SHAPE GEOMETRY OF FLOATING OSCILLATING WATER COLUMN FOR WAVE ENERGY CONVERTER AT LOW WAVE HEIGHT CONDITION

MUHAMAD AIMAN BIN JALANI

MASTER OF SCIENCE
(MECHANICAL ENGINEERING)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

2020

SHAPE GEOMETRY OF FLOATING OSCILLATING WATER COLUMN FOR WAVE ENERGY CONVERTER AT LOW WAVE HEIGHT CONDITION

MUHAMAD AIMAN BIN JALANI

Thesis submitted to the Centre for Graduate Studies, Universiti Pertahanan Nasional Malaysia, in fulfilment of the requirements for the Degree of Master of Science (Mechanical Engineering)

February 2020

ABSTRACT

The Oscillating Water Column (OWC) is one of the most promising Wave Energy Converter (WEC) concepts in terms of practicality, survivability, and efficiency. This study was done to design and investigate the performance of floating OWC for WEC in low wave height condition. In the past few decades, different ideas, designs and devices have been put forward to extract energy from high heave wave condition, therefore this research addresses to extract energy from low heave wave condition. Pugh Matrix method was used to select the type of WEC to be study. The Backward Bent Duct Buoy (BBDB) was selected and three different back bottom corner shapes of BBDB were developed. The experiment was conducted in a 3D wave basin at National Hydraulic Research Institute of Malaysia (NAHRIM). Wave heights of 0.05 m to 0.15 m with a wave period of 1 s to 5 s were used in regular wave condition. Results showed that water column characteristics of the BBDB for different bottom corners were quite similar in terms of pressure, water elevation and airflow rate at the nozzle outlet. In addition, it was found that the optimum wave height and wave period for all BBDB models were 0.15 m and 1.6 s, respectively. The highest performance of the BBDB was produced by the BBDB with a curve bottom corner shape with an efficiency of 1.50 followed by BBDB with square bottom corner shape with an efficiency of 1.20 and BBDB with 45^{o} bottom corner shape with an efficiency of 0.9. Overall, the obtained results provided important insights in selecting the BBDB as a best design for WEC. It can be proposed that the curve bottom corner shape is the most efficient BBDB performance in low wave height conditions. This is due to the minimising energy losses around corners compared to the sharp edges. Moreover, it is also found that the resonance

frequency help to increase the performance of the BBDB regardless the back bottom corner shapes. Thus, the observation was attributed to the suitability of floating OWC WEC in low wave height condition.

ABSTRAK

Turus Air Berayun (TAB) adalah salah satu konsep Penjana Tenaga Ombak (PTO) yang paling menjanjikan dari segi kepraktisan, daya tahan, dan kecekapan. Kajian ini dilakukan untuk mereka bentuk dan menyelidiki prestasi TAB terapung untuk PTO dalam keadaan ketinggian ombak rendah. Dalam beberapa dekad yang lalu, idea, reka bentuk dan peranti yang berbeza telah dikemukakan untuk mengekstrak tenaga dari keadaan ombak tinggi, oleh itu penyelidikan ini adalah untuk mengekstraksi tenaga dari keadaan ombak rendah. Kaedah *Pugh Matrix* digunakan untuk memilih jenis PTO yang akan dikaji. *Backward Bent Duct Buoy (BBDB)* dipilih dan tiga bentuk sudut bawah belakang BBDB yang berbeza dibina. Eksperimen ini dilakukan di lembangan ombak 3D di Institut Penyelidikan Hidraulik Nasional Malaysia (NAHRIM). Ketinggian ombak dari 0.05 m hingga 0.15 m dengan jangka waktu ombak 1 s hingga 5 s digunakan dalam keadaan ombak biasa. Hasil kajian menunjukkan bahawa ciri lajur air BBDB untuk sudut bawah yang berbeza sangat serupa dari segi tekanan, ketinggian air dan laju aliran udara di saluran keluar muncung. Di samping itu, didapati bahawa ketinggian ombak dan tempoh ombak optimum untuk semua model BBDB masing-masing 0.15 m dan 1.6 s. Prestasi tertinggi BBDB dihasilkan oleh BBDB dengan bentuk sudut bawah lengkung dengan kecekapan 1.50 diikuti oleh BBDB dengan bentuk sudut bawah persegi dengan kecekapan 1.20 dan BBDB dengan bentuk sudut bawah 45^{o} dengan kecekapan 0.9. Secara keseluruhan, hasil yang diperoleh memberikan pandangan penting dalam memilih BBDB sebagai reka bentuk terbaik untuk PTO. Dapat dicadangkan bahawa bentuk sudut bawah lengkung adalah prestasi BBDB yang paling efisien dalam keadaan ketinggian ombak rendah. Ini disebabkan oleh

