ALGADISK - NOVEL ALGAE-BASED SOLUTION FOR CO2 CAPTURE AND BIOMASS PRODUCTION

Author(s): P. Sebestyén[a], T. Bhaiji[b], A. Salimbeni[c], W. Blanken[d], I. Bacsa[e],G. Tóth[e], N. Pomázi[e], D. Molnár[e], M. Kozák[e], P. Kesserű[a], Q. Zhang[b],Zs. Libor[f], M. Janssen[d]

Company / Institute(s): a: Bay ZoltánNonprofit Ltd. for Applied Research, Szeged, Hungary; b:Cranfield University, Cranfield, United Kingdom; c: European Biomass Industry Association, Brussel, Belgium; d: Wageningen University, Wageningen, Netherlands; e:ATEKNEA Solutions, Budapest, Hungary, f: Olajgép-Tec Industrial Maintenance, Repair And Constructor Ltd., Hungary

ABSTRACT: The ALGADISK project aims to develop a biofilm reactor for algae biomass production which could compete with current algae cultivation technologies (e.g. open-pond and tubular photo-bioreactors), meanwhile focusing on the need of SMEs. Due to its innovative design, the ALGADISK reactor is going to be scalable, automatic, and it can be used to capture CO_2 both in the liquid and gas phase. Microalgae grow on the special surface of the disks by forming a biofilm, this construction permits to reduce water demand of the algae cultivation, lower the cost of harvesting processes such as centrifugation, drying by increasing the biomass concentration. Based on laboratory scaled research, a pilot system was installed in Spain; results obtained from continuous operation will validate the sustainability and calculations of energy consumption. Besides the reactor system, a prediction software is developed to assist customers before installing ALGADISK system.

1 INTRODUCTION

1.1 Introduction of the ALGADISK project.

The critical need at European level is present for economically reliable alga biomass production. At this research and development field many countries, especially the United States is much ahead Europe. On the other hand, nor the land space, neither the capital is present for creation of huge application sites. The need can only be fulfilled by small and medium sized enterprises (SMEs), that willing to apply innovative technologies for small scale algae production. On this market, however, the bottle neck is the lack of efficient, universal reactor, and information about sustainability and feasibility of algae production.

The ALGADISK project aims to develop a biofilm reactor for algae biomass production which could compete with current algae cultivation technologies (e.g. open-pond and tubular photo-bioreactors). Biofilm formation is a widely observed characteristic of microalgae, whichis considered as one of the main problems of tubular, flat-plate and other suspended photobioreactors. While in ALGADISK reactor, biofilm formation is enhanced and supported due to its special design, allowing harvesting high dry solid content biomass, reducing water loss and decreasing energy consumption. The reactor is scalable, modular, contains a sensor and control system to follow and keep growth conditionsin optimal range, real time (e.g. pH and volume of medium, nutrient concentrations, temperature). Reactor consists of vertically positioned plastic disks and non-transparent tanks, in which disks are placed half way in growth medium (see Picture 1.). Surfaces of disks are modified in order to intensify primary biofilm formation and provide sufficient cell number for regrowth of biofilm after harvest. Continuous rotation of disks provides proper wetting of the whole surface and light distribution over the biofilm. In addition, negative effects of saturating light intensity are precluded by cyclic movement of biofilm from light part into the dark tank.

Due to the position and orientation of disks, light utilization of reactor can reach a high level, resulting in high biomass productivity. Modules are covered with transparent, removable lids in order to reduce risk of contamination and protect biofilm from extreme weather changes. During the process of system development, concept of CO_2 capturing from flue gases was one of the main aspects of design. Reactor is capable of enhancing CO_2 to dissolve in the growth medium, just as to reach a high CO_2 percentage in the air phase, thus microalgae have access to CO_2 both in liquid and gas phase, that results in high biomass production. A semi-automatic harvesting system was developed uniquely for the ALGADISK reactor to provide an easy and efficient method of biomass collection.

