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Design of Floating Platform for Marine Agricultural Microalgae

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ABSTRACT

Microalgae is a type of microscopic organisms that are high in lipid with rapid biomass production, which is suitable to be used as biofuel for renewable energy. The aim of this study is to conceptually design a floating platform for microalgae cultivation on the sea and to determine the structural motion of floating platform subject to Malaysia wave. ANSYS Aqwa simulation was carried out to simulate the heave and pitch motion of the floating platform under Malaysia wave condition. From the ANSYS Aqwa simulation, design of the floating platform by increased the elevation angle of design, the stability of the increased from the stability of the floating platform. Cultivation of microalgae required greater movement speed in water to enhance high efficiency in biomass production. Based on the result of the simulation, the design of the floating platform which has greater elevation angle is the most suitable for cultivation of microalgae.

Keywords:
Microalgae cultivation, Floating platform, Pitch and heave motion, ANSYS Aqwa

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1. Introduction

Microalgae are a type of microscopic photosynthetic organisms thrive in freshwater and saltwater or marine habitat [1]. Microalgae usually exist in individual or chain group, commonly known as unicellular species. Microalgae is high in lipid and it has rapid biomass production which suitable to use as biofuel for renewable energy [2]. In recent year, the world population experienced a continuous growth resulted in a large increase in primary energy consumption. Unfortunately, this increment of primary energy consumption causes environmental pollution and energy crisis [3]. Microalgae have higher photosynthesis efficiency, it can produce up to 100 tons of microalgae biomass with the employment of 183 tons of CO_2. Therefore, the concentration of CO_2 in atmosphere can be reduced by microalgae biomass cultivation [3] However, there are mass production of microalgae require a large area for cultivation. However in the era of technology, human keep expanding the land to increase their standard of living. Thus, there are insufficient space for the cultivation of microalgae. From the information, there are 71% of earth' surface was cover by the ocean, cultivation of microalgae in the marine were decided to optimise the usage of free space in the sea.

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2.0 Methodology

2.1 *Microalgae Cultivation System*

Cultivation system of microalgae can be classified into two category, open systems and closed system. The selection of cultivation system depending on the requirement of microalgae, design condition and environmental factor [3]. The details are explained as below:

2.1.1 *Open System*

In open systems, microalgae are cultivated in open area environments such as ponds, lagoons, deep channels, shallow circulating units and others [3]. An open cultivation system is designated with the closed-loop flow channel and the depth is minimum ranging from 0.2m to 0.3m [4]. Since the pond is shallow, the surface to volume ratio could be increased and hence light is easier to penetrate to the interior.

2.1.2 *Closed System*

Closed systems also known as photobioreactor (PBR), microalgae are cultivated in vessels with transparent wall and exposed under sunlight or artificial radiation to facilitate photosynthesis. The closed system is used to cultivate environment-sensitive microalgae. PBR can be classify into tubular PBR, flat PBR and column PBR [3].

Tubular PBR cultivation is operated by maximizing the surface area-to-volume ratio for higher growth rates [5]. To ensure sufficient of light penetration for microalgae cultivation, the diameter of solar collector is designed with a maximum of 0.1m [6]. During the cultivation of microalgae, the microalgae medium is circulated between the solar collector and the reservoir by using an airlift pump. Flat PBR is another type of PBR, it usually set as horizontally or vertically on the ground. Unlike other type of PBR, flat PBR is structured by transparent flat plate with few millimetres thick in order to maximize the light exposure to microalgae [2]. Column PBR, also known as bubble PBR is constructed by two draft tubes to control the cultivation condition.

2.1.3 *Advantages and Disadvantages of Cultivation System*

The summary of advantages and disadvantages of open and close cultivation system is tabulated in Table 1.

Table 1 Advantages and disadvantages of cultivation system

System	Advantages	Disadvantages
Open system	• Low cost • Simple and easy to maintain	• Easily contaminated • High water losses rate
Close system – Tubular PBR	• Easy to design, install and operate • Shorter harvest time • Large quantity of microalgae biomass	• Require large space and cost • High concentration of CO_2 inhibit photosynthesis

Close system – Flat PBR	• High biomass productivities • Easy to clean and sterilize • Low contamination of microalgae	• Difficulties in controlling temperature • Limited degree of growth at near wall region

2.1.4 *Environmental impact from marine microalgae cultivation*

Open pond cultivation system is chosen as the best technology as it has the lowest environmental impacts [2]. However, open system brought higher environmental impacts than both tubular PBRs, as the latter compensates energy-consuming elements with higher productivity. Six per cent of total incident radiation energy was assimilated into biomass via microalgae cultivation [7]. In fact, cultivation of microalgae reduces the need for energy-intensive cleaning processes and chemical use as is standard in wastewater treatment. Generally, water footprint of microalgae biodiesel from open raceway is higher than closed system.