mengurangkan tenaga yang hilang di sekitar sudut berbanding dengan tepi yang tajam. Selain itu, didapati bahawa frekuensi resonans membantu meningkatkan prestasi BBDB tanpa mengira bentuk sudut bawah belakang. Oleh itu, pemerhatian tersebut dikaitkan dengan kesesuaian TAB PTO terapung dalam keadaan ketinggian ombak rendah.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Merciful and the Most Compassionate. All praise to Allah, the Lord of the world and peace be upon Muhammad, His servant and messenger, I managed to complete this project successfully. Firstly, I would like to express my sincere gratitude to my supervisor, Assoc. Prof. Ir. Dr. Rosdzimin bin Abdul Rahman, for his invaluable advices, guidance and encouragement throughout the preparation of this thesis. His profound knowledge and professional insight are of great value to me. His instructions not only on the research methodology but also on the truth in life mentor to the people now I am.

I would also like to thank Ir. Dr. Mohd Rashdan bin Saad for his suggestions, discussions and encouragement going through the completion of this thesis. Thank you very much for always helping and guiding me in this project.

Special thanks are also given to my parents especially my beloved father and mother, Jalani Abdullah and Suzana Zakaria, for their love and support throughout my life. I want to express my love and thanks to my wife, Nurul Kauthar Ahlaamie Binti Pakrudin. Also, my brothers and sisters, for all their support and motivation from the beginning until the end of this project. Their continuous love, care, encouragement and patience are of utmost importance to me.

Furthermore, the work that I have completed during the completion of my program would not have been possible without the support of. Last but not the least, I would like to thank everybody who are important to this thesis especially my partner project, Nur ‘Izzati Binti Mohmad Ismail for his guidance and I want to thank all of the individuals who have always provided their encouragement throughout my graduate career and who have contributed massively to the success of my project and academic Masters in Universiti Pertahanan Nasional Malaysia (UPNM).

Acknowledgement for partial support from Akaun Amanah Industri Bekalan Elektrik (AAIBE), under Grant No.- UPNM/2018/AAIBE-KETTHA/TK/1/P4.

Thank all of you so much.

APPROVAL

The Examination Committee has met on 10th February 2020 to conduct the final examination of Muhamad Aiman Bin Jalani on his degree thesis entitled 'Shape Geometry of Floating Oscillating Water Column for Wave Energy Converter at Low Wave Height Condition'.

The committee recommends that the student be awarded the Master of Science (Mechanical Engineering).

Members of the Examination Committee were as follows.

Prof. Madya Ir. Dr. Mohd Zaid bin Othman
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Chairman)

Dr. Zulkiffli bin Abd. Kadir
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Internal Examiner)

Dr. Azizuddin bin Abd Aziz
Faculty of Engineering
Universiti Malaysia Pahang
(External Examiner)

APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Master of Science (Mechanical Engineering)**. The members of the Supervisory Committee were as follows.