Figure 1: ALGADISK pilot reactor installed at Biogas Fuel Cell site in Almazan, Spain

1.2 Short summary of current alga cultivation technologies

Current algae production technologies are facing several issues that limit economically feasible production of algae biomass, such as high water demand, large occupied area and costly installation. Thus, photobioreactor development and production optimization are a main focus of research worldwide in order to level up algae production to industrial scale even for low value algae biomass and third generation biofuel production. In recent years, biofilm based cultivation of microalgae are receiving more and more attention; numerous system was developed and tested for biomass production or wastewater treatment. Wide variety of biofilm reactors exist from horizontal to vertical, rotating or steady set-ups of which the most important ones are rotating algal biofilm reactor with spool harvester [1];

rotating algal biofilm enhanced raceway system [2]; twin layer system [3] and horizontal flow cells [4]. These systems show the potential and advantages (Table I.)of biofilm based algae cultivation compared to a suspended system (either open or closed), although they are still in validation phase and need to be developed for industrial use.

Table I: Summary of the main drawbacks of conventional photobioreactors (PBR) and how ALGADISK system can provide a solution for them.

Conventional PBR Technologies	ALGADISK - Innovative design
Expensive maintenance required (unexpected biofilm formation, pumping systems, sterilization)	Low operation cost and easy maintenance. Easy construction procedure.
Low CO_2 efficiency (bubbling through the liquid phase)	Increase in CO_2 capture efficiency (buffer tank mixing)
High water required (raceway ponds, PBR)	Low water required
Harvesting is difficult, time consuming and inefficient (High Costs)	Automatic and continuous harvesting
Scale-up problems	Easy scalability trivial
Difficult to design at flexible scale	Modulable units. Competitive at small scale
High land use footprint	low footprint - 20g/m2 day of dry algae

3 STEPS TOWARDS THE PILOT REACTOR

3.1 Selection of algae species

In the first phase of the ALGADISK project, the consortium made a decision about the future directions of operation as well as the algal strains to be applied. Considering the climatic parameters of the installation site of the pilot reactor and usage of produced biomass, the following criteria were applied for selection of algae species:

- optimal growth temperature around 30-35°C
- biofilm forming ability
- high biomass production rate (high CO_2 uptake rate), and
- additional high value compounds such as lipids for biodiesel production

Knowing the current requirements, the strain *Chlorella sorokiniana* CCAP211/8K was recommended to be applied in the ALGADISK system as a primary candidate due to its large biomass yield, tolerance for temperature as well as CO_2 concentration and ability to produce valuable substances like pigments and vitamins. Besides this strain, samples were collected from several natural water basins in Central Europe (Picture 2.) and following a selection scheme which can be seen on Figure 1., isolates were chosen to be further tested in a laboratory scaled ALGADISK reactor

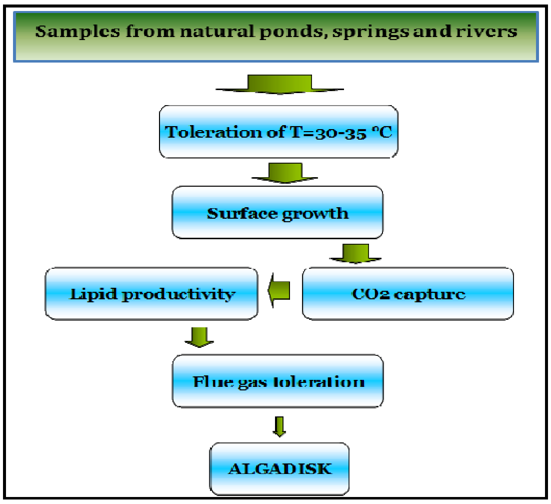
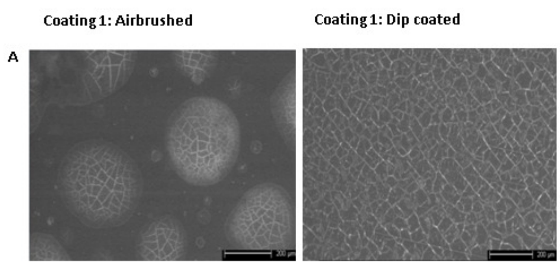


