only improve productivity but also is used to cultivate multiple strains of algae. The performance of a photo bioreactor is measured by volumetric productivity, the real productivity and productivity per unit of illuminated surface. Volumetric productivity is a function of biomass concentration per unit volume of bioreactor per unit of time. Areal productivity is defined as biomass concentration per unit of occupied land per unit of time. Productivity per unit of illuminated surface is measured as biomass concentration per area per unit of time.

The closed bioreactor supports up to fivefold productivity with respect to reactor volume and consequently has a smaller “footprint” on a yield basis. Besides saving water, energy and chemicals, the closed bioreactor has many other advantages that are increasingly making it the reactor of choice for biofuel production as its costs are lower .The closed bioreactor allows essentially single-species of microalgae to grow for prolonged periods. There are different types of closed photo reactors design for algae cultivation most common reactors are tubular and flat plate and vertical column reactors and other reactors are modified reactors of the above reactors .[23] Other less common designs like semi-hollow spheres also have been reported to run successfully to some extent [21].

The reactor is designed and built and operated in a closed, recirculating, continuous culture system to produce microalgae and rotates in sea water (25% salinity) for larval fish culture. The system opens up a new perspective in terms of automated production and without labor costs. Algae can be easily harvested daily with a conical harvest net, and there is no routing maintenance work. This new automated system has three components: a microalgae culture and storage with harvest and a water treatment and a rescue component [22].

Closed system (not exposed to open air do not have problem of contamination by other organism blow in by air) the problem for a closed system is finding a cheap source of sterile CO_2 .Several experiments have found the CO_2 from a smokestack works well for growing algae.

The preferred alternative is closed photo bioreactor where the algae fluid remains in closed environment to enable accelerated growth and better control over environmental conditions. These glass or plastics enclosure, often operated under modest pressure, can be mounted in a variety of horizontal or vertical configuration and can take many different shapes and size. Rigid frameworks or structures are usually used to support the photo bioreactor enclosures.

2.2.1 Tubular photo-bioreactor

Tubular photo-bioreactor are mostly manufactured from hollow glass or plastic tubes. Aeration and mixing in the reactors are done by air pump/ air lift system. The tubing arrangement may differ from horizontal /spiral vertical to conical. The orientation of these reactors may be horizontal, vertical or inclined .The formation of gradients of oxygen and carbon dioxide is the unique characteristics of these photo-bioreactor. The carbon dioxide gradient also creates pH gradients in them. An increase in the diameter of the tubing results in a decrease in the effect of photosynthesis efficiency due to a reduction in the surface to illumination ratio. Increasing tube length has no effect if these tubes are placed horizontally [Figure 2.4]. However mixing increases the photosynthesis efficiency considerably [24, 25]. Alternatively photosynthetic efficiency can also be enhanced by tilting the angle of these reactors since it increases the exposure time of reactors.

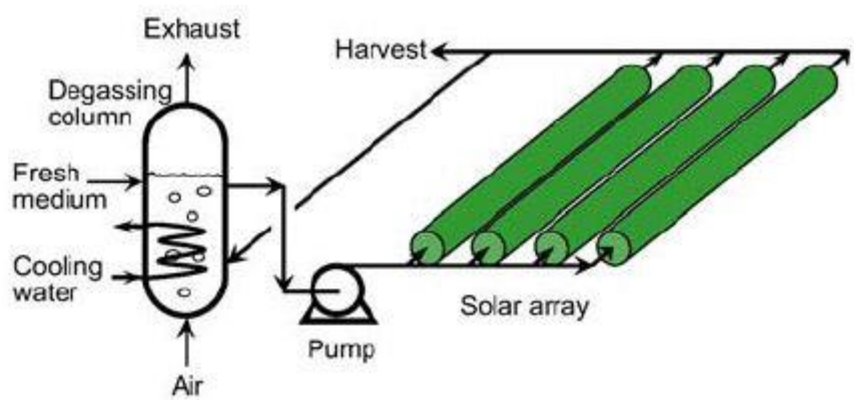

Figure 2.4 Tubular photo bioreactor with parallel run horizontal tubes [24]

2.2.2 Flat plate photo bioreactor

Flat plate is usually a transparent material. The larger illumination surface area allows high photosynthetic efficiency, low accumulation of dissolved oxygen concentration the reactors are inexpensive and are easy to maintain the advantage of these reactors is the availability of a large surface to volume ratio for illumination making them suitable for the mass cultivation of algae [24, 26]. Due to the availability of large surface area of illumination, higher photosynthetic efficient have been achieved [27] [Figure2.5]. The Photosynthetic efficiency may be improved further by tilting the angle of the reactors with the references to the ground [18].

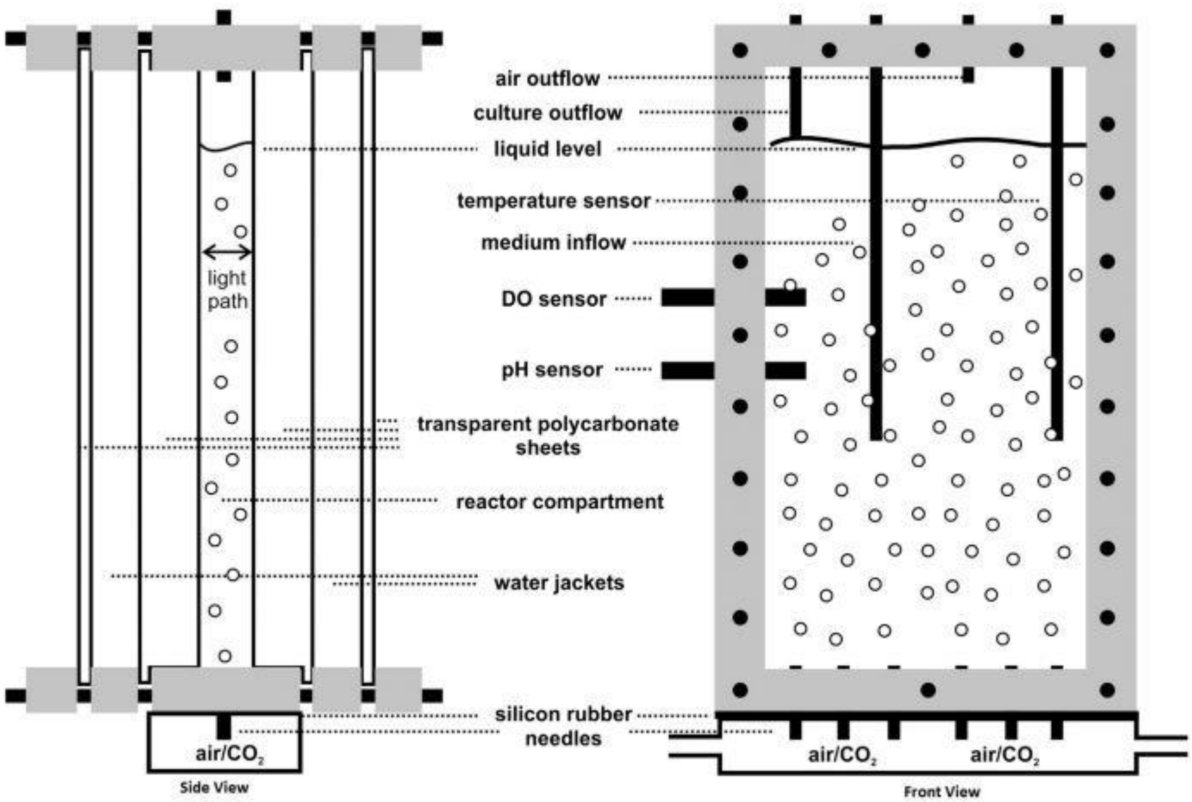

Figure 2.5 Schematic representation of flat plate photo bio-reactor [18]

2.2.3 Vertical column photo bioreactor

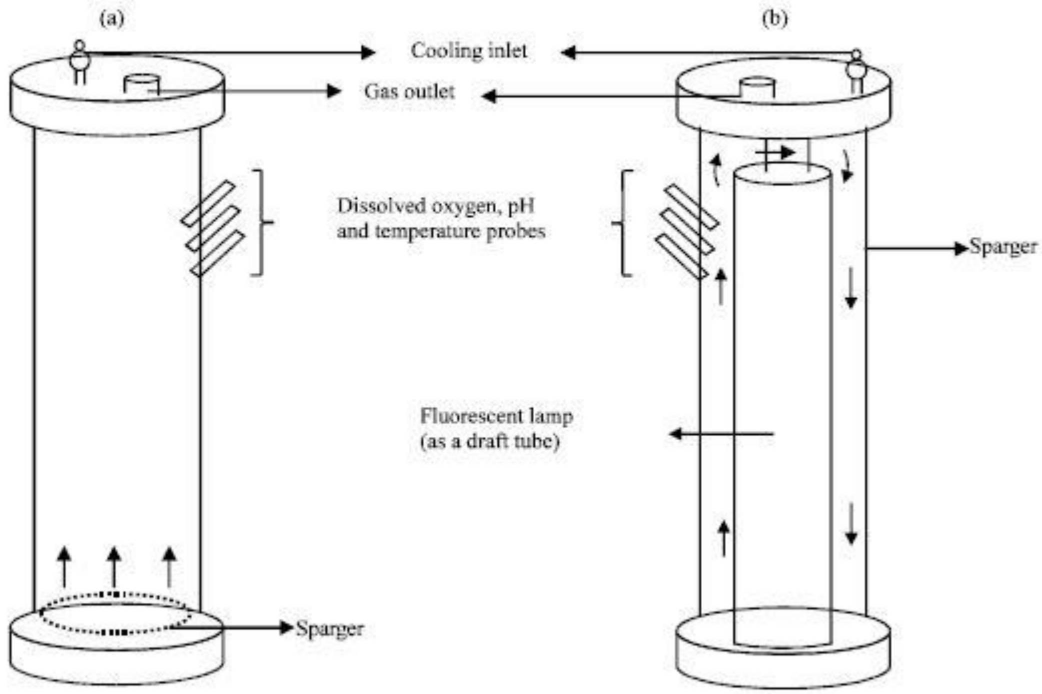

Figure.2.6 Schematic representation of vertical column photo bio-reactor [32]

These reactor are cylindrical photo bioreactors have gas bubble which enters from the bottom of the column, may be simple bubble column, and split cylinder/draft tube airlifts. Various prototypes of vertical-column photo bioreactors has been tested from time to time [28-29] and are considered to be the most promising for the purpose of scaling up [24] these reactors are characterized by high volume gas transfer coefficient. This is due to the gas bubbles travel along the column which also aids in mixing [Figure2.6] .CO_2/O_2 and pH gradient are created due to the same reason [30] [31].

