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GROWTH CONDITIONS OF THE ALGAE SPECIES BIOMASS IN A CONTINUOUS FEEDSTOCK PHOTO BIOREACTOR BY CONTROLLING THE SOLAR THERMAL RADIATION AND CLIMATE TEMPERATURE

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ABSTRACT

Algae are one of the important sources of bio-diesel. Micro algae growth rate is directly affected by the sun light intensity and temperature. However, there is no available data in the literature concerning the environment temperature control to optimize the cultivate process of the algae in outdoor conditions. In the present study the outdoor continuous feedstock photo bioreactor has been designed and built to control the solar thermal radiation and its effect on the cultivation media temperature. Thos have been achieved using a new Air Bubble Generation (ABG) system. The used technique in the current study can enhance the temperature stability within the optimum range despite of the ambient conditions temperature. The results show that by increasing the air bubble generation rate the continuous photo bioreactor temperature distribution was enhanced along the reactor dimension. The optimum condition of the media PH is found to be 7.5, Na_2CO_3 concentration of 5 g, the media width of 25 Cm, media height of 25 Cm and AWR (Air to Water Ratio by volume) of 150.

KEY WORDS

Solar Intensity, Microalgae Cultivation Control, Biodiesel Production, Biofuels, Algae, Photo bioreactor.

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INTRODUCTION

Algae are one of the most important sources of bio-diesel nowadays [1-3]. Algae have a lot of advantages that make it participate with the different sources of biodiesel production [4-5]. Algae have higher ability of converting the sun energy into a liquid energy (Biodiesel).Biological treatment of water can be done by algae as it absorbs nitrogen and phosphorus [6-10].Algae can be produced in any lands and at any nature and fresh water is not necessary in cultivation process (it can use any kind of water even sea or brackish water).Algae production systems don't have specified shape or design and it can be adjustable as an open or close lop cycle. Algae can be harvested all over the year without seasonal production. Algae also have ability to absorb CO_2which helping in reducing greenhouse effect [11]. Algae have a lot of species that give us a wide range of choices which provide high production rate in different conditions (green, red and blue algae). It has short life cycle than any other type of bio-diesel source and it can be also used in cosmetics and pharmaceuticals industries and as a source of protein for animals feed [12-13].The most important characteristics of algae biodiesel that it has higher calorific value, low viscosity, and low density that make it have diesel like properties in combustion process, in addition it is classified as renewable source or energy.

There are two main systems for harvesting and producing algae. The first technique is known as a race way pond system [14]. It is closed loop oval channel have 0.25:0.40m deep which open to air in which mechanical wheel is used for circulating the water and algae together. The main disadvantage of the race way pond system is the limits of system deep. Algal cells are shading each other when the depth of the media (water) is increased than a certain value. The second system is the Photo bio-reactor (PBR) [15] which is defined as an array of closed transparent pipes connected to the main tank and opposed to the sun light all the daytime. Pure or brackish water electric pump is used in this system for circulating the media and algae from tank to pipes and vice versa. The main disadvantage of Photo Bio-Reactor is being very expensive [16-18].

Controlling outdoor algae production systems is one of the hardest, complex and expensive operations due to the continuous change in the surroundings conditions over the daytime and over the actual life cycle of the algae. One of the most complex factors in algae biodiesel production is the sunlight intensity variation over the daytime and how to control its effect on the cultivation pond. Sunlight control system is aiming to increase the sunlight beam intensity as much as we can and decreasing the effect of the thermal radiation on the increasing the media of cultivation temperature [19-20].

According the previous research activity the best biomass productivity and lipid content have been recorded by Scenedesmus Obliquus green algae. However, the Scenedesmus Obliquus was chosen for this study to get the best biomass productivity [21-22]. Many investigates had been done to improve the Scenedesmus Obliquus green algae productivity. All the previous data suggested that the outdoor cultivation was the hardest method. It's difficult to control the thermal radiation of the sunlight and its effect on the media temperature in outdoor algae cultivation which will affect the biomass productivity. However, the weather conditions have been predicted in order to determine the day in which we can get the best productivity of the biomass for the outdoor Photo bioreactor [23].

In the present study, outdoor continuous feedstock photo bioreactor has been designed and built to control the solar thermal radiation and its effect on the algae cultivation temperature during the hours of the daylight. The system is designed to overcome the most difficulties of the algae biomass production by controlling the complex atmospheric conditions during the algae life cycle. This control method can adapt the system to the different conditions of climate change over the hours of the day sunlight. The designed system was adjusted to produce a tiny air bubbles inside the algae media to guarantee an easy crackdown of the heat energy to the surrounding air. The bubbles generation system can circulate the cultivation water, green algae, and the chemical components together during all day. However, the temperature distributions inside the bubbled glass boxes photo bioreactor were equalized even at different sunlight exposure during the day sunlight to all algae particles in the cultivation system. Also, the bubble generation system can increase the time of the algae exposure to sunlight [24-27]. The green alga exposure time to sunlight is enhances the transformation of sunlight energy transformation to biomass productivity.

EXPERIMENTAL TEST-RIG AND PROCEDURE

Experimental test rig should ensure a good and homogeneous flipping of algae and cultivation media (water) in the photobioreactor system. Guarantee a good sun exposure is also one of the most important fundamentals to be observed in the system. The availability of changing the height of media (water) has been considered during the designed system. The system can merge the characteristics of the common algae production systems, which are known as the race way pond system and tube photobioreactor. This production system enhances the sunlight utilization as in the pipe photobioreactor. However, less capital cost as in race way bond systems have been achieved with applying the closed loop automatic control system. To study the effect of photo bioreactor dimensions the different sizes of cultivation tanks have been designed. Three different tanks have been fabricated with fixed length of 75 cm and height of 45 cm and the width is changed to be 15, 20, and 25 cm. The tanks are made from Acrylic (medium high impact) sheets, which promote better exposure to sunlight, with10 mm thickness. Photo bioreactor system was set in Tanta city, Egypt (Latitude: 30°47′18″ N, and Longitude: 31°00′06″ E); they were put in a place, which ensures exposure to sunlight all day. The constructed test rig can be shown in Fig. 1.

There is a main cylindrical plastic tank have 60 cm diameter and 120 cm height. This tank is used to overcome the shortfall of water in the photo bioreactor tanks due to water evaporation and for the installation of separation unit. Separation unit consists of 2 Sieves with fine holes to separate algae from water to extract biodiesel from it. Two parallel centrifugal pumps are used for separating algae from the water and for emptying the system if required. Pumps also are used in mechanical flipping of system and to equalize the temperature in all system if needed.