Figure 2: Scheme shows the selection criteria and order of steps after samples were collected from Central Europe

3.2 Development of disk coatings and tests of biofilm formation

The objective of the disk coating is to attract algae onto the disk surface and encourage biofilm formation. The strategy developed consists of using charged polyelectrolyte multi layers to attract oppositely charge algae cells. The coating developed was proposed to increase surface energy by lowering the contact angles of predominant hydrophobic surfaces and encourage better attachment of algae via electrostatic and acid base interactions. A range of polyelectrolyteswas tested with the microalgae C.sorokiniana.

Results showed polyelectrolyte multilayer coating can aid in increased bio film formation of C.sorokiniana on cost effective commercially available polymers. This was most likely due to the decrease in electrostatic repulsion and aided attraction of algae onto the surface. Surface roughness could also aid in increased cell densities but was not found to be statistically significant. Airbrushingas a method of coating application had better potential for large scale application. It was found growth results for airbrushed substrates were comparable to the more traditional dipcoated substrates. Successfully growing algae on cost effective substrates could reduce the high production and harvesting costs. It is hoped that these findings along with further results will be employed in the ALGADISK project.



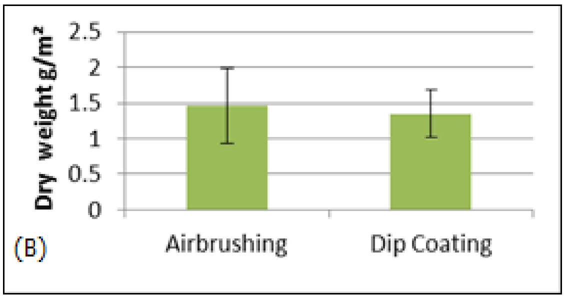


Figure 3: (A) Comparing dip coating and airbrushing via ESEM images of coating 1. (B) Graphs show weighted dry algae biomass after 8 days of growth with algae. UV C exposure of 6 hours.

4 GROWTH TESTS IN LABORATORY SCALED ALGADISK REACTOR

After preliminary experiments with the developed surfaces, best performing coatings and substrates were prepared in bigger scale and applied in systems, which modelled the possible biofilm formation in the pilot reactor. Two species of microalgae were tested, *C.sorokiana* and an unidentified, newly isolated strain from a river in Hungary, named *Chlorella*sp MS34. Effects of the following factors on biofilm formation and biomass productivity were investigated:

- light intensity,
- nutrient concentration,
- disk materials and coatings,
- disk roughness,
- disk rotation speed and
- CO_2supply.

The design of laboratory scaled systems based on the Biological Rotating Contractor structure with modifications. Research activities can be divided into two main set considering the examined algae strain and the construction of reactors. Experiments and results are detailed in the next sections.

4.1 Biofilm growth of *C. sorokiniana*

In the photobioreactor, referred to as ALGADISK, microalgae grow in biofilm on vertical rotating disks partially submerged in a growth medium. The objective was to evaluate the potential of the ALGADISK photobioreactor with respect to the effects of disk roughness, disk rotation speed and CO2 concentration[5]. These objectives where evaluated in relationship to productivity, photosynthetic efficiency, and long-term cultivation stability in a lab-scale ALGADISK system. C.sorokinianawas used as model microalgae.

The lab-scale ALGADISK reactor consisted of 4 disks, eight LED lamps and a non- transparent water container. During the experiments, temperature was maintained at 38°C and pH was controlled to be 6.7-6.8 by addition of CO2 gas. Schematic overview of the system can be seen on Figure 3.