3. ANALYSES ON ALGAE GROWTH PRODUCTION CHALLENGES AND DRAWBACKS ON THE CURRENT TECHNOLOGY

Today many R&D research's and company seek to replace petroleum fuels using algae. There are many fundamental biological, physical and chemical challenges that must be simplified and to be solve by using properly planned techniques and machines and devices to obtain sustainable algae fuel.

1. Water and nutrients: Even though algae can thrive in salt water and waste water, as well as fresh water, using large amount of water growing algae may be at odds with water needs of population center, agriculture and wildlife habitat. Evaporation alone can consume million liters a day from moderately sized operation instead of using open pond, closed system can be used. Using salt water for algae production eliminates direct competition with agriculture water use, but evaporation increases salinity in open ponds, and if salt concentration exceeds a certain level, the algae cannot survive. The availability and balance nutrients dramatically affect the types and productivity of algae population. Managing sufficient resource of nitrogen, phosphorus, carbon, and some other nutrients. By using various monitoring and controlling devices water and nutrients can be mixed together and can be fed to the algae as per the requirement.
2. Strain selection and temperature: Identifying and maintaining the ideal composition and temperature for species of algae to thrive in large scale production and needed to generate a consistent high quality production. Oil content and productivity, as well as, resistance to contamination and adaptation to the water chemistry, among several other factors are essential in determining a viable strain that promise high yields. Weather is inherently unpredictable requiring constant monitoring and heating and cooling equipment to maintain consistent temperature, one of the method is this can be done in closed system by heating or cooling the water nutrients that is feed to the algae.
3. Predators & parasites & toxins: Algae ecosystem vulnerable to invasive species and bacteria. Open ponds are is nearly impossible to control the introduction of undesirable algae strains, algae predators or other microbes that impact the cultivation. Maintaining a clean, unpolluted environmental is crucial for algal growth contamination from the outside sources puts ecosystem at risk of dramatic productivity losses. Closed system can lower the risk of exposure and monitoring system can detect all the contamination and feedback can be sent and required action can be taken to prevent the contamination.

Physical challenges

1. Pumping: The circulation of water and nutrients through the production system is crucial for maintaining algae growth and harvest rates. We need to pump the equivalent energy intensive, with current technologies we would need to pump the requirement/equivalent amount of water depend on the area of the rotating wheel sheet through feed pump.
2. Concentrating: Though algae laden water looks quite green, it is deceptively dilute. By weight algae are approximately one part in 3,000.Typical concentrating techniques (micro-strainer, Centrifuge, Filtration, etc.) can only bring this ratio down by an order of magnitude.

Chemical challenges

1. Extraction: Removing the oil and nutrients from harvested algae is a complex process. Many companies and R&D are searching for a "lipid trigger", or a way to easily turn algae into a single cellular oil factories. But altering the metabolism of microorganism is extremely complex to attain the production level of today's energy industry.

3.1 Drawbacks faced by the reactors

Photo bioreactor have the capacity to produce algae and has the ability to perform the task like scrubbing flue gases from power plant and removing nutrients from wastewater. Open pond growing technology are economic but it has lot of drawback left behind and closed reactor technology is currently in development stages and it's not much economic as compared to open pond reactors but the draw backs which the open pond technology faces can be avoided. Even though the close reactors have some more drawbacks which makes algae productivity low.

Photo bioreactor have higher efficiency and biomass concentration of 2 to 5g/L and lowest harvest time 2 to 4 weeks and higher surface to volume ratio (25 to 125/m) than open pond

- Open ponds suffers from various limitations like biological invasion by other grazers fungi and bacteria etc. which leads to contamination temperature limitation in cold and hot humid climate and loss of water due to evaporation and light penetration is limited.
- In tubular photo bioreactor the diameter of the tube is usually small and limited 0.2m in diameter or less. If the diameter of the pipe is more the liner growth rate of the algae and light penetration to the center of the tube will be decreased. Solar array (i.e.) arrangement

and size of solar collector tube are generally 0.1m or less diameter since the light does not penetrate too deeply in the dense culture.

- In flat plate the large surface area presents scale up problems, and difficulty in controlling culture temperature and carbon dioxide diffusion rate and more amount of algae adhering to the wall. The major problem in designing s the cost of the panel, wall growth that impairs the diffusion of light and moreover may inhabits the growth of some species owing to hydraulic stress.
- In vertical-column type the major limitation on these reactors is a low illumination surface area and increase in length of the column, which causes a shading effect. The shadow of the longer column falls over the column in closer proximity.

Table 3.1: Comparison of closed reactor with open reactor

Parameter	Open reactor	Closed reactor
Productivity	Low	High
Cost	Low(efficient)	High cost
Photon utilization	Low	High
Process control	Low	High
Mixing and gas exchange	Low	High
Contamination	High	Low
Water loss	High	Low
Flexibility of production	Change of production between possible varieties Nearly impossible.	Change of production Without any problem
Biomass quality	Not susceptible	Susceptible
Co_2-losses	High	Almost none
Biomass concentration during production	Low	High.

4. DEVELOPMENT OF DESIGN AND TECHNOLOGY ON CLOSED PHOTO BIOREACTOR FOR ALGAE TO GROW FAST

Reactor design should have good mixing property efficiency and reproducibility and be easy to maintain. An efficient reactor not only improves productivity but also used to cultivate multiple strains of algae

There are numerous aspects influence the growth and lipid content of algae. The conversion of sunlight into stored energy is photosynthesis and carbon dioxide and nutrients and water to grow the biomass [33] [34].

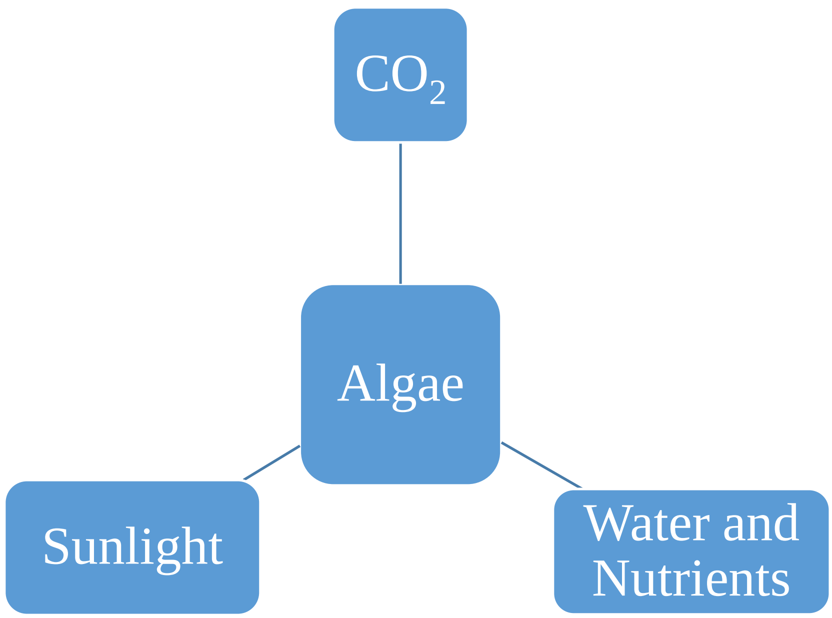

Figure 4.1 Algae growth requirements

All the components involved in this contribute growth of biomass algae, the factors discussed in this report, solar collector optical fibers and adsorbed and stripper and chemical solvent MEA (Monoethanolamide) $H_2NCH_2CH_2OH$ and water feeder with nutrients.

It is necessary to note each category the precise conditions for optimal depend on the strain of algae selected cultivation. (System was designed using Solid works 2014 and using Aspen Hyses V8.0 Trail version).