Assoc. Prof. Ir. Dr. Rosdzimin bin Abdul Rahman
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Main Supervisor)

Ir. Dr. Mohd Rashdan bin Saad
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

Dr. Mohamad Faizal bin Abdullah
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

Ir. Dr. Balamurugan a/l Annamalai Gurunathan
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

Ir. Dr. Abd Rahim bin Mat Sarip
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Student's full name : Muhamad Aiman Bin Jalani

Date of birth : 19th August 1995

Title : Shape Geometry of Floating Oscillating Water Column for Wave Energy Converter at Low Wave Height Condition

Academic session :

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

I further declare that this thesis is classified as:

☐ **CONFIDENTIAL** (Contains confidential information under the official Secret Act 1972)*

☐ **RESTRICTED** (Contains restricted information as specified by the organisation where research was done)*

☐ **OPEN ACCESS** I agree that my thesis to be published as online open access (full text)

I acknowledge that Universiti Pertahanan Nasional Malaysia reserves the right as follows.

1. The thesis is the property of Universiti Pertahanan Nasional Malaysia.
2. The library of Universiti Pertahanan Nasional Malaysia has the right to make copies for the purpose of research only.
3. The library has the right to make copies of the thesis for academic exchange.

__________________	__________________________
Signature	**Signature of Supervisor/Dean of CGS/ Chief Librarian
__________________	__________________________
IC/Passport No.	**Name of Supervisor/Dean of CGS/ Chief Librarian
Date:	Date:

Note: *If the thesis is CONFIDENTAL OR RESTRICTED, please attach the letter from the organisation stating the period and reasons for confidentiality and restriction.

** Witness

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

RE	Renewable Energy
OWC	Oscillating Water Column
PTO	Power Take Off
BBDB	Backward Bent Duct Buoy
CO_2	Carbon Dioxide
UNGA	United Nation General Assembly
IEA	International Energy Agency
OES TCP	Ocean Energy System Technology Collaboration Program
TWh	Tera Watt hour
GW	Giga Watt
USA	United States America
OTEC	Ocean Thermal Energy Conversion
WEC	Wave Energy Converter
PA	Point Absorbers
DoF	Degrees of Freedom
EMEC	European Marine Energy Centre
AWS	Archimedes Wave Swing
SSG	Seawave Slot-cone Generator
kW	Kilo Watt
λ	Length of Wave
k	Wave Number
ω	Angular Velocity
h	Water Depth
T	Wave Period
η	Efficiency
ρ	Water Density
g	Gravity
ζi	Amplitude of Incident Wave
Cg	Group Velocity
B	Width of Model
$P(t)$	Gauge Pressure in Air Chamber

Pa	Pascal
Q(t)	Air Flow Rate at Model Orifice
CAD	Computer Aided Design
2D	Two Dimension
3D	Three Dimension
NAHRIM	National Hydraulic Research Institute of Malaysia
DAQ	Data Acquisition Qualification
GPS	Global Positioning System
L	Length of the BBDB
T_0	Natural Period
D	Draught of Water Column
S	Sectional Area of The Water Column
R	Radius
IMU	Inertial Measurement Unit
CFD	Computational Fluid Dynamic
UPNM	Universiti Pertahanan Nasional Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background Research

In the era of industrial revolution in the eighteenth century, humans began to use fossil fuel as their energy source. The world's population has annually increased at an alarming rate, thus increasing the use of natural resources.

Development in science and technology increasing rapidly; hence, the demand of the society for energy has increased in terms of energy consumption. The fossil fuel combustion emits large amounts of toxic gases and produces greenhouse effect. This led to global anomalous climate and extreme weather changes.

The destruction of the global environment had a serious impact on the humans and living environment. The occurrence of climate change in recent years had caused increased price of fossil fuel, energy shortages and greenhouse effect, alarming the countries to begun to look for a full range of alternative energy solutions. To reduce fossil fuel energy, some countries conducted studies and developed a variety of alternative energy to reduce carbon and cost. Currently, renewable energy is the most promising alternative energy; this includes the solar energy, wind energy, geothermal energy, biomass energy and ocean energy. Nevertheless, this study focused specifically on the ocean energy and wave energy.

1.1.1 Wave Energy Potential in Malaysia

Malaysia is surrounded by the sea and the coastline of Malaysia has a landform length of 1,448 km. Malaysia also has strong seasonal monsoon blows causing this country to always have turbulent waves on its surrounding sea and some areas. After evaluated by experts and scholars [1], the energy reserves of the wave are rich and can be developed to the highest level; thus, the wave energy reserve can be said to be very rich, which is contributed largely by the ocean. If the geographical advantage of Malaysia surrounded by the sea can be used properly, development and research with marine protection will contribute greatly and solve the problems of difficult energy consumption in Malaysia.