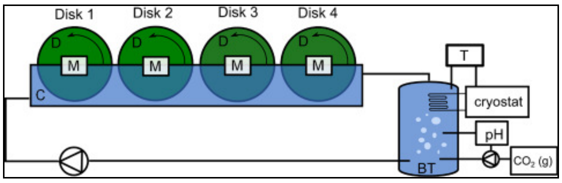


Figure 4: Schematic overview of used reactor. D=disk; M= motor; C= container; T=temperature measurement and control; BT=buffer tank. Grow medium circulated between buffer tank and container in order to maintain the appropriate liquid volume in the container.

Comparing disk materials (stainless steel mesh and polycarbonate) and surface roughness showed that rougher the surface of disk the higher the biomass productivity and gives better reproducibility. For further evaluations, rough steel mesh was used.

Disk rotation speed is one important parameter of the operation of pilot reactor, considering shear stress, energy consumption and substrate diffusion, hence rotation speeds of 3, 6, 11, 20 rpm were applied and biofilm production was measured. Different disk rotation speeds demonstrated minimal effects on biofilm growth and on the diffusion of substrate into the biofilm. As CO2 is the only carbon source for microalgae in this system, its availability has a significant effect on biomass production. Under replete conditions biomass productivity reached 20 g (m2*day)-1 while no aeration and 0.5% CO2 resulted in productivity lower than 4 g (m2*day)-1 . Biomass density does not change significantly under various conditions, an average 150 g dry mass per wet biofilm was obtained during the experiments, which is considerably higher than in any suspended alga cultivation system. [6, 7]

Productivity could be maintained over a period of 21 weeks without re-inoculation of the ALGADISK; average biomass productivity of 4 disks during 21 harvest cycles are shown on Figure 4, including the results of different experimental conditions such as disk roughness, disk rotation speed and CO2 limitation. Productivity decreased under extreme conditions such as pH 9-10, temperature above 40ºC, and with low CO2 concentrations. Maximal productivity, however, was promptly recovered when optimal cultivation conditions were reinstated. These results exhibit an apparent opportunity to employ the ALGADISK photobioreactor at large scale for microalgae biomass production if diffusion does not limit the CO2 supply.

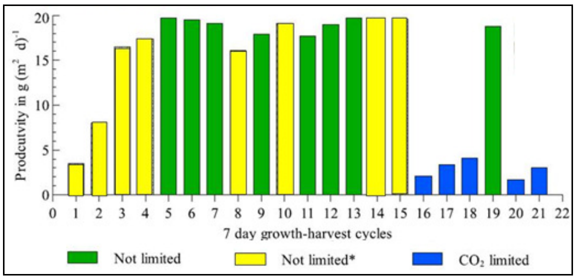


Figure 5: Average productivity, calculated as the average of the 4 disks productivity per growth-harvest cycle, in chronological order. The yellow bars represent the growth-harvest cycles that were not employed due to technical problemssuch as: overnight pH 10, 24hours of

darkness, and temperatures above 40 °C. The green bars represent the data from reproducibility experiment. The blue bars represent the experiments on CO2 limitation and rotation speed.

4.2 Biofilm growth of *Chlorella*sp MS34

Another type of laboratory scaled ALGADISK reactor, was tested in order to examine the primary biofilm formation on rotating disks, regrowth of biofilm after harvesting, and the stability of the system during a continuous operation with a newly isolated *Chlorella* sp. MS34 microalgae strain. Reactor set-up differed from the previously described system in the orientation of disk, direction of light source and light intensity. Schematic view of the used reactor can be seen on Figure 5with the position of disks and light source. The liquid container was covered allowing algae cells to grow only on the surface of disks.