CO_2 for algae

1. In this system we use monoethanolamide a chemical solvent is used to create a reaction between CO2 which is present in the flue gas. The inlet flue gas enters at bottom of the absorption tower and the amine enters from top of the tower, a reaction takes places when the temperature raised and the amine absorbs the CO_2 from the flue gas and exits at bottom of the absorber tower and the remaining flue gas exit at the top of the tower. The rich CO_2 solvent is pump to the heat exchanger and it passes through the desorber (stripper tower).The rich CO_2 solvent enters at the bottom of the stripper tower desorption (i.e. CO_2 stripping) can be achieved by reducing the pressure, rich CO_2 solution can be separated from the MEA solvent and the CO_2 exits at the top of the desorber tower and the lean amine solvent exits at the bottom of the tower and regenerated solvent is then used again in the absorber as a continuous process shown in [Figure 4.1& 4.2 & 4.3]

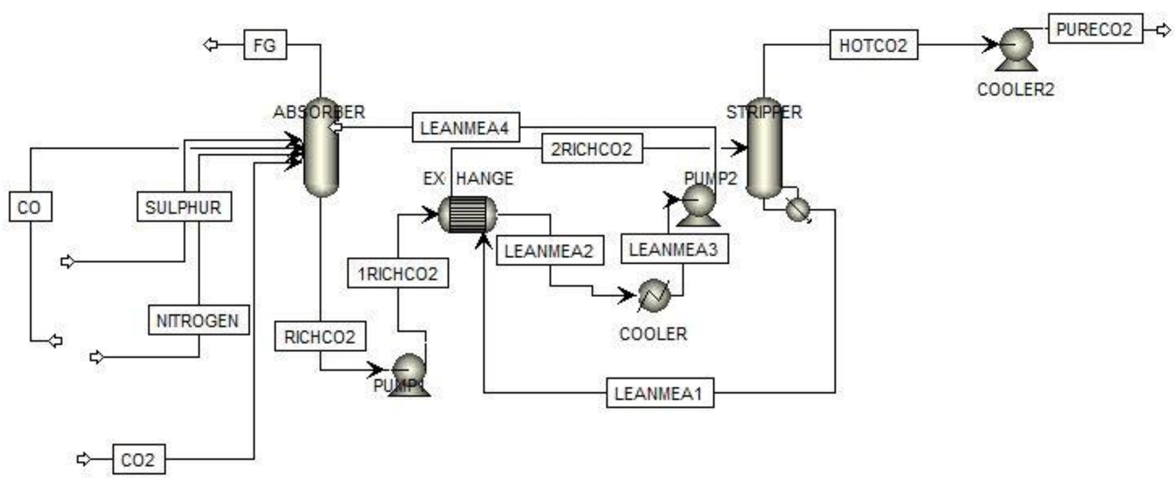

Figure 4.2 Absorber/desorber (Stripper) of CO_2 using chemical separation process

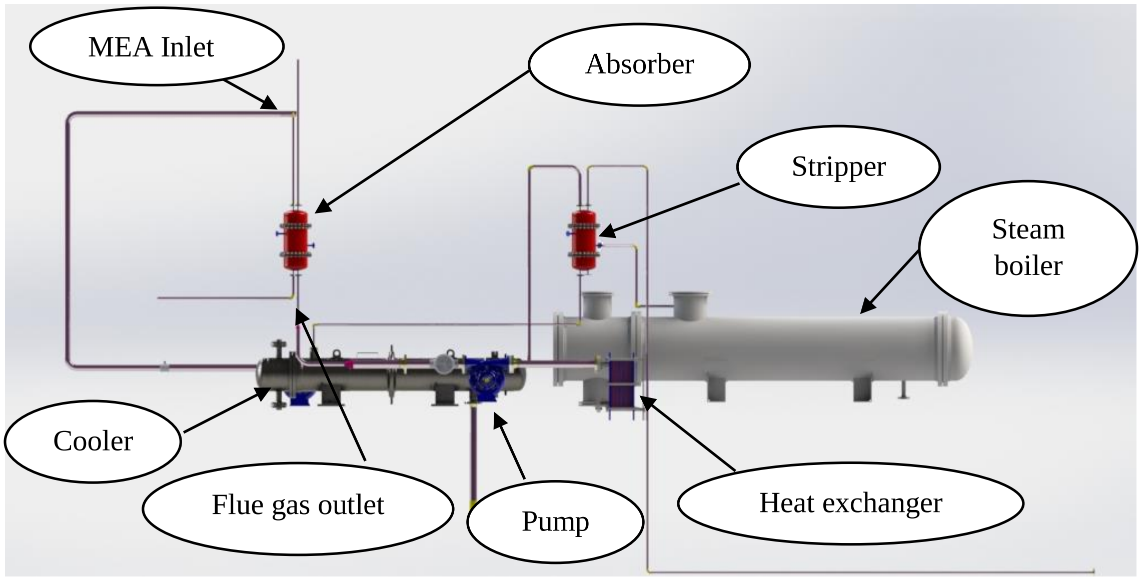

Figure 4.3 MEA absorber and stripper assembly

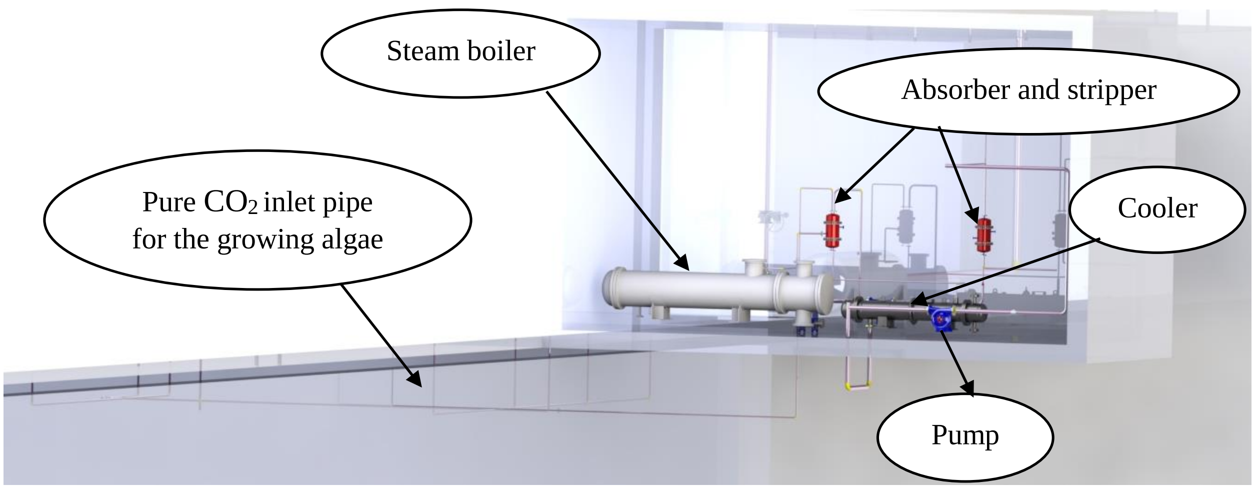

Figure 4.4 MEA absorber and stripper system

2. The separated CO_2 is then passed to the reactor chamber where the algae grows in the rotating roller the CO_2 is passed from the bottom surface of the Algae growing chamber.

Light illumination for algae

3. An efficient solar collector size of 1.5-2 meter concentrated towards sunlight, is used to collect the maximum sun light during the day hours, it can collect up to 30,000-35,000 lumens.
4. The sunlight is reflected to a point where UV (ultra violet rays is filtered first and visible light is collected and passed or piped to our reactor using fiber optic cables [Figure 4.4] [Figure 4.5].

