PERSONAL COMPUTER-BASED CONTROL AND MONITORING SYSTEM FOR BIODIESEL ALGAE PHOTOBIOREACTOR

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ABSTRACT

Growing of Algae for biodiesel production has gained popularity in recent times. This is because biodiesel from algae has an economic advantage over other oil crops. The oil content that can be extracted from microalgae biomass depends on the culture conditions and microalgae species. This means that besides selecting the best microalgae species, it is also necessary to ensure and maintain the best culture conditions for optimal biodiesel production. Optimum algae growth conditions can be best be provided by a Controlled Environment Bioproduction System (CEBS) for the algae called as photobioreactor (PBR). This paper reports design and fabrication of a PC based control system for a PBR production system for algae being developed at the School of Biosystems and Environmental Engineering (SoBEE) in Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Kenya. The control system is intended to ensure that optimum PH, temperature, nutrients content; light intensity/duration and salinity of growth medium for algae are maintained. The paper covers the design and fabrication of the PC control and monitoring system. The control and monitoring system consists of a computer program and a microcontroller connected to sensors and actuators. The computer program (master) provides the graphical user interface (GUI) consisting of control buttons and means for real time data logging and analysis as well as real-time simulation of PBR activities. It is available in executable file that can be run in any windows OS computer. The microcontroller program (slave) provides the means for connecting sensors and is used to measure as well as monitor the conditions in the PBR tanks. Communication between the computer program and the microcontroller is achieved through the universal serial bus (USB). The control system consists of both open and closed loop systems. The open loop system is used to control the light duration at predetermined intervals of time. The closed loop system is used to control the nutrient concentration, light intensity, PH and oxygen: carbon dioxide ratio.

Keywords: Control and Monitoring system, Graphical User Interface, Microcontroller, Microalgae, Photo-Bioreactor, Response time

INTRODUCTION

The three most important global challenges in the 21st century is food shortage, energy deficiency and environmental degradation. These three challenges are such that they should be mitigated simultaneously. Any attempt to mitigate any one of them in isolation will lead to escalation of the other two resulting in what has come to be known as the global ‘trilemma’. Biodiesel can be a potential alternative to fossil fuels as a source of renewable and environmentally friendly source of energy. This fuel releases less greenhouse gases to the environment and has the potential of reducing air pollution and cancer by up to 90% and 95%
respectfully (Huang et al., 2010). Of the current biodiesel sources, Algae biomass has the greatest potential for biodiesel production (Mata et al., 2010; Oilgae, 2013; Rodolfi et al., 2008). In addition, it does not compete with food crops. Thus, biodiesel production from algae is an attempt to mitigate the three global challenges simultaneously. For that reason, growing of algae for the purpose of biodiesel production has gained popularity over the past few years.

The oil content that can be extracted from microalgae biomass depends on the culture conditions as well as the microalgae species (Hu, 2004). Therefore, after selecting the microalgae species with the highest oil content (exceeding 80% of the dry biomass weight) production conditions should be optimum. This requires a Controlled Environment Bioproduction System (CEBS). The most suitable CEBS for algae production is a Photobioreactor (PBR). A PBR should ensure that the following requirements for algae growth (Sierra et al., 2008; Trendici, 2004 and Zittelli et al., 2013) are optimum: CO$_2$ supply, water, temperature, efficient light exposure, culture density, PH level, air supply rate and mixing regime. This requires control of CO$_2$, Nutrient content, light duration/intensity, Salinity, PH content and temperature (Anderson, 2003; Chen et al., 1994). There are different types of PBR systems namely: tubular reactors, horizontal reactors, vertical-flat panel reactors, vertical column reactors, bubble column reactors, airlift reactors, stirred tank reactors and immobilized reactors (CathCart, 2011; Merchuk, 2003; Molina, 2008; Richmond and Zhang, 2001 and Tredici, 2004). Vertical column reactors are the most convenient for PBR (Molina, 2008 and Richmond and Zhang, 2001).

PBR systems comprise of the lighting system (Light source, optical transmission system); air handling and gas exchange system; mixing system (reaction area); instrumentation and control system; nutrient system; filtration system and electrical system. The instrument and control system play the most important role in ensuring that optimum algae growth conditions are maintained (Davis et al., 2011; Dormido et al., 2014 and Trendici, 2004). This paper reports development of a control and monitoring system for a flat plate PBR system being developed at School of Biosystems and Environmental Engineering, Jomo Kenyatta University of Agriculture and Technology. Figure 4.1 is an illustration of the algae PBR system when completed.