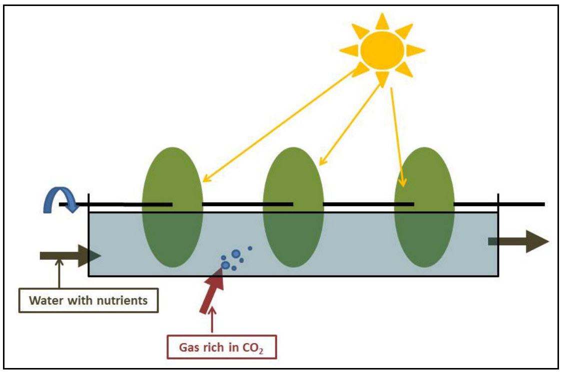


Figure 6: Schematic view of the second type ALGADISK reactor. CO_2 gas is bubbled into the liquid, maintaining pH between 6.7-6.8. Light source is placed above the disks, medium container is covered with a metal sheet to prohibit cell growth in suspension.

.

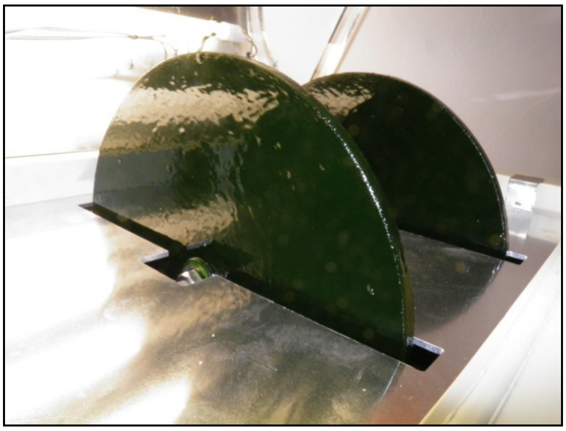


Figure 7: Biofilm growth on disk surface. Disks are partially submerged in medium, only half of the disks are illuminated.

During 97 days operation, 7 regrowth-harvesting cycles took place. The primary biofilm formation took 18 days than the time required for regrowth of biofilm after harvest decreased to 7-8 days, due to the remaining microalgae cells on surfaces. Under controlled conditions, an average 2-3 g/m^{2}day biomass productivity was reached, with a biofilm density of 100-150g/l. Although several technical issues occurred during the experiment (e.g. broke of rotating engine, lack of pH and temperature control) the algae culture in the ALGADISK reactor was found to be robust and stabile, giving reproducible biomass productivity and biofilm density, as it was seen in the parallel experiments. A slight increase in productivity can be seen as well by time.

Further test are conducted to examine biomass productivity under different light intensities, growth medium and

4.3 Conclusion of lab scale ALGADISK reactor

During continuous operation, the laboratory scale ALGADISK system worked with only small functional problems and the achieved biomass produced on disks is comparable to other literature results both suspended and biofilm growth, while biomass density was about 10-20 times higher than literature values [6, 7, 8]. Due to high biomass density, disk materials and construction of ALGADISK reactor, harvesting is simple, fast and cost- effective, which can be easily scaled up and be automatized in the pilot reactor. The disk roughness and surface coating are essential features of the system, faster re-growth and better light utilization can be reached due to the remained microalgae in the scratches/pores of disks after harvest. Tested algae species were suitable for such type of cultivation; C. sorokiniana was chosen to be used first in the pilot system.