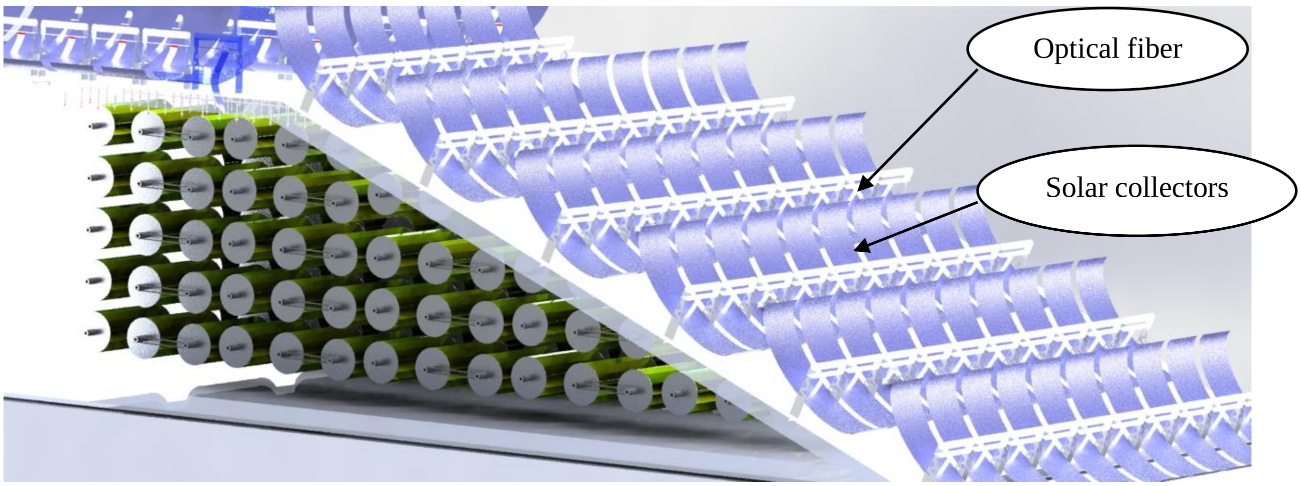

Figure 4.5 Optical fiber connected to solar collector

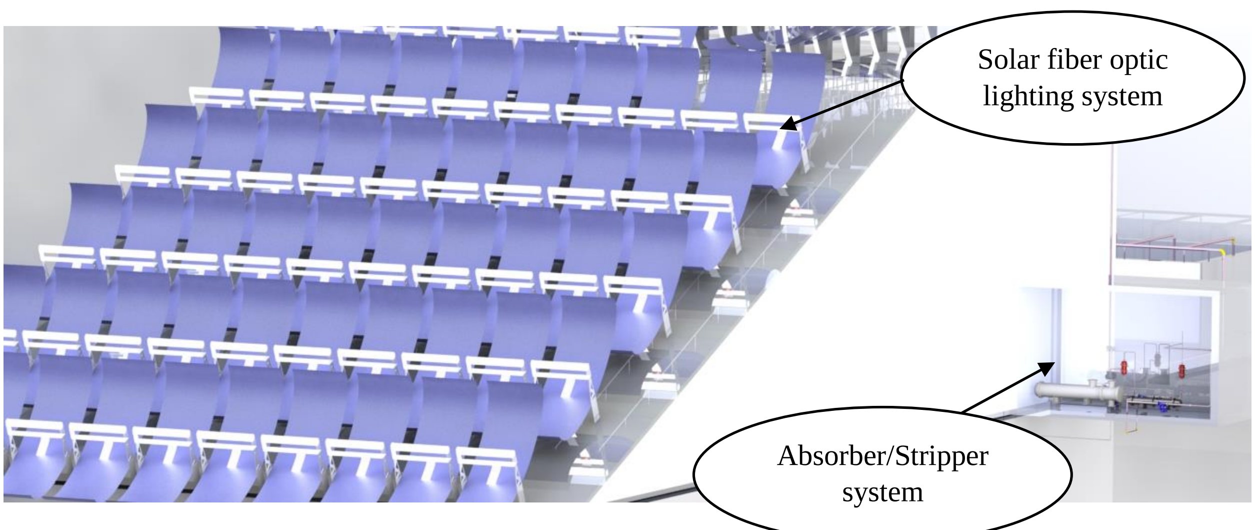

Figure 4.6 Solar collectors

5. The fiber optic cables then channeled the sunlight into closely placed vertical (sides)/Horizontal (top &bottom) acrylic glow plates with a very high surface area [Figure 4.6].

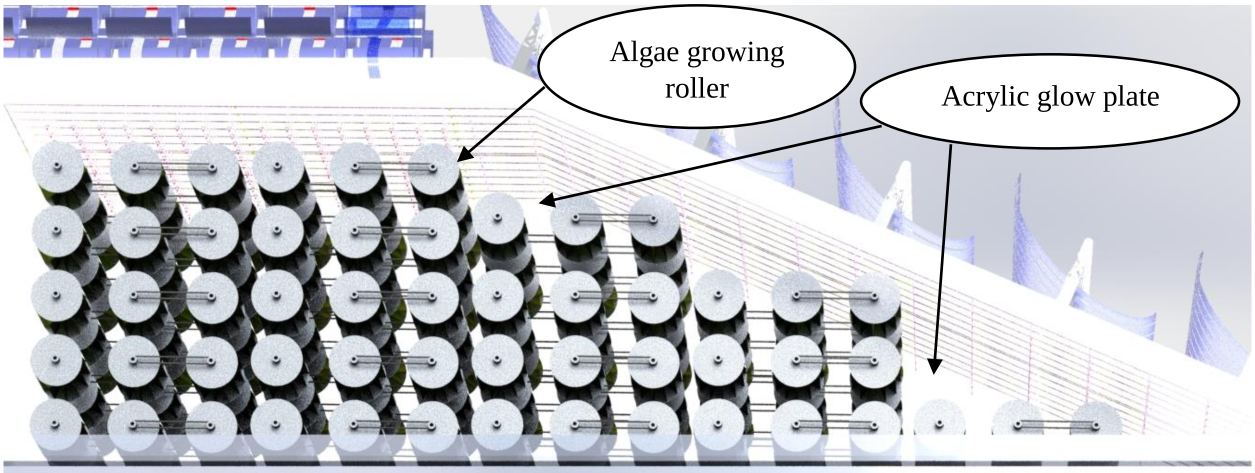

Figure 4.7 Acrylic glow plates

6. Thus allowing the sun to reach much greater growth area than it would a most powerful generation exhaust their carbon dioxide into the atmosphere. This lead to high concentration of greenhouse gas emission in creation of significant environmental challenges the algae in our bioreactor.

7. The Biomass algae will be grown on a thick steel plate [Figure 4.7] [Figure 4.8]. The thick Steel plate taped with polyester sheet or white cotton fabric on which the algae grows, the total growing area of algae will be about 1.026 ha. The steel plate is fixed with the roller at both the ends, the roller is connected to the belt drive which is driven by motor the rotating roller helps the algae to go more closely to the artificial illuminated sunlight and algae also receives more CO_2 the more and more CO_2 and sunlight it gets algae grow faster.

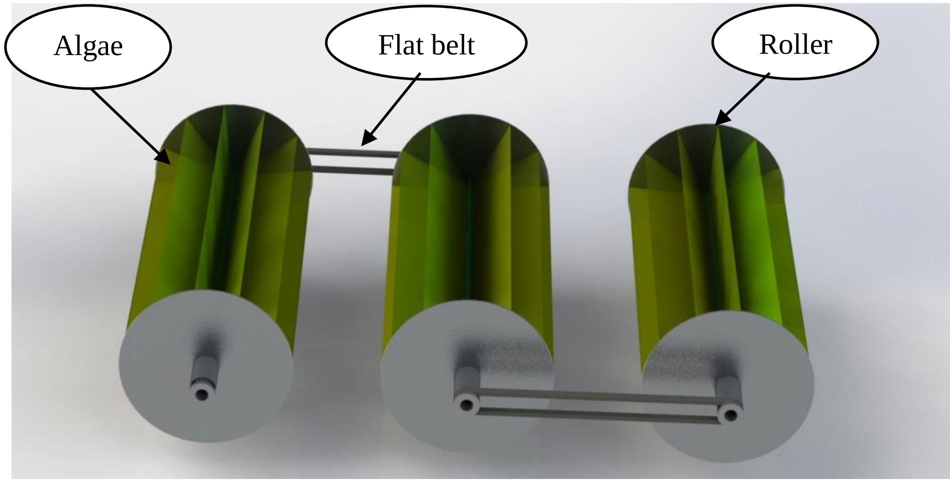

Figure 4.8 Algae growing roller connected to belt

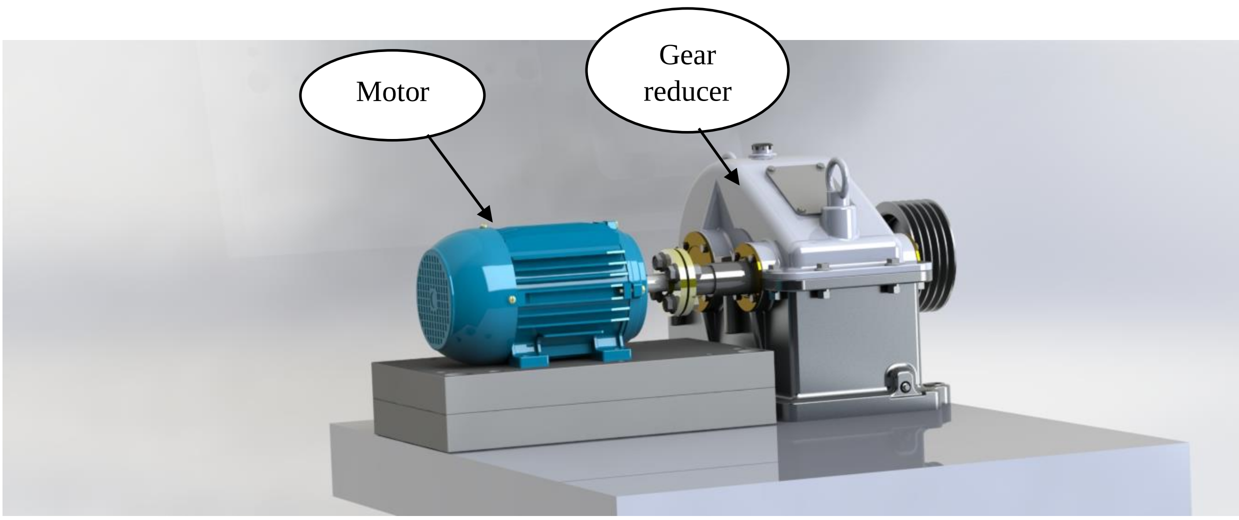

Figure 4.9 Motor with gear reducer

8. The algae in the bioreactor captures the emission and act as a carbon skin while giving oxygen which either released in the atmosphere or for power plant chambers for additional emission reduction.