Air compressor was used to supply air to the system. Air Rotameter is used to measure Air volume flow rate (Q air) and 220 volts solenoid valve used to regulate the air entry to the system. Controlled electrical signal was used to open and close the solenoid which delivers air to Bubble Generation System (BGS) which consists of 8 mm copper pipes having 1 mm diameter holes at rate of 1hole every 6 cm ^{2} as shown in Fig 2. Control system consists of two main sub systems in order to measure the system temperature and control the air solenoid valve. Temperature measuring system gives the signal to the controlled component to keep the system in the best operating conditions that allows the best production.

The first sub system consists of the Arduino Uno board and digital temperature sensor (DS18B20) installed so they can give a detailed Temperature sheet for the system every ten seconds. We can guarantee that if any change happens, the system will have a continuous feedback which allows fast processing of the changes to keep the system in balance. Second sub system consists of Arduino Uno board as a controller and relays connected to solenoids. Level switch is connected to the Arduino to give level feedback to the Arduino when water level decreases due to evaporation (about 4% of total water evaporated per day). Air quantity is defined by the air solenoid opening time which defined from the Arduino signal. Pumps are connected to the second sub system to control which function they will perform. Pumps functions are algae separation, flipping the system, equalize system temperature, and emptying the system. Flipping can be Intermittent depending on specific time plan to Save expense. Also, the separation can be performed automatically every completed life cycle. This control system guarantees full controlling the system and can be defined as automatic system. Emptying system is used in case of contamination of the system by any unwanted pollutants.

Experimental Procedure

Laboratory experiments (Indoor examinations)

Green algae S. Obliquus was developed in 250 ml Erlenmeyer flasks containing 150 ml medium. The ways of life were lighted by tubular fluorescent lights with light intensity of 32 watt/m^2.

Outdoor experiments (Continuous Feedstock Photo bioreactor)

Three different widths of the acrylic tanks were used to merge the advantages of race way bond and photo bioreactor. System is installed in a direct exposure to the sun light. Solar radiation, Water temperature, and compressed air flow rate were measured from 9 AM to 6 PM. (DS18B20) temperature sensor was used in the temperature measurements. Solar radiation was measured by EKO Pyranometer (MS-802). The uncertainties and the relative errors of the measurements are summarized in Table 1.

RESULTS AND DISCUSSION

The optimization process is divided into two parts, indoor and outdoor optimization. The first parts of the experiments were performed to get the optimum conditions for algae growth such as media salinity, PH, and Na_2CO_3 concentration. This kind of the experiments have been done in laboratory in small scales. The second part is dealing with the outdoor optimization which is concerning the controlling on the solar thermal radiation and its effect on the cultivation temperature during the hours of the daylight. This kind of the experiment has been done in an outdoor continuous feedstock photo bioreactor.

Indoor Experiments

The impact of a variety of ph values [(ph control is7.5), (ph 6.5), (ph 5.5) and (ph 8.5)] on the development of S. Obliquus was recorded at O.D 680 for 18 days of brooding. (OD680) is the strategy in which the optical thickness of the way of life at 680 nm is utilized. The obtained results are available Fig. 4. It can be watched that, lessening or increment PH qualities prompted to decreases in the microalgae development.

The use of the various amount of Na_2CO_3 [control (0), 1, 3 and 5 g] have been applied per liter of the cultivation media as a carbon source brought about the dynamic increment in algae growth, as shown in Fig. 5. It can be watched that, 1, 3 and 5 g of Na_2CO_3 empowered development by 9, 26, and 36 %, separately, as for control. The obtained data of the determination of the EFA substance of diversely treated cultures with 0, 1, 3, and 5 g Na_2CO_3 are displayed in Fig. 6. Utilization of 1gof Na2CO3 brought on acceptance in EFA content by 11% as for control. However, 3 and 5 g of induction were demonstrating a similar percent of increment in EFA content by 24% over the control. Because of incitement of development and EFA generation, the EFA efficiency expanded by expanding the centralization of acceptance. The expansion was recorded by 32, 45, and 53% over the control level at 1, 3 and 5 g of Na_2CO_3 individually.

Outdoor Experiments

The ruling factor in outdoor algae cultivation is temperature. To obtain optimum green algae productivity the cultivation conditions of temperature, salinity, and Na_2CO_3 concentration must be also optimized.

In order to ensure the optimum green algae productivity the outdoor cultivation system must be arranged at certain value of media temperature of 35 ºc. Also, the media salinity and Na_2CO_3 concentration requires a positive control on its values. Outdoor experiments were made to shorten the time of water temperature that is higher than 35ºc.Due to the different atmospheric conditions the Temperature fracture used to compare the heights and choose the best of them. Temperature fracture is the period in which the temperature is higher than 35ºc to the time in which the temperature of the surroundings is higher than 35ºc. Outdoor experiments were done in a specific sequence to get the optimum operating conditions of tank width, water height, cooling compressed air quantity and using mechanical circulation or not as showed in Table 2.

Optimum width

This test is done using widths of 15, 20 and 25 cm with solar intensity distribution as shown in Fig. 7. The mean average value of IR is 666.25 W/m^2 for all-day of experiment. The maximum recorded value was 915 W/m^2.

Figure 8 shows the temperature variation in tanks and the effect of width in temperature distribution. For the minimum width of 15 cm the water temperature reaches its peak and stay around this peak value the longest time then the curve starts descending. The width of 25 cm reaches its peak value last this peak value is the least of three cases. The 20 cm width acts between 15 and 25 widths with an intermediate behavior. Width of 25cm is the maximum allowable width due to algae shading in higher widths.

Optimum medium height

Three heights (15 cm, 20 cm, and25 cm) were experimented to choose the optimum height 15, 20, 25 Cm. 25 Cm height is maximum allowable height due to algae self shading. Solar intensity is almost constant during the measuring days in the three heights as shown in Fig 9. The max recorded. Solar intensities in range of 915 to 930 W/m^2 and the mean average value all the days of study were about 670W/m^2.

a) Media height of 15 Cm

The max obtained day temperature in the cycle was chosen for illustrating the effect of height variation. The day of 46.5˚C max recorded temperature was chosen for 15 cm height. The behavior of the system didn't change all over the mini cycle. We noted that the temperature fracture is (1.0061) as shown in Fig. 10. It's observed in this case that the productivity became (0.3821 gm. L^{-1}.Day $^{-1}$).

b) Media height of 20 Cm

The max obtained day temperature in the cycle was chosen for illustrating the effect of height variation. The day of 45˚C max recorded temperature was chosen for 20 cm height. The behavior of the system didn't change all over the mini cycle. We noted that the temperature fracture is (0.917782) as shown in Fig. 11. It's observed in this case that the productivity became (0.3874 gm. L^{-1}.Day $^{-1}$).

c) Media height of 25 Cm

The max obtained day temperature in the cycle was chosen for illustrating the effect of height variation. The day of 43.6˚C max recorded temperature was chosen for 25 cm height. The behavior of the system didn't change all over the mini cycle. We noted that the temperature fracture is (0.905222) as shown in Fig. 11. It's observed in this case that the productivity became (0.4189 gm. L^{-1}.Day $^{-1}$).