The objective of this paper is to present the design and fabrication of a personal Computer (PC) based control and monitoring system biodiesel algae PBR.

The paper is divided into four sections. Section 1 is the introduction in which the contents of the paper are introduced. Sections two and three presents discuss the design and fabrication of a PC based control and monitoring system for an algae production PBR. Section four explains how the fabricated system works and presents some simulation testing results.

![Control and Monitoring System](image1)

![Nutrient System](image2)

![PBR Tanks](image3)

**Figure 4.1:** Illustration of the complete PBR system (a: pictorial view; b: front view)
1. Design Of The Pc Control System

The PBR control and monitoring system was designed using the master-slave approach. The circuitry layout of the system is shown in Figure 2.1. It comprises of two programs that can interact with each other: the computer program and the microcontroller program. The computer program is higher in hierarchy (master) than the microcontroller program (slave) and is the decision maker. The microcontroller is the implementer of the controller decision. The master-slave approach has a number of advantages: it reduces microcontroller overload; ensures consistency of the system; reduces time losses; provides an interactive Graphical User Interface (GUI); and ensures effective real time simulation, data logging and data analysis. However, with this approach the control function cannot be take place when the computer is off. This is because the microcontroller cannot make the decisions on its own. There is an effort to improve the microcontroller program so that it can be in a position to perform the control decision in case the computer program is off.

The procedure used to design the control system for the photo-bioreactor was divided into three parts: selection of components, design of the computer program and design of microcontroller unit.

i. Section of components

The components for PBR control and monitoring system included hardware and software components. Factors considered in the selection of these components included accuracy, availability, speed of response and cost among others.

After consideration of different combinations of these factors the following components were selected for development of the PBR control and monitoring system.

a. HP Laptop
   - Processor: Intel (R) Pentium (R) CPU N3710 @ 1.60 GHz
   - RAM: 4.00 GB (3.85GB usable)
   - System type: 64-bit operating system, x64 based processor
   - Operating System: Windows 10
b. Micro-controller: Arduino Mega 2560
c. Solenoid valves
d. Bread board
e. Sensors (temperature sensors, PH sensor)
f. Visual studio 2015 professional
g. Visual basic programming language
h. Proteus 8 Professional Software
ii. Design of Computer program

The computer control program contains the graphical user interface (GUI) which allows for interaction and simulation of the control system. The GUI was designed in visual studio 2015 with visual basic as the programming language using HP laptop.

iii. Design of the microcontroller unit

The microcontroller unit comprises of a box casing, micro-controller and system circuitry and micro-controller program. The micro-controller box casing was the last component to be sized. The circuit diagram for the system was designed and tested in proteus8 professional software on a HP laptop. Figure 2.2 shows a circuit diagram that controls opening and closing of solenoid valves through transistor switching. Similarly, circuits for temperature, PH and light intensity control and monitoring were designed for the complete control system. The microcontroller selected was the Arduino Me 2560.
3.0 Fabrication of Control System

Fabrication of the PBR control system involved fabrication of system hardware and development of system software. The hardware component comprises of the HP laptop, control circuit boards and microcontroller box. The software component comprises of the computer and the microcontroller programs.

i. Fabrication of the system hardware

Prototype control circuits were assembled on bread boards as per the corresponding circuit designs to test actual operation of the control system using the components shown in Table 3.1. After ensuring that the prototype circuits were working as required, various electronic components were soldered to their respective positions in the circuits to form corresponding circuit’s boards. Figure 3.1 shows the bread board assembly of the circuit in Figure 2.1.

Figure 2.2: Circuit diagram for the power regulation and solenoid valves control

Figure 3.1: Power regulation and solenoid valves control unit
Table 3.1 Components used to develop the power regulation and solenoid valves control circuit

| Value          | Component/Description                  |
|----------------|----------------------------------------|
| C1, C2         | Capacitors, 10uf Radial                |
| J1, J2, J3     | Header pins, male straight             |
| J4, J5, J6     | JST connectors, two pin male           |
| L1, L2, L3, L4, L5, L6, L7, L8, L9 | LEDs, 5mm green diffused |
| Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9 | Transistors, TIP120 NPN |
| R1, R2, R3, R4, R5, R6, R7, R8, R9 | Resistors, 240Ω 1/4W 5% |
| T1             | Temperature Sensor, LM35DT             |
| V1             | Voltage regulator, L7805               |

After developing circuit board assembly units for all components of the control system, they were assembled in a metallic housing to form the microcontroller box unit shown in Figure 3.2.