Water supply and nutrients for algae

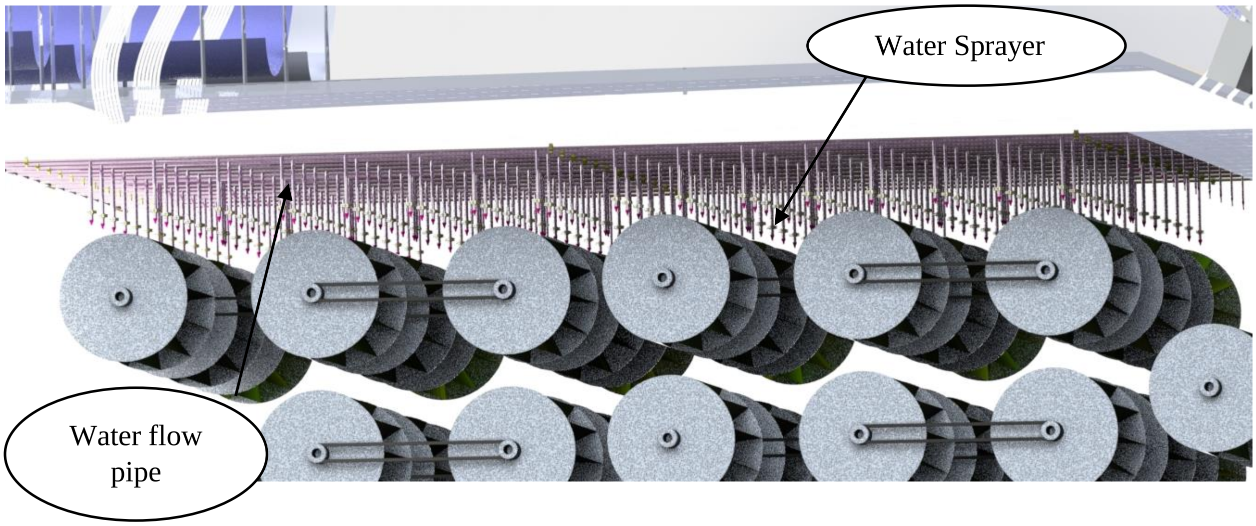

Figure 4.10 Water and nutrients distribution system

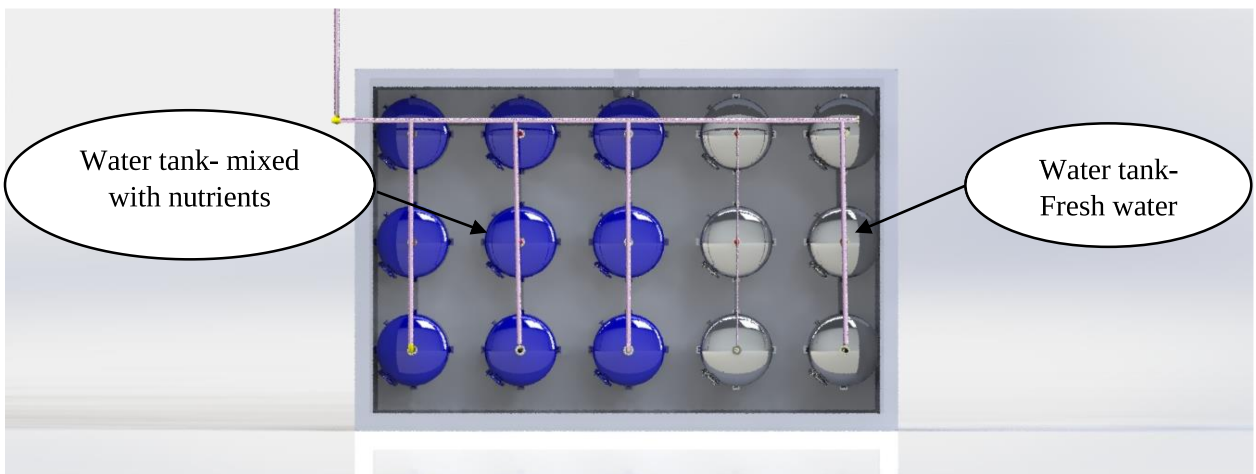

Figure 4.11 Water tank for growing algae

9. Water and nutrients are fed to algae on all the layers through the use of feed header/Sprinkler from the roof on top and sides. One tank is mixed with the nutrients for growing the algae other tank filled is freshwater to wash off the algae from the roller [Figure 4.9] [Figure 4.10].
10. The algae in the bioreactor then grows in a white cotton fabric/polyester sheet on rotating wheel as the CO_2 gas passes through the bioreactor it consumed by the algae on specific

strain algae has been proven in bench scale studies actually It can double the mass in less than 12 hrs.

11. Farming each crop of algae is then accomplished by increasing the water pressure on the respective layers.
12. The majority of the algae to shear off the growth medium for collection at the bottom and pumped to the tank. And again few biomass algae sent back to the bioreactor through the pipe and the process repeats.

5. SELECTION OF COMPONENTS EQUIPMENTS TECHNIQUES THAT REQUIRED FOR GROWING AND CAPITAL COST FOR THIS SYSTEM

For developing this closed reactor there are various thing that need to be selected its components, equipment and techniques that required for this development are explained in detail in the following.

5.1 CO_2 Capture and separation technology

There many methods available to capture CO_2 by pre combustion, oxy combustion and post combustion, physical absorption, chemical absorption, membrane separation and cryogenic separation, and pressure swing absorption and vacuum swing absorption as per the studies in this report we choose chemical absorption method reason for the selection of chemical absorption is it is cost effective and consume less energy and better result of separation and there are various chemical absorption method for absorbing CO_2 using MEA (monoethonolaminne) and potassium carbonate and chilled ammonia as per the studies the MEA solvent gives the best result as compared to the other solvent and methods the process of CO_2 absorption has been discussed below [35][36][38].

The process for CO_2 absorption can be divided in to

1. Flue gas inlet
2. CO_2 absorption
3. Rich CO_2 desorption
4. Cyclic process of lean solvent

1. Flue gas inlet:

In this system the absorber operates at a temperature of 40°C this temperature has to be maintained because the absorption of CO_2 from flue gas reaction takes place only at this temperatures hence the inlet flue gas should be between 30-40°C.The temperature of the flue gas from the power plant exhaust is around 100-120°C and these gas need to be cooled before it enters the absorption tower. The flue gas is cooled by passing it through a direct contact cooler (DCC).DCC is a cooling tower in which the water flows in a counter current direction of flue gas. The flue gas enters at the bottom of the tower and the water enters at top of the tower this reduces the temperature of flue gas by the evaporation of water at the top of the tower and the water is collected at the bottom of the tower and reused again.

1. CO_2 absorption

The absorber tower operates at 40°C the cooled gas enters the tower at the bottom of the tower the lean solvent MEA enters the absorber tower from the top of the tower the chemical reaction takes place between the flue gas and MEA solvent and the MEA solvent strips the CO_2 from the flue gas and exits at the bottom of the absorber tower and rich CO_2 solvent is sent to inline pump before it is being sent to the heat exchanger.

2. Rich CO_2 desorption

The desorption column that has kettle re-boiler built to it, the rich CO_2 enters the desorption/stripping column from the bottom of the tower, the tower is maintained at a slightly elevated pressure of 1.7-1.8 atm and at temperature of 120°C only at this temperatures the amine solvent and CO_2 and be separated ,a hot steam of vapor enter the desorption column from the re-boiler the entering vapor steam, the rich CO_2 steam flows down in the counter direction of hot vapor from the re-boiler this separates rich CO_2 and rich CO_2 gas is allowed to exit at the top of the desorber column and it is cool down ,lean MEA solvent and exits at the bottom of the desorption column .

3. Regeneration of lean solvent

   The amine solvent that has been separated from CO_2 is sent to the cooler to reduce its temperature since the absorber column is operated at 40°C the lean amine solvent has to be cooled down till it reaches the desire temperature equal to the absorber temperature and the solvent is allowed to enters the top of the absorber column and the cyclic process repeats.

The CO_2 that is separated is passed to the cooler and then it's passed to the algae growing chamber since the coming out CO_2 steam will be hot, the hot steam has to be cooled down or it will affect the algae.

MEA solvents ability of absorb CO_2 can be reduced by nitrogen oxides and Sulphur oxides these are impurities which can form stable salts these impurities need to be removed and fly ash and other black particles like soot need to be removed.

Chemical absorption/desorption system operates at given temperatures this system is proposed to find the molar flow rate of the treated gas and concentrated gas; Nt & N_c, and to calculate the molar flow rate of the amine to the entering flue gas in the absorber and to find the amount of absorption column loaded; and to find the % recovery of CO_2 for the absorption and desorption process assuming flue gas is take from the 300MW power plant [35] [38] [39].

Table 5.1 Absorption/desorption system steam flow

Stream	Variable	Actual volumetric Flow rate (m^3/min)	[CO_2]	T(°C)	P(atm)
Flue gas	n_f	11.6%	11.6%	40	0.9997
Treated gas	n_t	-	2%	40	0.9997
Concentrated CO_2	n_c	-	100%	40	0.9997

Liquid solvent

Amine Solution- MEA (monoethonolamine)

Density (lb_m/gal) - 8.445

Flow rate (gal/min) - 6.72

M_{MEA} (g/mol)-61

[MEA] -32.50%

Molar flow rate of n_t & n_c

Molar flow rate of the entering flue gas (feed) can be calculate: P=0.9997 and T=40°C, (313K)

PV=nRT (Ideal gas law) solving the equation in terms of moles

$$n = {}^{PV}\!/_{RT}$$

$$n = {}^{(0.9997\ atm) \times (11.6 \times 10^3\ L/min)}\!\Big/_{(0.08026\ \frac{L.atm}{mol.k} \times 313} = 461.6\ \frac{Mol}{min}$$

The molar flow rate of the entering flue gas is ($n_{f)}$ = $461.6\ \frac{Mol}{min}$

Total molar flow rate of CO_2

Total Molar flow rate of CO_2 can be calculated by using molar flow rate of the flue gas

The molar composition of CO_2 is 11.6% (feed Stream)

Can be calculated by multiplying the (n_f) the molar flow rate and molar composition of CO_2

$n^{CO2}{}_{feed}$= n_f (11.6% mol CO_2/100 mol feed)

n^{CO2} = $461.6\ \frac{Mol}{min}$ ×(11.6 mol CO_2/100 mol feed) =$53.54\ \frac{Mol\ CO2}{min}$

The total molar flow rate of CO_2 (n^{CO2}) is $53.54\ \frac{Mol\ CO2}{min}$

The total flow rate of other gases (O.G) can be calculated by using the total molar flow rate of CO_2 in the feed stream which are not absorbed by the MEA solution.

$n^{O.G}{}_{feed} = n_f - n^{CO2}{}_{feed}$

$n^{O.G}{}_{feed} = 461.6\ \frac{Mol}{min} - 53.54\ \frac{Mol\ CO2}{min} = 363.06\ \frac{Mol}{min}$

The total flow rate of other gases (O.G) is ($n^{O.G}{}_{feed}$) = 363.06 $\frac{Mol}{min}$

Flow rate of treated gas can be calculated by using the total molar flow rate flue gas of other gases since other gases won't react with the MEA Solution.