Effect of flipping the medium using pumps

This test is done in two cases which are, flipping in all the day and flipping half day. Solar intensity is almost constant during the measuring days in the two cases. As shown in Fig. 13, the max recorded solar intensities in range of 920 to 930 W/m^2 and the mean average value of solar intensity all the days of study was about 670 W/m^2.

a) Flipping the medium using pumps all the day

Media height of 25 cm was chosen for the study and centrifugal pumps were used in flipping the system. Previous studies show that flipping media is enhancing the productivity. First case we use pumps in flipping all day with a working rate of 10 minutes on and 10 min off. Using pumps made the temperature to be high quickly which is negative effect besides the positive effect of flipping in enhancing the productivity. The max obtained day temperature in the cycle was chosen for illustrating the effect of Flipping the medium using pumps all day. The day of 47.4˚C max recorded temperature was chosen. The behavior of the system didn't change all over the mini cycle. We noted that the temperature fracture is (0.923893) as shown in Fig. 14. It's observed in this case that the productivity became (0.3230 gm. L^{-1}.Day $^{-1}$). Pump has positive effect in the second half of the day as it helps in decreasing system temperature rapidly than the ordinary one that which will be studied in the next case.

b) Pump flipping half the day
This case we took the positive effect of the pumps which happened in the second half of day that helps in decreasing the system temperature. Pumps have been used in the same previous rate 10mins on and 10mins off but this time they started working at 2:00 PM to allow the system curves to descend with surrounding curve. The max obtained day temperature in the cycle was chosen for illustrating the effect of flipping the medium using pumps half the day. The day of 45.5˚C max recorded temperature was chosen. The behavior of the system didn't change all over the mini cycle. We noted that the temperature fracture is (0.818182) as shown in Fig. 15. It's observed in this case that the productivity became (0.4192 gm. L^{-1}.Day $^{-1}$).

The optimum is not using pumps because the productivity has no significant increase or increased at very small value relative to pump power consumption.

Effect of using Air Bubble Generation in flipping and cooling the system
Compressed air was used in Bubble Generation System for two main purposes are media flipping and cooling system by decreasing heat transfer from surroundings to water. Air was inserted to media according to AWR (Air Water Ratio) which is air volume during day to the water volume in system. Two main ratios were used 100and 150 AWR. Fixed flow rate of air of 90L/Min. The total amount of air entering the system was defined by the opening times of the air solenoid and the intervals between openings. Solar intensity is almost constant during the measuring days in the two cases bas shown in Fig. 16. The max recorded solar intensities in range of 940 to 948 W/m^2 and the mean average value all the days of study was about 672 W/m^2.

a) Effect of air bubble generation system of 100 AWR
Fixed flow rate of 90 LPM was used with solenoid opening for 66 seconds and closing time for 254 seconds that allows for 11.25 m3 (AWR of 100) of compressed air to enter the system through bubble generation system. The max obtained day temperature in the cycle was chosen for illustrating the effect of using air bubble generation system. The day of 46.3˚C max recorded temperature was chosen. The behavior of the system didn't change all over the mini cycle. We noted that the temperature fracture is (0.708185) as shown in Fig. 17. It's observed in this case that the productivity became (0.6249 gm. L^{-1}.Day $^{-1}$).

b) Compressed air in flipping and cooling the system of 150 AWR
Fixed flow rate of 90 LPM was used with solenoid opening for 90 seconds and closing time for 230 seconds that allows for 16.8 m3 (AWR of 150) of compressed air to enter the system through bubble generation system. The max obtained day temperature in the cycle was chosen for illustrating the effect of using air bubble generation system. The day of 45˚C max recorded temperature was chosen. The behavior of the system didn't change all over the mini cycle. We noted that the temperature fracture is (0.605556) as shown in Fig. 18. It's observed in this case that the productivity became (0.7561 gm. L^{-1}.Day $^{-1}$).

Table 3 and Fig. 19 are showing the different productivties of all tested cases.

CONCLUSION

Experiments work have been conducted to study the effect of various operating and designe conditions on the photo bioreactor system to obtain the optimal gree algae productivety. However, the main conclusion are sumarized as follow:

- Generally, for all cases of the study the value of temperature of water decrease by increasing the width of the tank until a specified limit of 25 cm to avoid the shading of the alagal cells.
- Increasing the height of the water level decreases the time of being on temperature higher than 35˚C of the system to the time in which surroundings be in higher than 35˚C.
- Using mechanical pump circulating all the day make it worse it inhanced heat transfer and inreased the time of being in deadly temperature so the production decreased and become the less productivity rate.
- Using the half day flipping helps in exploiting the positive effect of the pump flipping and ignoring the negative effect and also we made agreat benefits of flipping it self .All of the above things had involved a clear participation in improving productivity but still very small improving Compared to its cost.
- Using the compressed air in it's two cases had made an obvious improvement in produtivity and from experiments increasing air quantity increases the productivity and enhances the type of producted bio mass.
- Optimum PH is 7.5 and $Na2CO3$ concentration of 5 g.
- Optimum tank width is 25 Cm and water height of 25 Cm with no mechanical circulating.
- Optimum Air to water ratio is 150 for more AWR the benefits are less than coasts.