2.2 *Design of Floating Platform*

The design of floating platform was a complicated process in needs of satisfied numerous functional requirements. Thus, few important criteria that are required to take into consideration are floating system, stability system and motion keeping system. The procedure of design process is based on a "spiral" model, meaning that a design cycle was used to manage risk [8]. The important criteria will be discussed as below:

2.2.1 *Waves Conditions*

Waves condition is the natural phenomena where the ocean surface waves are generated by the wind forces. The waves force is directly proportional to the wind force. The waves become equilibrium under continuous blew steadily in large area for long time as known as fully developed sea [9]. The waves condition in Malaysia from 2001-2010 are tabulated as below [10].

Table 2 Waves condition in Malaysia from 2001-2010

	Peak Period (s)	Wave height (m)	Amplitude (m)
Minimum	3.5	0.25	0.125
Average	5.5	0.75	0.375
Maximum	8.5	2.25	1.125

2.2.2 *Floating System*

The offshore floating structure is supported by force of buoyancy [11]. Eq. (1) shows the calculation of buoyant force.

$$F_B = \rho g \nabla \quad (1)$$

The buoyant force generated by a hydrostatic pressure will act on the same magnitude with an opposite direction of the weight force.

2.2.3 *Stability System*

The stability calculation act as an important step in designing of floating structure. Stability is the ability of the platform return to the undisturbed position after external force is removed. The platform with a high tendency to return to the upright position after acting by external force known as stable platform. When external upsetting force is acting to the floating structure, the platform become incline position due to the water resistance. Centre of buoyancy, *B* will move to the down dip side. The buoyant force pushes the floating structure vertically upward to the metacentre, *M*. Hence, the restoring moment will generate the floating structure to original position that shown in Fig. 1 [11]. The higher metacentric height of an object and provide a greater stability [12].

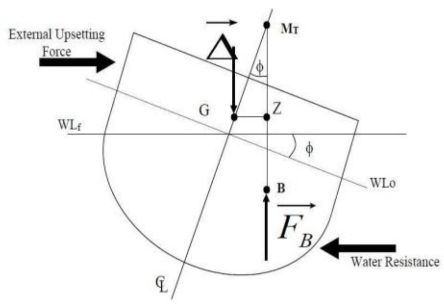

Fig. 1. The role of GM due to an External Moment [11]

2.2.4 *Mooring System*

The available of mooring system can limit the movement of the platform due to the environmental condition such as current, wind and waves. Catenary mooring is the most common mooring system applied in shallow water [13]. In catenary mooring system, the mooring line terminated at the seabed horizontally. Thus, the anchor of the mooring system only inflicts by the horizontal force at the seabed. Spread mooring system consists of multiple mooring lines attached to the floating structure to limit the movement of the structure. Hence, the structure will not rotate due to environment loading.

2.3 *Six Degree of Freedom*

Offshore structures have six degree of motion which will occurr simultaneously [14]. This scenario also known as wave induced motion [15]. The sway, surge and heave can be defined as the three motion displacements around the center of gravity while roll, pitch and yaw motion were the angular rotation around axis [16].

2.4 *Ideal Offshore Microalgae Cultivation System*

As regards to the ideal design of the microalgae cultivation farm, there are multiple floating platforms that were connected in line to the frame of the cultivation farm in order to ensure the station keeping of the floating platform. Also, out of six degrees of motion in the floating platform, four was limited in the system. Thus, only pitch and heave motion are available for the movement of the floating platform. As compared to the single floating platform cultivation system, such design of multiple floating platforms that linked up together as a cultivation system has appeared to be a much convenience approach. The comparison between both methods can be presented in Table 2.