![Microcontroller Box Unit](image)

**Figure 3.2: Microcontroller Box Unit**

The components of the microcontroller unit box: Arduino mega 2560 board; Power regulation and solenoid valves control unit (switching on and off solenoid valves); Fan; Liquid Crystal Display; LCD contrast adjustment Potentiometer (10KΩ); Temperature and PH sensors attachment ports; Light bulb attachment ports; Air pumps control Port and Solenoid valves attachment port

### ii. Fabrication of the system Software

The control system for the photo-bioreactor is composed of two major units; a computer program and the microcontroller unit. The computer program provides the graphical user interface while the microcontroller measures the control parameters. The computer program is higher in hierarch than the microcontroller program and acts as a master to the microcontroller. All the decisions to control the actuators are made by the computer program.

#### a. The Computer graphical User Interface

The graphical user interface (GUI) for the control systems was developed in visual studio with visual basic as the programming language. The materials and tools used for the development of the GUI were: HP Laptop, visual studio 2015 professional and visual basic programming language

The GUI was developed using visual basic as the programming language. The interface provides the platform for real time data logging and analysis as well as buttons to perform control operations. It consists of data cells for real time data viewing. The buttons provides the means for controlling the control parameters as shown in Figure 3.3. The interface also provides a visual simulation of the activities that are happening in the tanks as shown in Figure 3.4.
Figure 3.3: Graphical User Interface (GUI)

Figure 3.4: Graphical User Interface switched to photo-bioreactor tanks simulation mode
iii. The development of the microcontroller program

This was the last stage in the design and development of the microcontroller box unit. It involved the development of the microcontroller code that can interact with the computer GUI. The code was developed in the Arduino Internal Development Environment (Arduino IDE 1.6.9) and a number of libraries were incorporated within the program: GLCD library, PH sensor library and One wire library.

4.0 Preliminary Performance Tests

Figure 4.1 is a picture of the PC based control and monitoring system developed in this study. Figure 4.2 is a schematic summary of the components of the system.

How the system works

The computer program is higher in hierarchy than the microcontroller program and acts as a master to the microcontroller. All the decisions to control the actuators are made by the computer program. The microcontroller does the measurement of the control parameters such as temperature, PH, Nutrients content, light intensity/duration and oxygen carbon dioxide ratios. The measurements obtained are then shared to the computer program through the serial communication. The computer program then checks the parameters and compares them with the desired set points to see if they are within the acceptable limits. If the parameters are within the accepted limits the computer program bothers no the microcontroller. In case the parameters are outside the acceptable limits then the computer program will order the microcontroller to perform the necessary action in order to control the parameters. This may be to tell the microcontroller to turn on the solenoid valve for more nutrients to enter a tank or to tell the microcontroller to turn off the light because eighteen hours of lighting are over.

Preliminary tests

Preliminary tests were conducted to determine the response time of the control and monitoring system. The response time between the time a command is sent by the computer program to the actual time that the microcontroller performs the command is dependent on the delay time in the microcontroller program and the write-timeout value for the serial port in the computer program.

Microcontroller time delay is the time interval between two consecutive readings of measurements from a sensor by the microcontroller. It is the time rest taken by the microcontroller after taking a reading or a set of readings from a given sensor before it can take another reading or a set of readings from the same sensor. The microcontroller time delay is included in the microcontroller program and is equal to 1000 milliseconds. Serial port write-timeout is the number of milliseconds before a time-out occurs when a write operation does not finish. The average serial port time was found to be 500 ms

Response time = Microcontroller time delay + Serial port write-timeout

Thus; Response time = 1000 + 500 =1500 milliseconds

5. CONCLUSION

This paper reports the design and fabrication of a Personal Computer (PC) based Control and monitoring system for biodiesel algae photobioreactor (PBR). Preliminary tests showed that the system has a response time of 1.5 seconds. However more tests are required to characterize its performance. This will be done once the whole PBR system is completed. Once completed the PBR system will be used to optimise conditions for biodiesel algae production. This will contribute greatly towards promoting production of microalgae as a commercial venture. It will also promote the utilization of biodiesel from algae as a viable clean fuel thus mitigating energy deficiency and environmental degradation without negatively affecting food production.
**Figure 4.1**: PBR Control and Monitoring system

**Figure 4.2**: The flow diagram of the system
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