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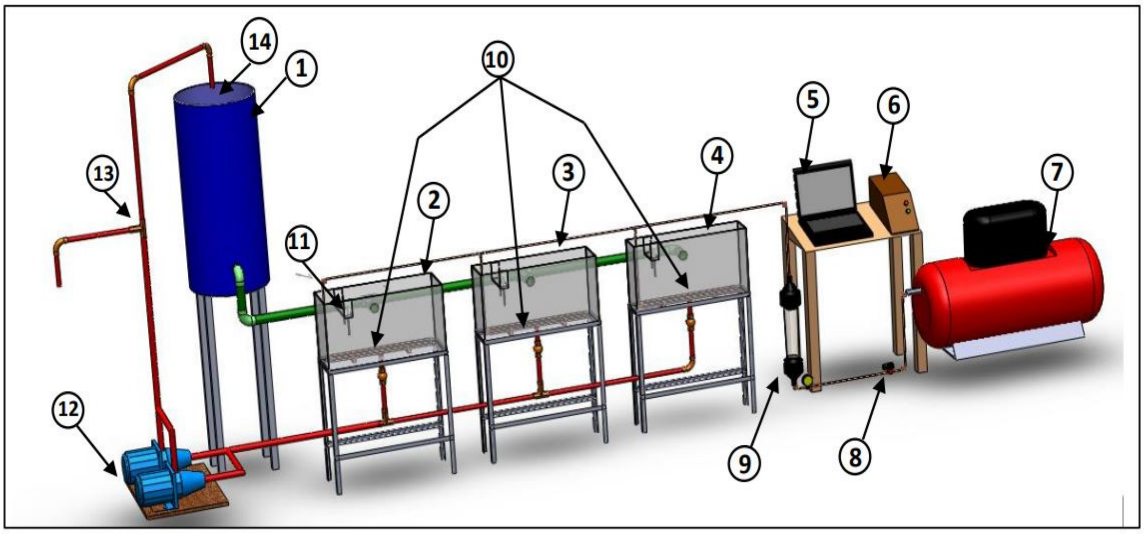
Figures and Tables:



No.	Component	No.	Component
1	Main tank	8	Air solenoid valve
2	25 cm width tank	9	Air measuring device (Rotameter)
3	20 cm width tank	10	Air bubbles generation system (BGS)
4	15 cm width tank	11	Temperature measuring set
5	Computer device`	12	Centrifugal pumps
6	Control system	13	Water direction changer (WDC)
7	Air compressor	14	Algae separation system

Fig. 1. Test rig layout with the main components.

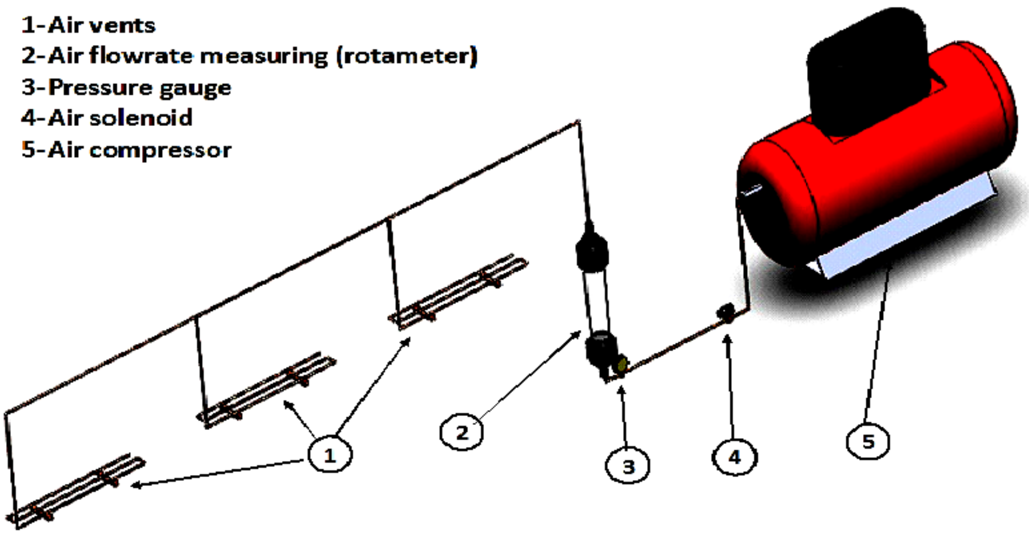


Fig. 2. Air Bubble Generation (ABG) system layout and component.

Fig. 3. Photos of the algae growth hestroy during one of the tested cultivation cycle**.**