5 ENERGY BALANCE CALCULATION

In order to estimate the reliability of ALGADISK reactor, energy balance calculation was made upon the transparent greenhouse gas (GHG) calculations using the methodology as given in the Directives 2009/28/EC and 2009/30/EC. Directive 2009/28/EC is the directive on the promotion and the use of energy from renewable energy sources …" and will in this document be usually referred to as "RED" (Renewable Energy Directive). Directive 2009/30/EC is Fuel Quality Directive referred as "FQD". Apart from these EU Directives, public available methods and standard values were used from the so called BioGrace project. The calculation was made for Fatty Acid Methyl Esters (FAME) as standard final product. The GHG emission and saving was determined for each step of the FAME production process using the ALGADISK reactor. For the production and harvesting input values were estimated based on the preliminary laboratory results of the ALGADISK reactor (WP2 and WP4), while the emission for the up-stream process of raw algal biomass was determined from the Excel template published at the BioGrace public web page for FAME production from rapeseed. GHG emission of the FAME production using the ALGADISK reactor was calculated in two main cases: when the CO_2 is absorbed from the atmosphere (similar to rapeseed) and when the CO_2 is captured from other emission sources, calculated as "CO_2 saving" according to 2009/28/EC. Further, 3 different N-fertilizer scenarios were compared, since, it was found that N-fertilizer need represents one of the most important GHG emissions of the algae cultivation:

- all fertilizer requirement is calculated
- half amount of the N-fertilizer is from waste water source with zero GHG emission
- full amount of N-fertilizer is from wastewater or other waste source.

In the worst case scenario (no saving is calculated and no N-fertilizer from waste sources), the GHG emission of the overall FAME production form algae using the ALGADISK system was found total 66 gCO_2,eq/MJ which is significantly lower than the GHG emission of standard diesel (83.8 gCO_2,eq/MJ). This 21% GHG emission reduction is important, but lower than the 35% required for biofuel according to 2009/28/EC Directive.

In case of half amount of Nfertilizer is used, the GHG emission reduction was 33% (56 gCO_2,eq/MJFAME), which is very close to the 35% requirement limit. In case of whole amount of N-fertilizer is from waste source, the GHG emission is 45 gCO_2,eq/MJFAME, reduction by 46%, which is even better than of rapeseed (38%). Furthermore, if "CO_2 saving" (2009/28/EC) was calculated, the GHG emission balance for FAME production using the ALGADISK system was found negative, i.e. the GHG reduction compared to diesel was found more than 100%.

In summary, production of energy carrier FAME from microalgae using the ALGADISK system can be considered as reduction of GHG in all cases according to the EU Directives 2009/28/EC and 2009/30/EC.

6. PROTOTYPE DEVELOPMENT AND CONSTRUCTION

6.1 Sensors and control system

First, a laboratory scale test system was constructed in order to develop, test and finalize the control setup, and further to make an opportunity for harvesting trials. The control system and control loops realized in the laboratory scale system were identical to the pilot system, modifications on the actuators and sensors may occur, due to the different sizes and working methods of the systems.

The following parameters were agreed to be essential in the pilot ALGADISK reactor: pH, media level, media electrical conductivity, media temperature, input gas temperature and flow, and disk rotation should be controlled, other parameters such as media dissolved oxygen, gas composition and insolation need to be monitored only. The constructed control system is simple, stable, modular and easily adaptable to fulfil the needs of an industrial marketable ALGADISK system. Some examples of the control software can be seen on Figure 8.

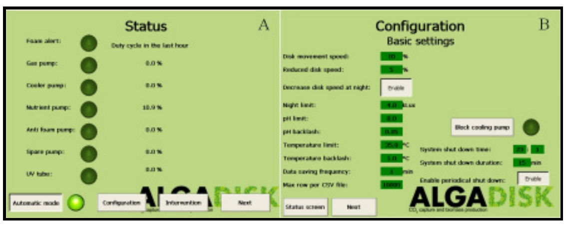


Figure 8: Screenshots taken of the control system. A) status screen, where activity of different parameters can be seen. B) basic settings of several parameters, such as pH, disk rotation speed, cooling system.