Table 2 Comparison between multiple cultivation system and single cultivation system

Multiple cultivation system	Parameter	Single cultivation system
Yes	Material Saving	No
High	Cost	Low
High	Space Occupied	Low
Easy	Ability to control	Difficult
Easy	Ability for Maintenance	Difficult

2.5 *Geometry Modelling of Design*

Basically, the geometry design of floating platform depends on the *a/b* ratio where *a* was the length of the top of platform and *b* was the length of the bottom of the platform and *h* is the height of the platform with 0.6m. Fig.2. had presented the front view of the design for floating platform with the a/b ratio.

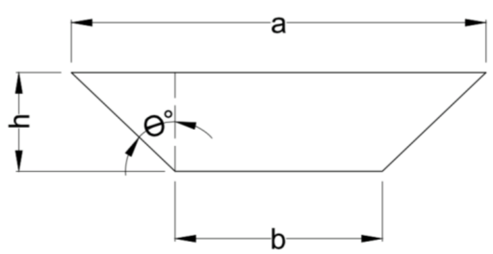

Fig. 2. Design for floating platform with the a/b ratio

3. Results and Discussions

3.1 *Finite Element Analysis*

SolidWorks 2017 software was used to conduct 7 initial design of floating platform refer to the a/b geometry ratio and the angle of elevation. The dimension of the design was shown in the TABLE 3.1. After importing the design into Ansys, total mass, total volume and moment of inertia had been obtained. Table 4.x had shown the properties of the design of floating platform

Table 3 Dimension of design

Design	a (m)	b (m)	a/b	Angle , θ	Angle of Elevation, θe
1	5	5	1.0	0	90.00
2	5.5	5	1.1	22.62	67.38
3	6.0	5	1.2	39.81	50.19
4	6.25	5	1.25	46.17	43.83
5	6.5	5	1.3	51.34	38.66
6	7.0	5	1.4	59.04	30.96
7	7.5	5	1.5	64.36	25.64

Table 4 Properties of the design of floating platform

Design	a/b	Total Mass, kg	Total Volume, m^3	Moment of Inertia, kgm^2		
				x	y	z
1	1.0	10856.39	7.76	14365	14365	28531
2	1.1	11299.45	8.13	15325	15324	30438
3	1.2	11877.95	8.55	16603	16600	32978
4	1.25	12129.10	8.83	17291	17288	34347
5	1.3	12327.90	8.99	18015	18017	35793
6	1.4	12857.35	9.44	19551	19548	38846
7	1.5	13408.00	9.90	21221	21216	42171

3.2 *Buoyamcy Force and Volume Displaced Analysis*

The buoyant force and total volume displaced of platform calculated and tabulated in table below.

Table 5 Buoyant force and volume displaced under sea level

Design	a/b	Buoyant force, kg	Volume displaced, m
1	1.0	7954	0.4260
2	1.1	8333	0.4420
3	1.2	8763.75	0.4427
4	1.25	9050.75	0.4477
5	1.3	9214.75	0.4485
6	1.4	9676.00	0.4515
7	1.5	10147.5	0.4541

3.3 *Hydrodynamic Diffraction Simulation*

3.3.1 *Hydrostatic Analysis*

Hydrostatic analysis was carried out to determine the hydrostatic displacement properties and the small angle parameter of the object. The result from the hydrostatic simulation had presented in the Table x.

Table 6 Result of hydrostatic analysis.

	Centre of Buoyancy (CoB), m			Metacentric Height, m	CoB to Metacentre, m	Restoring Moments, N.m/°
	X	Y	Z			
1	$-7.036x10^{-10}$	$4.274x10^{-8}$	-0.21300	4.627	4.840	8595.936
2	$5.001x10^{-8}$	$-1.086x10^{-7}$	-0.21572	5.521	5.736	11399.780
3	$1.437x10^{-7}$	$1.455x10^{-7}$	-0.21114	6.777	6.988	15075.560
4	$-1.822x10^{-8}$	$1.685x10^{-7}$	-0.21106	7.414	7.625	17323.750
5	$2.367x10^{-7}$	$-2.894x10^{-7}$	-0.20914	8.132	8.341	19732.328
6	$3.004x10^{-7}$	$.1.029x10^{-6}$	-0.20608	9.666	9.872	25356.891
7	$1.256x10^{-7}$	$6.067x10^{-8}$	-0.20304	11.360	11.564	32137.850

3.3.2 *Motion Amplitude*

Motion amplitude analysis had been obtained from the Hydrodynamic Diffraction simulation. The result of motion amplitude analysis were able to visualization the motion of the wave toward design by importing the wave frequency and wave direction. Table 4. had presented the result of wave amplitude from pressure and motion analysis.