Concentration of other gases (O.G) in the treated gas by using the concentration of CO_2 in treated gas % CO_2 =2 % (CO_2 is subtracted from 100% since only two components of stream available)

%O.G= (100% - 2%) =98%

Concentration of other gases (n O.G) is 98 % of other gas, now we can calculate the Molar flow rate of ($n_{T.G}$) can be calculated by using molar flow rate of other gases (O.G) and the molar composition fraction

$(n_{O.G}) = (n_{T.G}) \times (98\ \text{mol O.G}/100\ \text{mol feed}) = 0.98$

$(n_{T.G}) = (n_{O.G})/0.98$

$(n_{T.G}) = 363.06\ \frac{Mol}{min} / 0.98 = 370.46\ \frac{Mol}{min}$

Total flow rate of treated gas ($n_{T.G}$) is 370.46 $\frac{Mol}{min}$

The flow rate of concentrated CO_2 can be calculated by the amount of CO_2 absorbed by the liquid amine before escaping in $n_{T.G}$. Let's now assume 100% of CO_2 will be stripped from the amine liquid in the stripper column and this exits in the concentrated CO_2 stream. And the molar flow rate of CO_2 in this stream is equal to the molar flow rate of n_C due to 100% composition.

n_{nc} of CO_2 = n_{nc}

Since,

$n_{nc\ of\ Co2} = n_f$ of $CO_2 - n_{n\ (T.G)}$ of CO_2

$n_{nc\ of\ Co2} = 53.54\ \frac{Mol\ CO2}{min} - (370.46\ \frac{Mol}{min} - 363.06\ \frac{Mol}{min})$

$n_{\text{nc of Co2}} = 46.14 \frac{Mol}{min}$

The Flow rate of $nc_{\text{ of CO2}} = 46.14 \frac{Mol}{min}$

The molar flow rate of monothnonalamine (MEA)

By using the given data of density and Volumetric flow rate we can calculate the mass flow rate of stream

$\text{Mass}_{\text{MEA}} = 6.72 \frac{gal}{min} \times 8.445 \frac{lbm}{min} = 56.7504 \frac{lbm}{min}$

$\text{Mass}_{\text{MEA}} = 56.7504 \frac{lbm}{min} \times 453.5937 \frac{grams}{min} = 25.74 \times 10^3 \frac{grams}{min}$

(i.e.) $(1\text{lb/min} = 453.5937 \frac{grams}{min})$

$\text{Mass}_{\text{MEA is}}$ $25.74 \times 10^3 \frac{grams}{min} \times$ Molar composition fraction of MEA

$\text{Mass}_{\text{MEA is}}$ $25.74 \times 10^3 \frac{grams}{min} \times (32.5 \frac{grams}{min}) / (100\text{grams}) = 8.366 \times 10^3 \frac{grams}{min}$

To calculate the molar flow rate of monothnonalamine n_{MEA}

$n_{\text{MEA}} =$ total mass flow rate of MEA/molar mass of MEA

$n_{\text{MEA}} = (8.366 \times 10^3 \frac{grams}{min}) \times (1 \text{ mol}_{\text{MEA}}/61\text{grams}_{\text{MEA}}) = 137 \frac{mol\ MEA}{min}$

Amount of momoethonalamine loading in absorber

Total CO_2 absorbed by the stripper and total molar flow rate of the momoethonalamine is equal to the molar flow rate of CO_2 leaving the stripper column,

Absorber Loading = $(n_{\text{M of CO2}})/(n_{\text{MEA}}) = (46.14 \frac{Mol}{min}) / (137 \frac{mol\ MEA}{min}) = 0.33 \frac{Mol\ co2}{mol\ MEA}$

Absorber Loading= $0.33 \frac{Mol\ co2}{mol\ MEA}$

Percentage of recovery of CO_2 for the absorption / stripping process

The percentage of recovered CO_2 can be calculated by $(n_{\text{c of CO2}})/(n_{\text{f of CO2}})$ (i.e.) Concentrated steam of CO_2 by total contained CO_2 in the feed stream.

CO_2 Recovered % = (46.14/53.54) × 100=86.17%

5.2 Illumination through solar fiber optical system

Light intensity is one of the major drawback for the other designs which is noted that algae culture in the photo bioreactor have high optical density which lead to improper distribution of light. As a result algae which is on the top surface exposed to the light and the cell in the algae absorbs the most of the light leaving very little part of radiation for the other cells underneath which limits in their growth like flat plate and open pond and in tubular reactor and other closed reactor only half amount of light is allowed to fall on growing algae. They need more than 15,000 lumens for a large system, due to the various factors mentioned above, thus reduces the algae growth. Algae has an ability of doubling its mass in 24hr with the help of light (i.e.) photosynthesis. Due to the failure of light intensity in the other designs the author designed reactor in the way that the algae gets maximum intensity of sunlight during day time and the light is allowed to fall on algae in all the directions/sides so that there won't be overlapping of shadows of above roller rotating,.

In this reactor the illumination for algae to grow is given by Solar fiber optic lighting system, it has the parabolic dish facing towards sunlight which act as primary mirror concentrates the light to towards the secondary mirror the secondary mirror will strip the infrared and ultra-violet wavelength. Removing the infrared and U-v rays from the sunlight will reduces the heat to the fiber optics. Specially manufactured cable for sunlight transmission is used it is made up of large diameter quartz glass fiber.

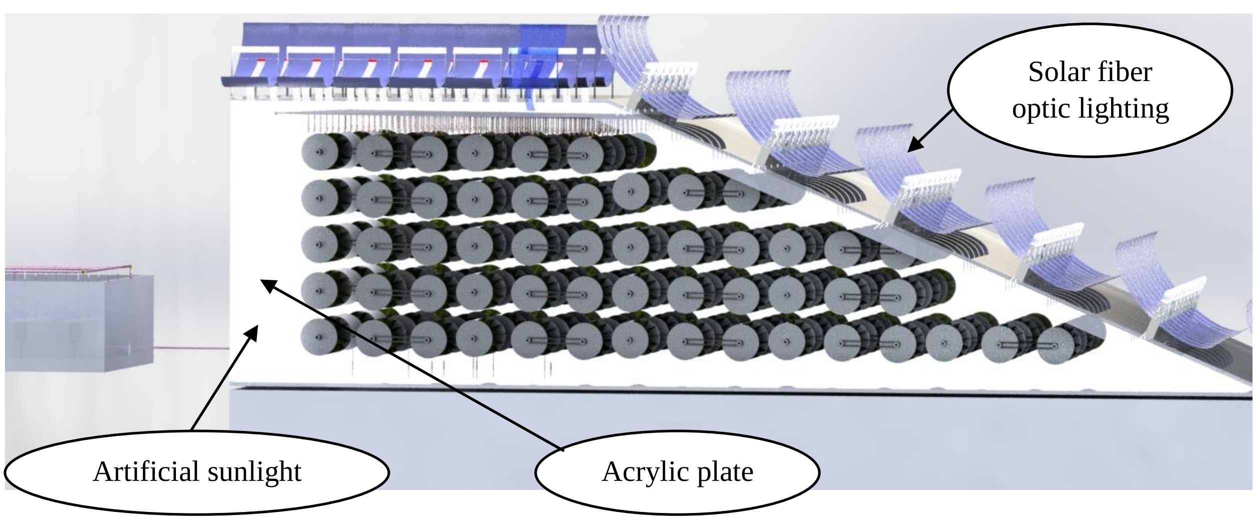

Figure 5.1 Illumination through solar fiber optic lighting system

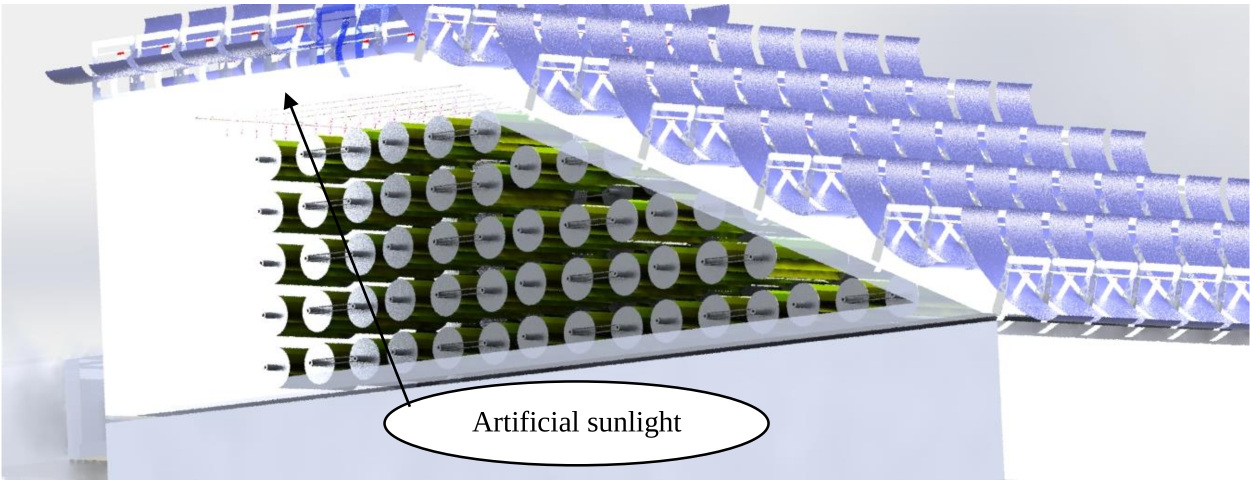

Figure 5.2 Illumination through solar fiber optic lighting system side view

A single cable with core size of 1 mm made in to a bundle of optical fibers in the optical fiber receiver, visible light is then focused on the fiber optic receiver, which contains bundles of optical fiber, each one cable transmits sunlight collected by lenses, and passed in to the walls just like electric wire sent to lighting fixtures fibers are easily installed .It needs 9 volt battery to power solar tracking system per week it consist of two motor that are controlled by GPS microprocessor which can track the location of the sun. One system can give peak up 25,000-30,000 lumens for 92.90 m^2 during bright sunny day but during dull day it is not possible to get the peak lumens for algae to grow for this we separate the lighting effect for the area of 18.59 m^2 per system so even during dull day the growing algae will get the required amount of light intensity to grow and it is channel to the acrylic glow plates and the light is allowed to fall on the growing algae.