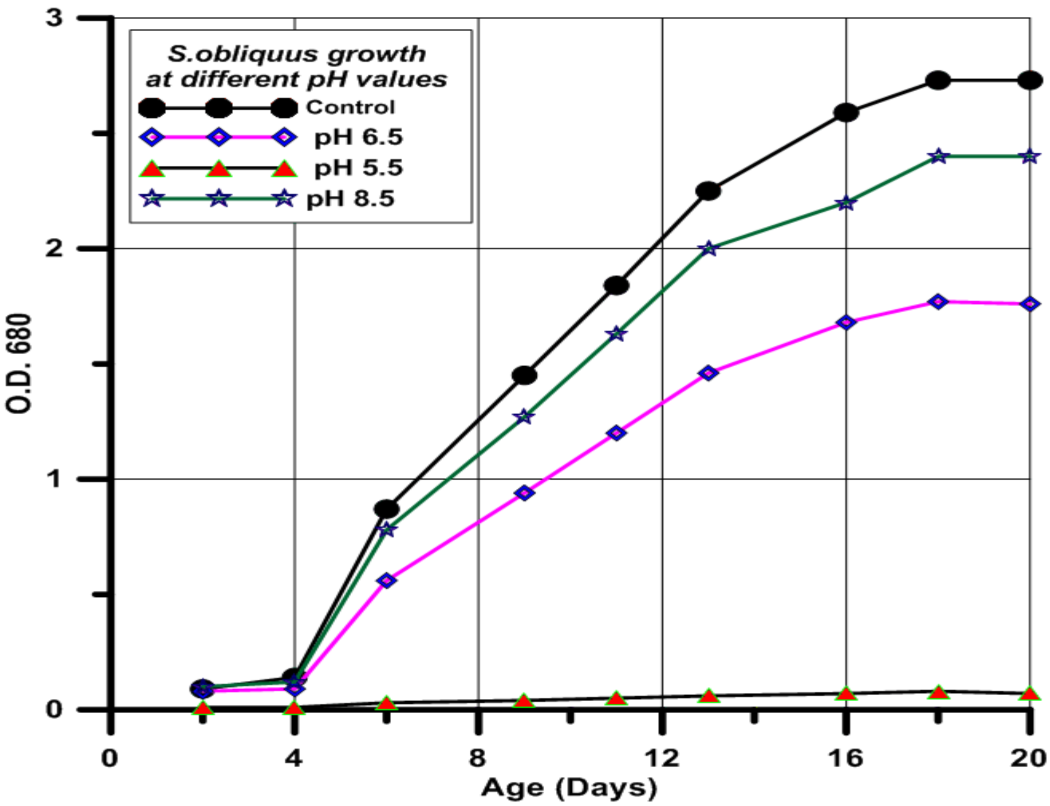


Fig. 4. Productivity at given PH values**.**

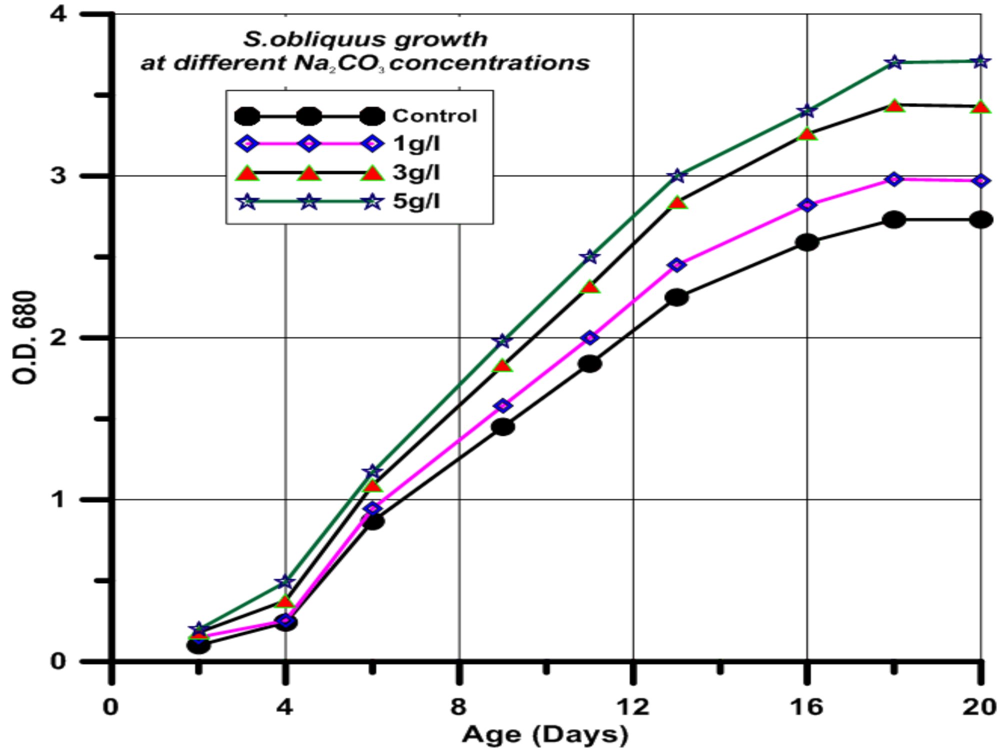


Fig. 5. Growth at Na2CO3 concentrations**.**

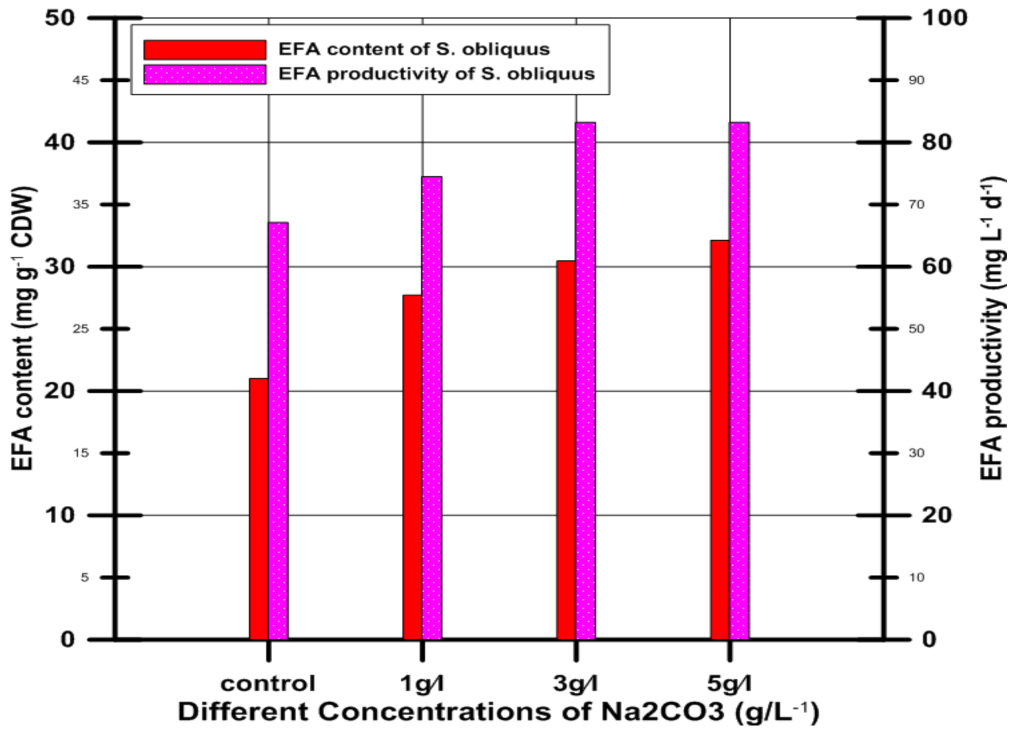


Fig. 6. EFA productivity at Na2CO3 concentrations.

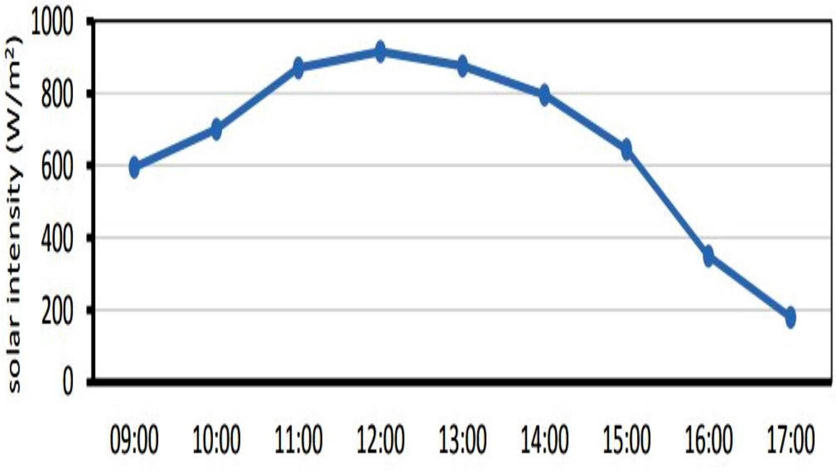


Fig. 7. Hourly variation of IR during the day of the experiment.