Table 7 Result of wave amplitude from motion amplitude analysis

Design	Wave Amplitude, m	
	Maximum	Minimum
1	1.0213	0.9694
2	1.0213	0.9584
3	1.0214	0.9470
4	1.0213	0.9407
5	1.0214	0.9434
6	1.0214	0.9208
7	1.0212	0.9061

3.3.3 *Response Amplitude Operator (RAOs) Analysis*

RAOs analysis was carry out to present the distance and rotation of the floating platform change with frequency in pitch and heave motion by importing the wave frequency and wave direction. By using RAOs simulation, it able to generate a 2 Dimensional graph to present the distance and rotation of the object change with the wave frequency and wave direction.

3.3.3.1 *RAOs Analysis in Pitch Motion*

The motion of RAOs simulation in pitch motion was tabulated in Table x. Refer to the result obtained, design 1 had the highest peak point with and design 7 had the lowest peak point. The angle of rotation of the design significantly and gradually decreased from 45.510° (design 1) to 17.672° (design 7) as the a/b ratio increased.

Table 8 Maximum and minimum angle of rotation of the design in pitch motion

Design	Angle of Elevation, θe	Minimum point		Maximum point		Differences, °
		Frequency, Hz	Rotation, °	Frequency, Hz	Rotation, °	
1	90.00	1.293	0.004	0.489	45.514	45.510
2	67.38	1.408	0.259	0.492	29.186	28.927
3	50.19	1.431	0.421	0.400	22.756	22.335
4	43.83	1.445	0.445	0.400	21.713	21.268
5	38.66	1.459	0.264	0.400	20.896	20.272
6	30.96	1.446	0.476	0.400	19.442	18.966
7	25.64	1.317	0.509	0.384	18.181	17.672

3.3.3.2 *RAOs Analysis in Heave Motion*

From the result obtained for the RAOs analysis, design 1 had the highest peak point with and design 7 had the lowest peak point. Table 4. had shown the result RAOs of the design in heave motion.

Table 9 Maximum and minimum distance or rotation of the design in heave motion

Design	Elevation angle, θe	Minimum point		Maximum point		Differences, m
		Frequency, Hz	Distance, m	Frequency, Hz	Distance, m	
1	90.00	1.382	0.00018	0.100	0.99900	0.99882
2	67.38	1.408	0.00300	0.100	0.99800	0.99500
3	50.19	1.431	0.00500	0.100	0.99700	0.99200
4	43.83	1.445	0.00500	0.100	0.99600	0.99100
5	38.66	1.459	0.00500	0.100	0.99600	0.99100
6	30.96	1.446	0.00600	0.100	0.99500	0.98900
7	25.64	1.317	0.00800	0.100	0.99400	0.98600

3.4 *Hydrodynamic Response Simulation*

3.4.1 *Structural Position Actual Response Analysis*

The structural position in heave motion and the angle of rotation in pitch motion had been obtain by importing the amplitude and the period from the Table 10.

3.4.1.1 *Structural Position Actual Response Analysis in Pitch Motion*

The maximum and minimum of angle of rotation in pitch motion under three type of wave condition are presented in Table x. From the data shown, the design 1 with elevation angle of 90 had the largest angle of rotation. Design 7 with elevation angle of 25.64 had the smallest angle of rotation. The relationship between the elevation angle of design and their angle of rotation in pitch motion under three type of wave condition had presented in Fig. 3.

Table 10 Angle of Rotation Analysis under different type of wave condition in pitch motion

Design	Elevation angle, θe	Angle of rotation, °		
		Minimum	Average	Maximum
1	90.00	3.994	5.540	7.174
2	67.38	3.726	5.516	7.164
3	50.19	3.573	5.495	7.163
4	43.83	3.542	5.486	7.128
5	38.66	3.286	5.448	7.127
6	30.96	3.203	5.444	7.118
7	25.64	3.048	5.397	7.117