5.3 Water distribution for the growing algae:

Supplying water to the growing algae is potentially a major limiting factor, algae can grow in any type of water a significant feature is they can even grow well in non-potable water also but the required water is as equal as that of cotton or wheat. Algae growing in open ponds needs million liters of water per day, which leads to loss of water due to evaporation the biggest drawback for open pond system and in closed pond system that is tubular and flat plate reactors water flow is significantly good but it leads to scale formation in the inner layer which leads to improper light distribution for the growing algae to overcome this problem in this system algae will be grown on a thick steel plate. The thick steel plate taped with polyester sheet or cotton fabric on which the algae grows. The roller has to be rotated for the proper distribution of light and proper distribution of water supply for the growing algae, water is supplied from the top of the roof through the water sprinkler. Two type of tank will be used one tank is mixed with the required nutrition for the algae to grown and is used during the algae growth and another tank will be with fresh water and is used to wash off the algae from the polyester sheet/cloth once its grown . The roller is rotated with the help of motor and belt, the required motor and belt has to be selected as per the required power and rpm and weight of the roller and belt material and length has to be selected as per the length between the rollers and required material and type of belt and water required for the algae to grow in 1 hector of algae is about 75,000-80,000 liters/ hr. so the pump has to be selected as per the required water flow and pump head (m), the pump selection is done by using the pipe flow software

5.3.1 Motor selection

Motor is necessary to rotate the algae growing roller since and the weight of the each roller is 616.66 the roller is big and its total mass of 3 roller connected to the belt is 1850kg and the total roller available is 54 with an area covering of 1.0260 ha. The roller will be driven by the motor which is coupled by belt to drive the roller the motor should have the power (W), and torque and should give the efficiency to drive the roller.

Assuming safety factor as 1.2 and Efficiency ŋ as 98%, diameter = 0.30

Required RMP is 6= (ω), time (t) =10

Torque$(\tau) = I\varepsilon$

Moment of Inertia

$I = \frac{1}{2}MR^2$

$I_1=\frac{1}{2} \times 2 \times 1850 \times 0.15^2 = 41.625$

$I_2=\frac{1}{2} \times 3 \times 1850 \times 0.15^2 = 62.4375$

$(\omega)= \varepsilon/t$ = 6/10 =0.0628 rad/sec^2

(ω)= 0.0062832 rad/sec

The required motor torque is

$\tau1 = I\varepsilon$ =41.625×0.0628 = 2.6154 Nm

$\tau2 = I\varepsilon$ =62.4375×0.0628 = 3.92307Nm

Considering safety factor 1.2

$\tau_s=\tau_y$ ×safety factor

τ_{s1} = 2.6154 Nm×1.2= 3.1384Nm

τ_{s2} = 3.92307 Nm×1.2=4.70768Nm

Torque efficiency $\tau_{n1} = \tau_x / n = 3.13848/0.98^5 \times 0.95 = 3.655$Nm

$\tau_{n2} = \tau_x / n = 4.70768/0.98^8 \times 0.95 = 5.825$Nm

Power required to drive the motor is

W= $\tau \times \omega$

W_1= 3.655× 0.62832 = 2.297 Watt ~2.3 Watt

W2=5.825 ×0.62832 = 3.660 Watt ~3.7 Watt

In this design we use two types of motor since we split the algae rotating roller into 2, 3 each roller has two belt connected (i.e.) four belt drive and six belt drive and 2 roller will be connected by one extra belt so 5 belt will be used and 3 roller will be connected with 2 extra belt to rotate so 8 belts will be used. One motor with 2.3 watt with 1800rpm and at 0.012Nm torque and another motor with 3.7 watt with 1800 rpm and 0.019 NM. Since we required only 6rpm we need to use gear reducer it is selected as 300:1 for single stage, 5:6:10 for three stage.

5.3.2 Selection of belt

Belt type

Open belt is used with shaft arranged in parallel and rotating in same direction,

The length of the belt can be calculated using the diameter of the driver D1 and D2 diameter of the follower

r1 and r2 =radii of the driver and pulley

x= Distance between the center of two pulleys

l=Total length of the belt

r1=0.15m,

r2=0.15m,

x=3m.

Rpm (N1) =6

Velocity of the belt

$v = \pi dn/60$

Length of the belt

$l^{=}\pi(r1 + r2) + 2x + (r1 - r2)^2/x$

$l = \pi(0.15 + 0.15) + 2(3) + (0.15 - 0.15)^2/3$

The length of the belt l is 6.94m

Speed of the belt

$v = \pi dn/60$

$v = \pi \times 0.3 \times 6/60$

$v = 0.0942 m/s$

5.3.3 Pump and valves

Water from the tank to the growing algae is discharged by using pumps proper water flow through pipe is necessary there are various factors need to be considered to select the appropriate pump the various factors are total head or pressure, desired Flow rate, the suction lift and required power and efficiency by using pipe flow software. The data obtained from the software [Figure 5.1] for proper distribution of water supply for this growing algae system are the pump power is 15.7623 KW and the efficiency of the pump is 58.85 obtained from the graph [Figure 5.2] and required Speed rpm is 2080.

Table 5.2: Pump data

Pump head(+)m.hd fluid	Discharge pressure bar.g	Pump NPSHr m.hd fluid (absolute)	Pump NPSHa m.hd (absolute)	Pref. op from m^3/sec	Pref. op to m^3/sec	Flow In/out m^3/sec	Velocity m/sec	Suction pressure bar.g
59.115	5.7856	1.4789	10.108	0.0138	0.0256	0.0161	1.245	None

Table 5.3: Pump flow rate

Pipe name	Total K	Mass Flow kg/sec	Flow $m^{3/}$sec	Velocity m/sec	Entry pressure bar.g	Exit pressure bar.g
P1	0.7300	16.0334	0.0161	1.245	0.000	5.6315
P2	0.7300	16.0334	0.0161	1.245	5.6315	5.4746
P3	0.2600	17.0314	0.0208	1.332	5.4756	4.4387
P4	0.2700	18.0294	0.0171	3.788	4.4387	4.1027