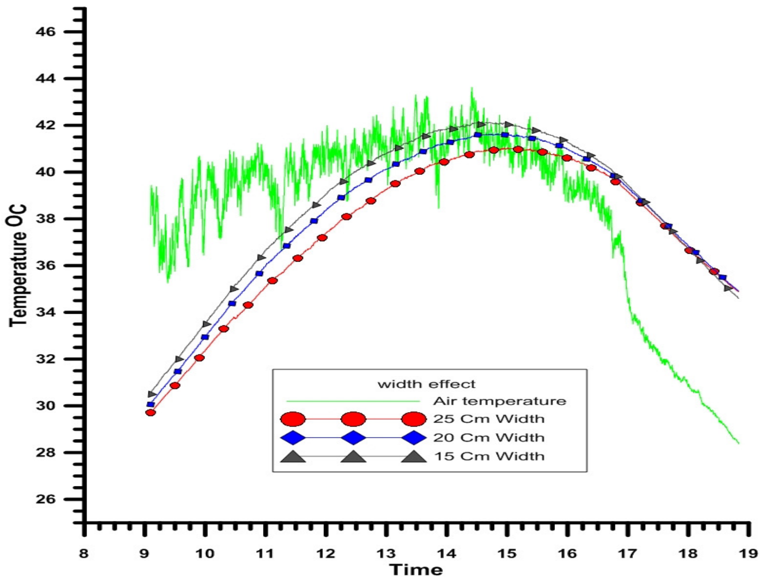


Fig. 8. Temperature variation in tanks with width.

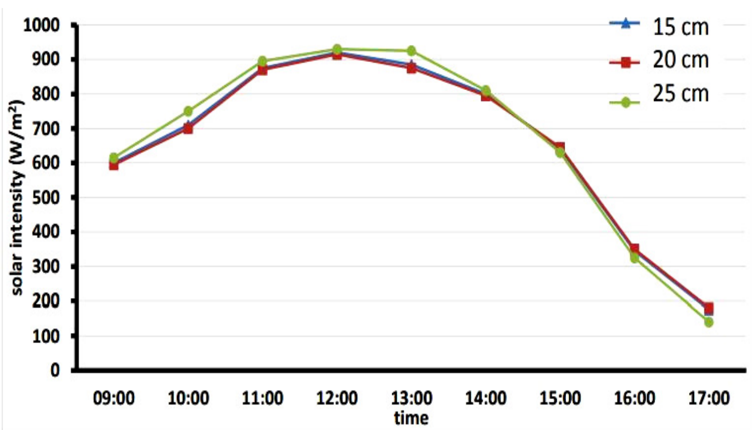


Fig. 9. Hourly variation of IR during height tests.

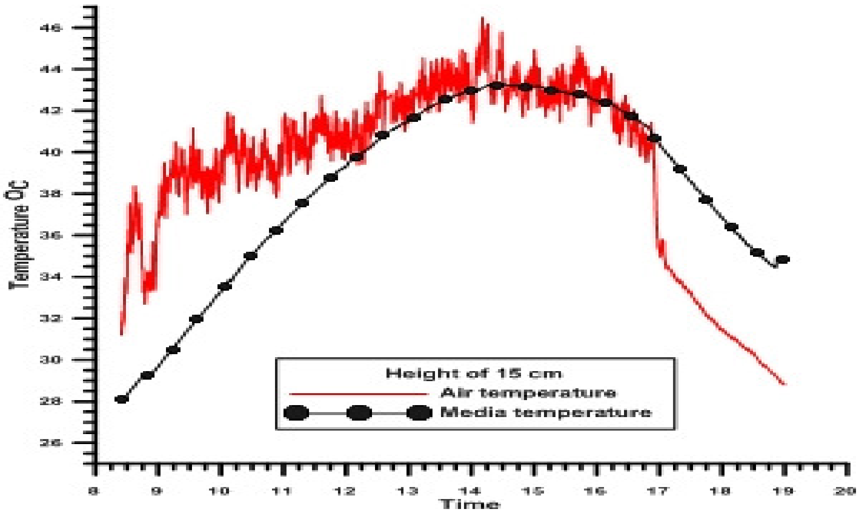


Fig. 10. Temperature variation at height of 15 Cm**.**

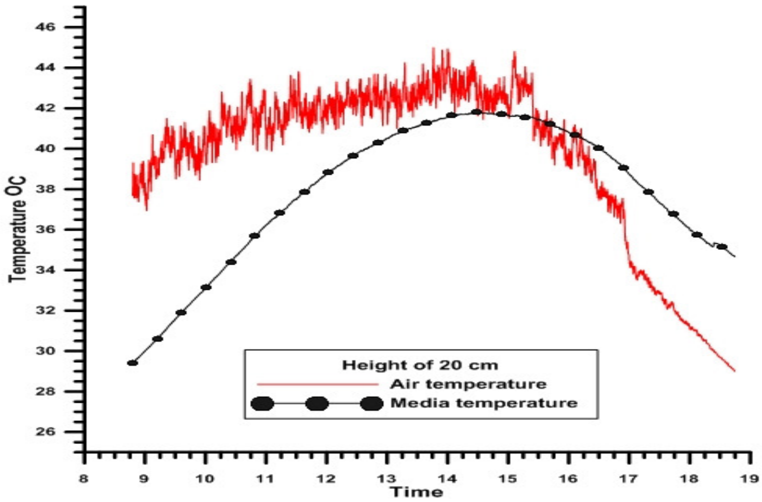


Fig. 11. Temperature variation at height of 20 Cm.

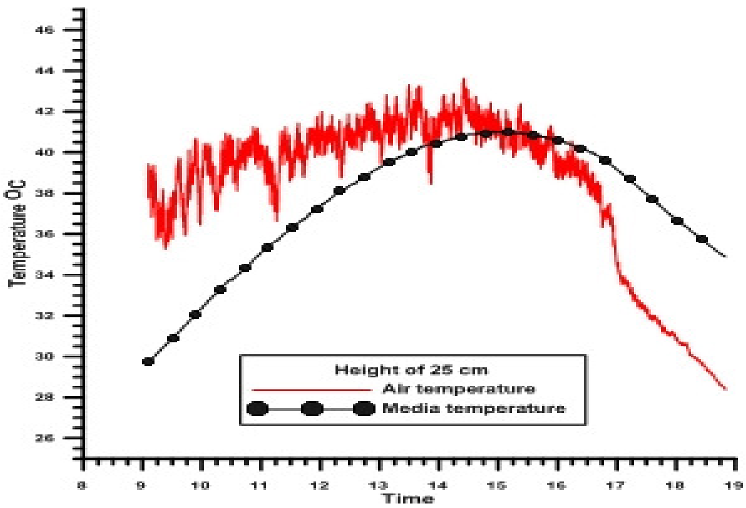


Fig. 12. Temperature variation at height of 25 Cm.