6.2. Mechanical design and installation

The supporting system of the first prototype ALGADISK reactor for microalgae production has been designed. The ALGADISK system is based on biofilm cultivation of microalgae on partially submerged and rotating disks. The prototype is installed at BFC Biogas plant in Almazan, Spain and it is fed with real flue gas from a gas engine. The system is dimensioned such that it can support maximal productivity of the ALGADISK operated outdoors in summer in central Spain. For this reason, first the productivity of the ALGADISK prototype was estimated by model calculations, taking into account the results of laboratory scaled algae cultivation. The prototype consists of 6 disks of 1.3 m in diameter and the estimated productivity of *C. sorokiniana* biomass is 5.5 kg per month in summer. Figure 5. shows the orientation of disk and the design of ALGADISK reactor. The supporting system is comprised the following units: flue gas supply and treatment system; carbon dioxide (CO2) supply and pH control system; nutrient supply system; cooling system. The functioning and dimensioning of all these sub-systems is described in detail. The supporting system is able to control all relevant cultivation parameters at near-optimal levels: pH and CO2 concentration, nutrient concentrations and temperature.

The energy requirement for the supporting energy system is calculated. The energy requirement is substantial but the supporting system has surplus capacity. A number of crucial parameters are yet unknown: power required for disk rotation and cooling capacity needed in summer time. These parameters will be determined in outdoor field tests with the prototype during the summer of 2014. Based on the field test and energy calculations marketable versions of the ALGADISK system can be designed with substantial less energy requirement.

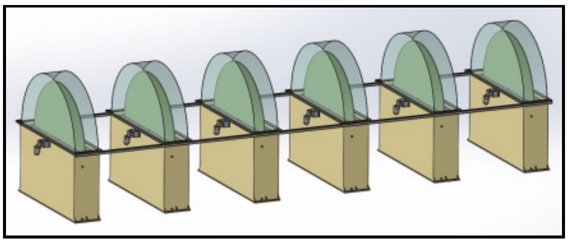


Figure 9: Schematic view of the pilot reactor. It consists of 6 modules, which are closed with transparent plastic lids, in order to maintain high CO2 concentration in both gas and liquid phase, meanwhile allowing light to reach disks

6.3 Harvesting system

A simple and robust harvesting technology for biofilms has been developed. The technology is based on suction and allows for complete harvesting of concentrated biofilms with minimal water dilution. The technology can be fully automated and will be incorporated in a pilot-scale ALGADISK system. The pilot-scale system can thus be operated continuously and automatically. The technology is adaptable for any biofilm harvesting process provided the biofilm is grown on a rigid preferably flat surface. Repetitive grow-harvest cycles in lab scale reactors have demonstrated consistent and highproductivity of microalgae biofilms in the ALGADISK system.

Based on theoretical mathematical models developed biofilm growth and productivity can be described. Based on this theoretical modelling the optimal harvesting frequency was deduced and it can be balanced to the costs involved with harvesting. The model outcome was confirmed with the practical growth-harvest cycles. The model therefore can be further optimization of the ALGADISK harvesting procedure

7 PREDICTION SOFTWARE DESCRIPTION

In addition to the ALGADISK hardware, the project contains a prediction software module as well which is web-based assistive-tool that will help users make informed decisions when considering the installation of an algae production reactor. It contains an artificially intelligent algorithm designed to predict from the conditions given at a certain site the productivity of algae biomass, used consumption of N, C, and P. From this information the pricing of the products and the estimated income can be calculated. The pricing will include the following predicted parameters:

- number of ALGADISK units to be installed
- estimated operational condition
- estimated installation costs
- estimated operational costs

It is important to note that all the data calculated by this tool covers only an optimal scenario. It cannot take into consideration unforeseen events like bad weather or viral/fungal infection. Furthermore, this web-application provides an interface for the ALGADISK users. The members of this community can generate useful content (such as articles, findings, media receipts, recorded performance data of their own ALGADISK reactor) which can be shared among the community to improve the quality of growing algae.