P5	1.000	19.0274	0.0191	3.788	4.1027	None

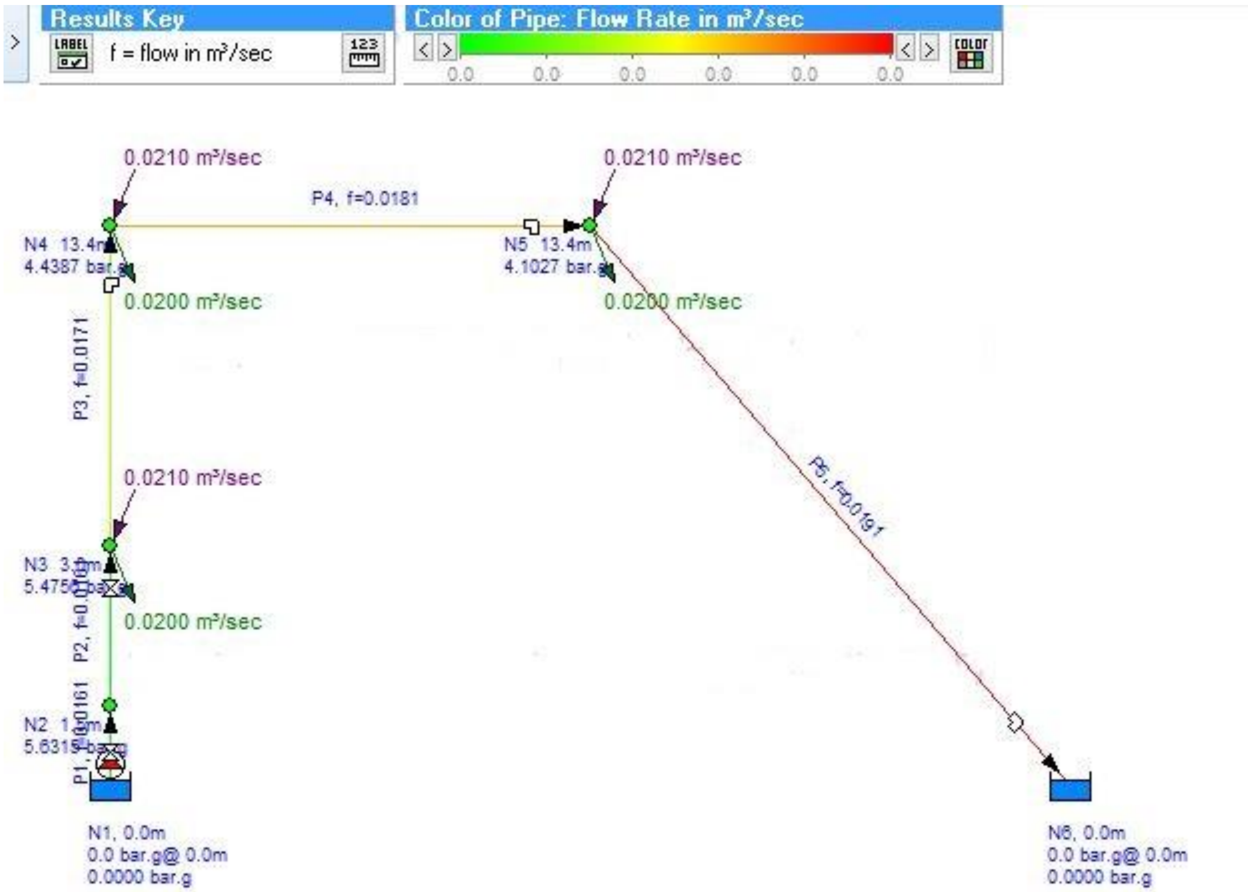

Figure 5.1 Water flow through the pipe for algae growing system using pump

Water flow L/sec is on the X-axis and flow head of fluid (m) is on the Y-axis the piping system depend up on the total head, suction lift and flow rate and pump characteristics, the operation point of the pump flow rate and pressure depend up on the piping system and pump interact. The pump to the piping system and flow rate and efficiency that is required can be obtained from the graph. A pump usually have reduced capacity as the pressure/head it is pumping against increases. The curve describes the operation point of the system that can be achieved. From the graph the red line meeting at the point is the required pump characteristics, pump efficiency 58% and fluid flow head meter at 50m and flow of 20 l/sec at impeller diameter of 330mm and required motor rpm is 3600 [Figure5.2].Since the pump type is the end suction pump a most common type of centrifugal pump and one of the most cost effective type of pump with above characteristic can be selected. The following table will describe the pump data.

Figure 5.2 Pump curve

Table 5.4: Pipe data

Pipe Id	Pipe Name	Material	Inner Diameter mm	Roughness µm	Length mm
1	P1	125mm steel Sch. 40	128.194	0.046000	1499.997
2	P2	125mm steel Sch. 40	128.194	0.046000	3048.00
3	P3	125mm steel Sch. 40	128.194	0.046000	13411.20

4	P4	125mm steel Sch. 40	77.27	0.046000	18415.00
5	P5	125mm steel Sch. 40	52.02	0.046000	1362.000

Table 5.4: Node data

Node Id	Node	Elevation(m)	Pressure at Node bar.g	HGL at Node m.hd Fluid	Total Flow In m^3/sec	Total Flow out m^3/sec
P1	Tank	0.00	0.000	0.00	0.00	0.0161
P2	Joint Point	1.5	5.6315	59.040	0.0161	0.0161
P3	Joint Point	3.00	5.4756	58.948	0.0371	0.0371
P4	Joint Point	13.40	4.4337	58.353	0.0381	0.0381
P5	Joint Point	13.40	4.1027	55.320	0.0391	0.0391

Table 5.6 Energy losses to pipe

Pipe Id	Pipe Name	Energy loss to pipe friction (KW)	Energy Loss to pipe fittings (KW)	Energy loss pipe Control valve (KW)	Energy loss to Pump Inefficiency (KW)
1	P1	0.002695	0.009067	None	6.499058
2	P1	0.005276	0.009067	None	None
3	P3	0.343624	0.003871	None	None
4	P4	0.502220	0.034921	None	None
5	P5	9.584585	0.737838	None	None

Table 5.7 Energy losses to pipe

Subtotal loss Pipe item+ Pump (KW)	Energy loss to discharge Pressure(KW)	Energy loss to change in elevation	Total Used Sum of all Items
6.510819	None	0.235850	6.746670
0.014542	None	0.235850	0.250393
0.032540	None	1.737013	1.769554
0.606968	None	0.000000	0.606968
10.322423	None	-2.500368	7.822056

Pump Data

Name:	Pump
Catalog:	General
Manufacturer:	Generic
Type:	End suction
Size:	1-1/2x1-8 AA
Stages:	0
Speed:	2080 Rpm
Impeller Diameter:	330.000 mm
Min Speed:	1800 Rpm
Max Speed:	3560 Rpm
Min Diameter:	228.600 mm
Max Diameter:	330.200 mm

Fluid Data

Fluid:	Water
Density:	998.000 kg/m³
Viscosity:	1.0020 cP
Temperature:	20.000 °C
Vapor Pressure:	0.0240 bar.a
Atm Pressure:	1.0132 bar.a

Operating Notes

Pref. Op. Region: 70% - 130% of BEP

Pref. Flow Range: 0.0138 - 0.0256 m³/sec

Notes:
This pump performance is generally similar to certain ranges from these pump manufactures: Ansi Pro AP96, Goulds 3196, Peerless 8196, Griswold 811, Summit 2196 & Durco Mark III Series ANSI pumps

Design Curve

Shutoff Head:	69.145 m.hd Fluid
BEP:	60.7% @ 0.0197 m³/sec
Power at BEP:	16.78 kW
NPSHr at BEP:	2.134 m.hd Fluid
Max Flow Power:	17.12 kW @ 0.0234 m³/sec

Data Point

low:	0.0161 m³/sec
Efficiency:	58.85%
Power:	15.79 kW
NPSHr:	1.479 m.hd Fluid

Figure 5.3 Selected pump result

Sluice valves necessary to hold the water with minimal leakage since we required 20 liter/sec water flow to the reactor by using the flow meter the flow of water can be allowed to pass through or can be controlled so that there won't be much water loss and can avoid excess amount of water flow to the reactor the flow meter should have low head loss, good sensitivity and initial starting. Sluice valve and flow meter is selected as 125mm diameter per the pipe diameter used in the pipe flow software. At low flows: ±5 %(error) minimum between flow rate (Q1) and transitional flow
At high flows: ±2 % (error between transitional flow rate (Q2) and Overload flow rate (Q4))

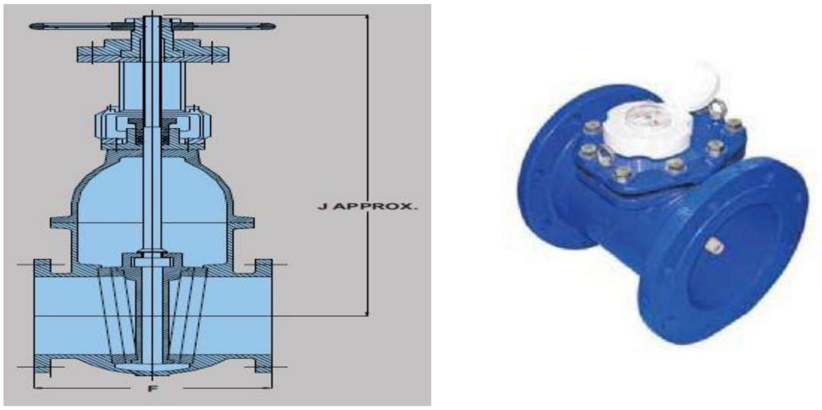

Figure 5.4 Sluice valve and flow meter

Table 5.8 Capital cost for the developed system:

The cost for this system was obtained by getting quotation for the required components and equipment's for this system from [40]

Land	1.214 ha	15,600€
Building cost including road and drainage construction and roller	1.092 ha	970,994€
Absorber and stripper	1.5metric tons/hr.	163,875€
Heat exchanger	1.5 metric tons/hr.	21,850€
Cooler	1.5 metric tons /hr.	30,040€
Piping and fitting	17tons	11,000€
Pumps & Motor		2581€
Water distribution/supply	metric tons /ha	3641€
Monoethanolamide solution	1 metric tons	1457€
Cotton fabric/polyester sheet	1 ha	14,000
Nutrition cost	metric tons /ha	820€
Electricity distribution/supply	mt/ha	1820€
Solar fiber optic lighting system	44 sets	546,252€
Total capital cost		1,783,930€

The capital cost may vary from location to location, current cost estimation was made by taking consideration in industrial park in USA but the approximate total cost for this system will be about €1.7 to €2.3 million.

CONCLUSION:

1. Detailed analysis on companies their markets, products and their cost of system and the problems they face in the market has been analyzed. Some companies couldn't survive in the market due to the total output they obtain is low, they needed additional resources and the companies are limited to the low output without the advanced technology. The amount of output they yield is not enough for the investment the companies have made and the oil they yield is not enough for the future generation we still needed millions liters of oil per day. Thus a new innovative idea to develop a new closed photo bioreactor system to overcome the problems that are faced by the previously available systems
2. A new innovative closed photo bioreactor system was developed, system principle working method was explained and discussed. This system can also be maintained easily and can overcome the problems of other reactors in the market.
3. Component were selected as per the needed requirements for this system for high production and the molar flow rate of the entering flue gas is ($n_{f)} =$ 461.6 $\frac{Mol}{min}$, input for the algae growth are the flow rate of concentrated CO_2 nc $_{\text{of } CO2}$ = 46.14 $\frac{Mol}{min}$ and percentage of recovered CO_2 is 86.17% and amount of light intensity sent to the algae growing system is about 25,000-30,000 lumens for 18.59 m^2 and water flow rate from 0.0161 to 0.0200 m^3/sec.
4. In this developed system of closed reactor 1.026 ha of algae can be grown. It can produce up to 540 tons of algae which can give oil up to 200,000 liters /ha/year.
5. The capital cost of investment will be approximately around € 1.7 million to €2.3 million which is more economic, higher amount algae (biomass) yield can be achieved than other system. This system can be implemented in countries with temperature from 15°C to 35°C and daylight of up to 10 to 12 hr. per day, the countries within these geographical location can give high amount of productivity.

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