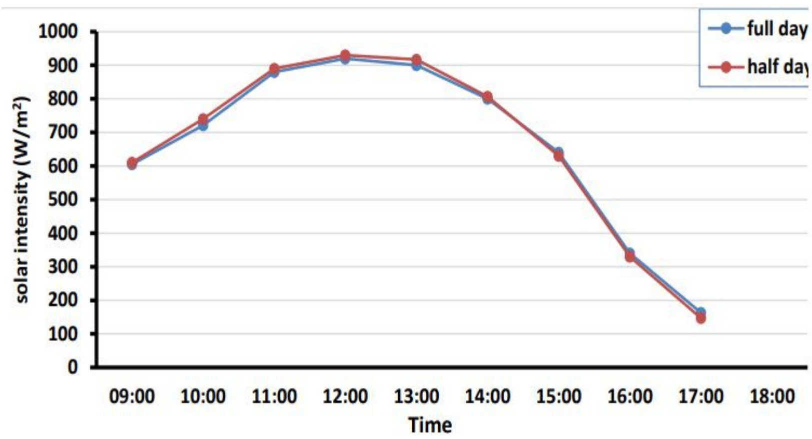


Fig. 13. Hourly variation of IR during flipping tests.

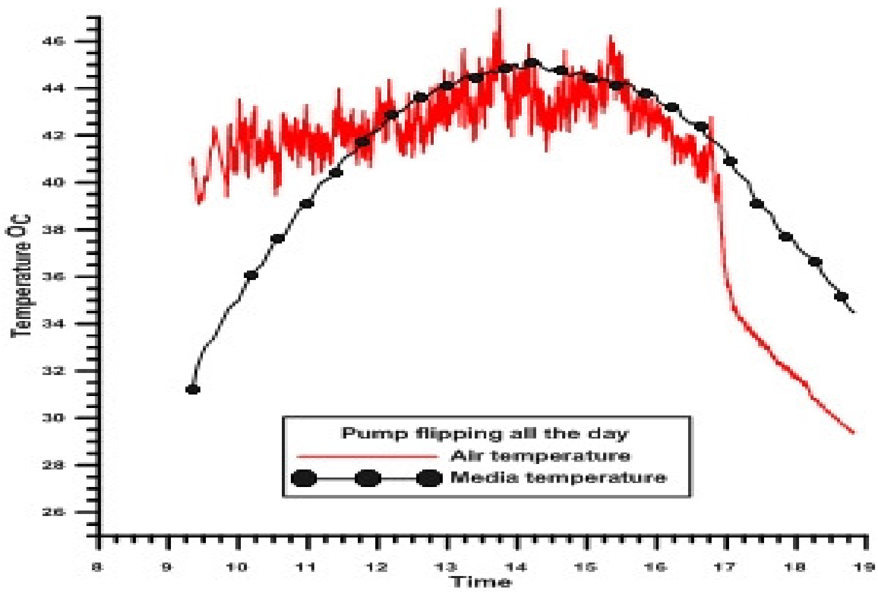


Fig. 14. Pump flipping all day.

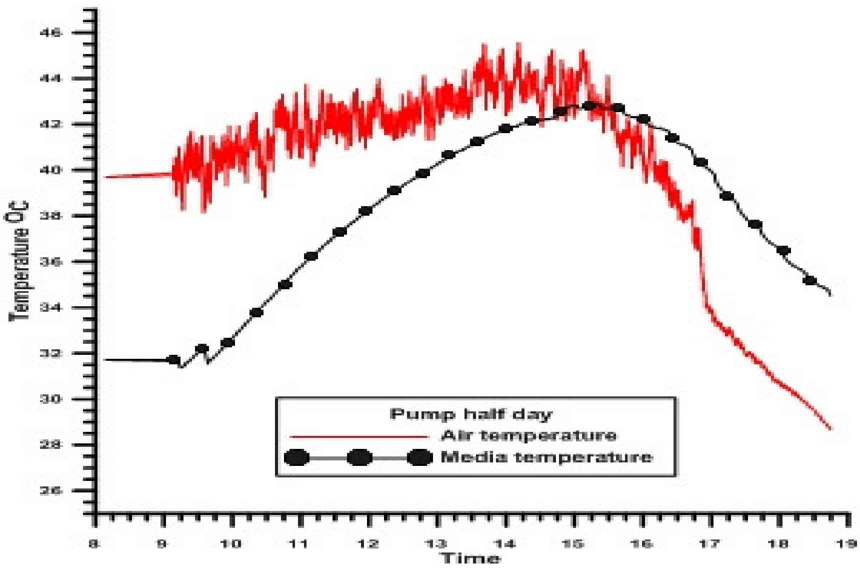


Fig. 15. Pump flipping half day.

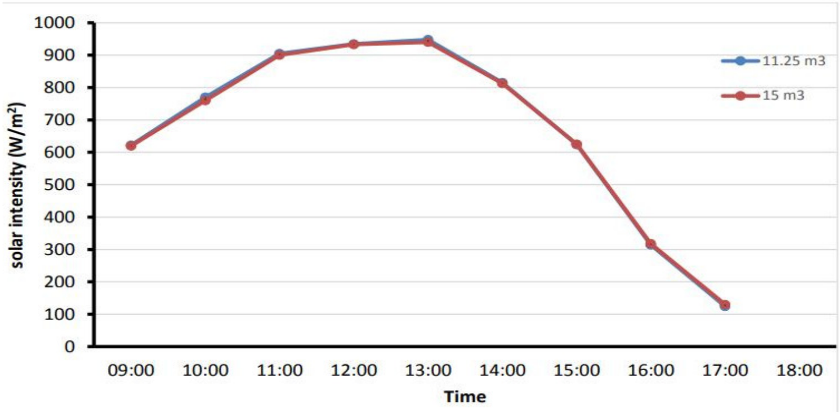


Fig. 16. Hourly variation of IR during compressed air test.