8 CONCLUSION

Laboratory scaled experiments proved the concept of the ALGADISK project.In ALGADISK reactor, biofilm formation is enhanced and supported due to its special design, allowing harvesting high dry solid content biomass, reducing water loss and decreasing energy consumption. Pilot reactor was developed and installed by a biogas plant in Almazan, Spain. During continuous operation validation of the prototype can be done and results will be compared to current algae cultivation technologies (e.g. open-pond and tubular photo-bioreactors). The reactor is scalable, modular, contains a sensor and control system to follow and keep growth conditions in optimal range, real time (e.g. pH and volume of medium, nutrient concentrations, temperature). Modified disk’s surfaces enhancing primary biofilm formation and provide sufficient cell number for regrowth of biofilm after harvest. Reactor is capable of enhancing CO_2 to dissolve in the growth medium, just as to reach a high CO_2 percentage in the air phase, thus microalgae have access to CO_2 both in liquid and gas phase, that results in high biomass production. A semi-automatic harvesting system was developed uniquely for the ALGADISK reactor to provide an easy and efficient method of biomass collection. The prediction software will help customers to match their goals with ALGADISK reactor and thus increasing the marketability of it.

9 REFERENCES

[1] Christenson, L. B., & Sims, R. C. (2012). Rotating algal biofilm reactor and spool harvester for wastewater treatment with biofuels by-products. Biotechnology and Bioengineering, 109(7), 1674-84

[2] Gross, M., Henry, W., Michael, C., & Wen, Z. (2013). Development of a rotating algal biofilm growth system for attached microalgae growth with in situ biomass harvest. Bioresource Technology, 150C, 195–201.

[3] Naumann, T., Çebi, Z., Podola, B., &Melkonian, M. (2012). Growing microalgae as aquaculture feeds on twin-layers: a novel solid-state photobioreactor. Journal of Applied Phycology, 25(5), 1413–1420. doi:10.1007/s10811-012-9962-6

[4] Mulbry, W. W., &Wilkie, A. C. (2001). Growth of benthic freshwater algae on dairy manures, Journal of Applied Phycology, 13, 301–306.

[5] Blanken, W., Janssen, M., Cuaresma, M., Libor, Z., Bhaiji, T., Wijffels, R.H. (2014). Biofilm growth of Chlorella sorokiniana in a rotating biological contractor based photobioreactor. Biotechnology and Bioengineering.doi: [10.1002/bit.25301]

[6] Pulz, O. (2001). Photobioreactors : production systems for phototrophic microorganisms, Applied Microbiology and Biotechnology 57: 287–293. doi:10.1007/s002530100702

[7] Kumar, K., & Das, D. (2012). Growth characteristics of Chlorella sorokiniana in airlift and bubble column photobioreactors.Bioresource Technology, 116, 307–13. doi:10.1016/j.biortech.2012.03.074

[8] Cuaresma, M., Janssen, M., Vílchez, C., &Wijffels, R. H. (2009). Productivity of Chlorella sorokiniana in a short light-path (SLP) panel photobioreactor under high irradiance.Biotechnology and Bioengineering, 104(2), 352–9. doi:10.1002/bit.22394

9 ACKNOWLEDGEMENTS

The research leading to these results has receivedfunding from the European Union's Seventh Framework Programme (FP7/2007-2013) managed by REA Research Executive Agency http://ec.europa.eu/research/rea under grant agreement n° 286887.

The authors thank for SME Association and SME members of the ALGADISK consortium for their contribution:

- Confederacion Espanola De Fabricantes DeAlimentosOmpuestos Para Animales, Spain
- European Biomass Industry Association, EU
- FundacionCesfac, Spain
- Olajgep-Tec Industrial Maintenance, Repair AndConstructor Ltd., Hungary
- BFC - Biogas Fuel Cell Sa, Spain,
- AlgEn, Center ZaAlgneTehnologije, d.o.o.,Slovenia.
- Umwelt-Technik Pipe Cleaner, Constructor AndService Provider Ltd., Hungary,
- Caglar Dogal Urunler, Yenilenebilir Enerji Gubre Gida Ve Tarim Ithalat Ihracat Sanayi Ticaret Limited Sirketi, Turkey

10 LOGO