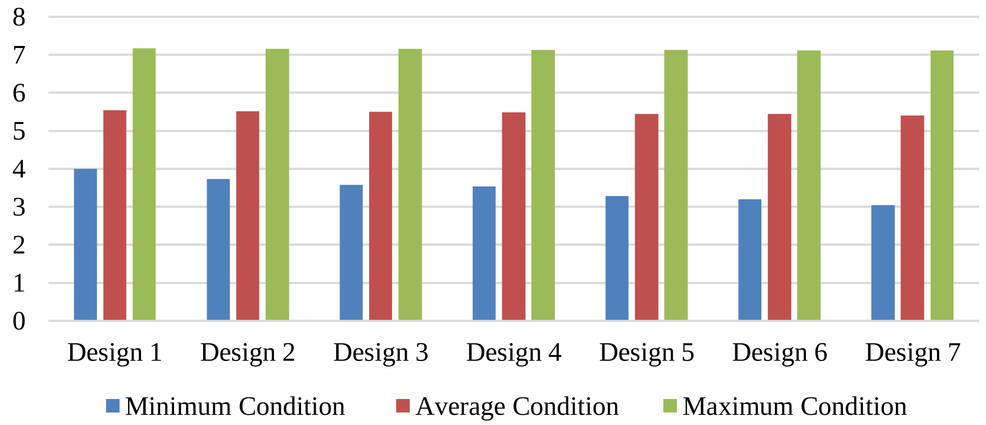

Fig. 3. Angle of rotation of design in pitch motion under different type of wave condition.

3.4.1.2 *Structural Position Actual Response Analysis in Heave Motion*

The maximum and minimum of distance travelled in heave motion under three type of wave condition are presented in Table x. From the data shown, the design 1 with elevation angle of 90 had the largest distance travelled. Design 7 with elevation angle of 25.64 had the smallest distance travelled. The relationship between the elevation angle of design and their angle of rotation in heave motion under three type of wave condition had presented in Fig. 4.

Table 11 Angle of Rotation Analysis under different type of wave condition in pitch motion

Design	Elevation angle, θe	Distance Travelled, m		
		Minimum	Average	Maximum
1	90.00	3.994	5.540	7.174
2	67.38	3.726	5.516	7.164
3	50.19	3.573	5.495	7.163
4	43.83	3.542	5.486	7.128
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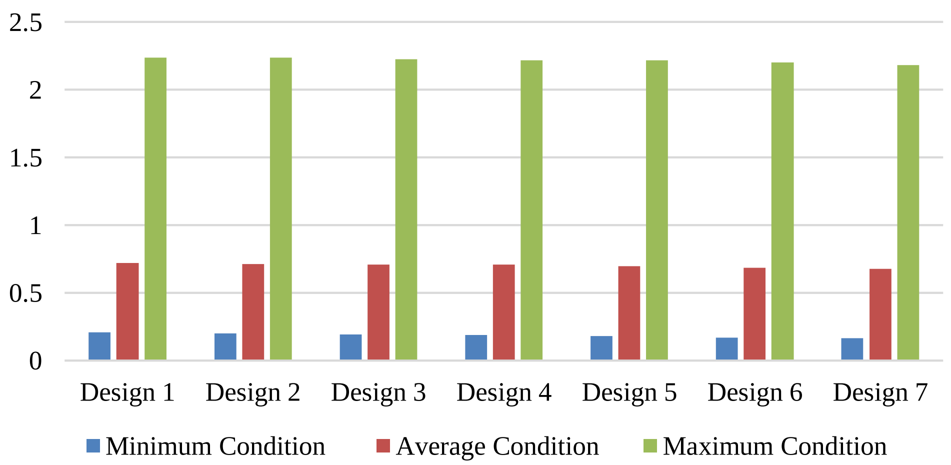

Fig. 4. Distance travelled of design in pitch motion in different type of wave condition.

4.0 Conclusion

Prior to this study, there was no record of any studies of the floating platform for microalgae cultivation. During the ideal generation for the design of floating platform, the key performance in microalgae system and the stability is important for the cultivation of microalgae on the sea. This study then focused on the simulation of the motion of floating platform by using Hydrodynamic Diffraction and Hydrodynamic Responses, ANSYS Aqwa. The result had proved that the stability of the design inversely proportional to the elevation angle of the design. Hence, the design with a larger elevation angle had greater angle of rotation in pitch motion and the distanced travelled in heave motion. Overall, design 1 with a/b ratio of 1.0 and the angle of elevation of 90° was getting a largest movement in pitch and heave motion. Thus, design1 is the most suitable design for the floating platform to cultivate the microalgae.

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