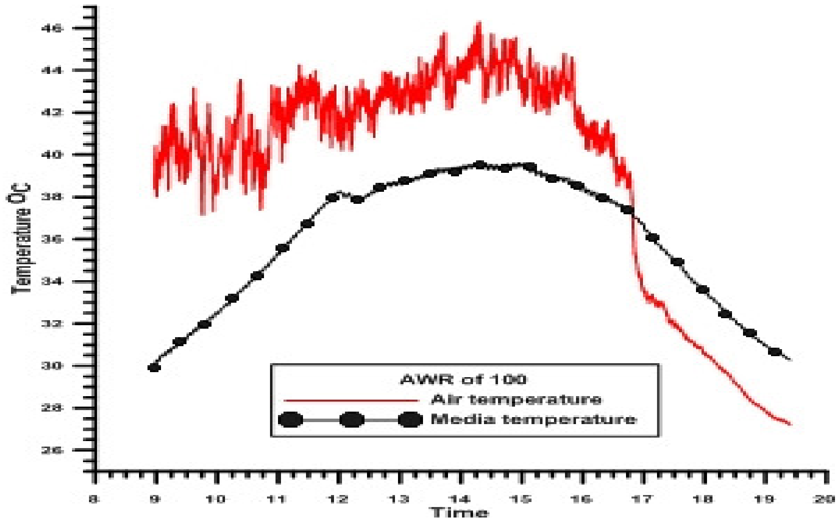


Fig. 17. Temperature variation using ABG at AWR of 100.

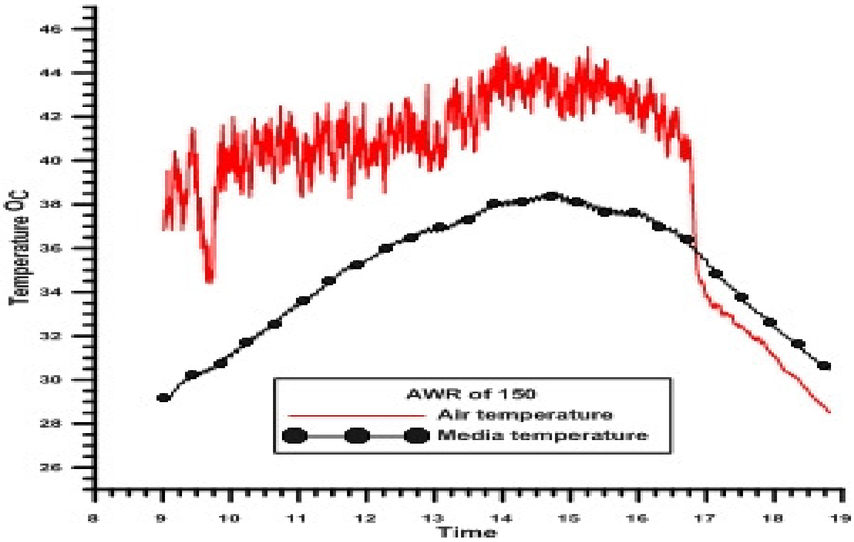


Fig. 18. Temperature variation using ABG at AWR of 100.

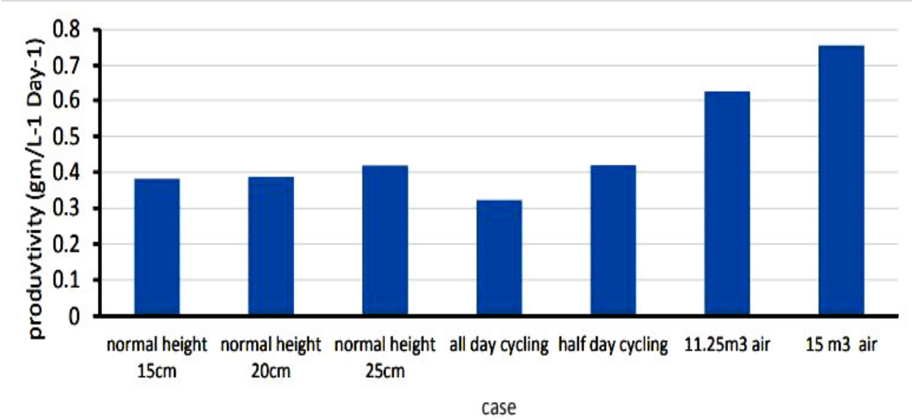


Fig. 19. Productivity of the Studed cases.

Table 1. Measurements uncertainties and relative errors**.**

Parameter	***Uncertainty***	***Relative error***
Temperature (˚C)	±0.5℃	1.06%
Solar radiation (W/m^2)	±2	0.2%
Air flow rate (LPM)	±2.35	2.5%

Table 2. Outdoor experiments

No:	**Experiments**	**Days**	**Circumstances**	
			Temperature	**Solar radiation**
1	Optimum width	1:11/June 2017	Max recorded temperatures (41˚C to 45˚C)	Max recorded solar intensity (915 W/m^2)
1	Ordinary at height of 15cm	12:21/June 2017	Max recorded temperatures (39.5˚C to46.5˚C)	Max recorded solar intensity (915 to 930 W/m^2)
2	Ordinary at height of 20cm	23/june:2/July 2017	Max recorded temperatures (41˚C to 45˚C)	
3	Ordinary at height of 25cm	4:13/July 2017	Max recorded temperatures (40˚C to 43˚C)	
4	Pump circulating all day	15:24/July 2017	Max recorded temperatures (41.5˚C to 47.5˚C)	Max recorded solar intensity (915 to 930 W/m^2)
5	Pump circulating half day	26/July:4/august 2017	Max recorded temperatures (41.5˚C to 45.5˚C)	
6	Air cooling and circulating at AWR of 100	6:15/August 2017	Max recorded temperatures (43˚C to 46.3˚C)	Max recorded solar intensity (915 to 930 W/m^2)
7	Air cooling and circulating at AWR of 150	17:26/August 2017	Max recorded temperatures (41˚C to 45.2˚C)	

Table 3. Tested Cases productivities (gm. $L^{-1}.Day^{-1}$).

N	Experiments	Productivity (gm. $L^{-1}.Day^{-1}$)
1	Ordinary at height of 15cm	0.3821
2	Ordinary at height of 20cm	0.3874
3	Ordinary at height of 25cm	0.4189
4	Pump circulating all day	0.3230
5	Pump circulating half day	0.4192
6	Air bubble generation at AWR of 100	0.6249
7	Air bubble generation at AWR of 150	0.7561