To reduce the nation's dependency on fossil fuel, Malaysia's government has implemented several energy policies as well as financial support for research and development on renewable energy (RE) particularly in the local universities. Ocean wave energy is known as one of the potential renewable sources in Malaysia as Malaysia comprises 2068 km of coastline in Peninsular Malaysia and 2607 km in East Malaysia [2].

Compared to tidal energy generated by the gravitational pull of earth, wave energy is converted from the wind energy and the potential energy carried by the waves that have travelled for a long distance in the ocean accompanied with little energy loss. Waves can be found limitless along the shoreline during the day and night. The continuous supply of the wave energy has provided Malaysia with a great opportunity to convert it into electrical energy. Other than that, it can be considered as the renewable energy source that is low cost, environmentally friendly and able to reduce the dependency on fossil fuel for electricity generation.

1.2 Problem Statement

Malaysia is a tropical paradise with many natural resources and surrounded by many islands. According to the Department of Survey and Mapping Malaysia, the country has 878 islands [3]. Malaysia's largest island consists of the states of Sabah and Sarawak, located in Borneo, the third largest island in the world shared with Brunei and Indonesia. However, most of the islands in Malaysia are made up of small islands (under 200 km^2), which are usually powered by standalone diesel systems due to their remote location from central power generation and distribution networks [4].

The difficulty of transporting diesel to a remote island and hard supply of electricity is the fate of people in remote villages [5]. This situation had worsened during the monsoon season where high tides and rough seas caused not only increased diesel price due to the risks involved, but also disruption to diesel supply to the islands.

To solve this, several solutions have been suggested such as creating the energy without the use of fossil fuels. This study was conducted to generate electricity from waves surrounding the island to replace fossil fuels.

1.3 Objective

The main aim of this study is to determine the optimum shape for the Floating Oscillating Water Column to provide the best performance in low heave wave condition. The specific objectives of this study are:

i. To design floating oscillating water column wave energy converter for low heave wave condition.

ii. To develop back bottom corner of Backward Bent Duct Buoy (BBDB) in low heave wave.

iii. To evaluate the performance of floating oscillating water column wave energy converter for low heave wave condition.

1.4 Research Scopes

The scopes of this research include:

(i) Malaysia wave condition

• A floating OWC was tested and adapted based on Malaysia wave condition.

• Wave fluctuation pattern or wave spectrum same with Malaysia condition.

(ii) Type of Liquid

• The experimental water type does not behave as the actual ocean water type, which less dense compare to salty ocean water that may cause the occurrence of non-optimum power output measurement

(iii) Floating offshore OWC devices

• A floating OWC centred at a circular floating platform with a finite width was analytically modelled to investigate the effects of the floating OWC system and characteristic inside the chamber on hydrodynamic performances and extraction primary efficiency.

• The geometry similarities of the floating OWC prototype and the 3D model floating OWC would be slightly varied due to the limitation of workmanship and fabrication tool.

(iv) Backward Bent Duct Buoy (BBDB)

• A floating OWC model was done following the BBDB concept [6] and scale dimension [7].

1.5 Significance of Study

The optimum design of floating OWC bottom profile as concluded in this study may help to improve power efficiency of the future floating OWC structures. This study will be continued with real scale fabrication and installation that may help to ease the community of isolated islands in terms of environment sustainability and economic cost. In addition, this project will be the pioneer in Malaysia to contribute to home grown technology in Malaysia. Moreover, theories and techniques involved during this study may contribute as supporting information to the future projects on the parametric optimisation of floating OWC.

1.6 Thesis Outline

This report is succeeded by Chapter 2 where literature reviews are presented and commented. Chapter 3 describes the methodology and work plan of this study. After that, Chapter 4 presents the design selection and experimental results along with discussions. Lastly, conclusion and recommendations of this study are presented in Chapter 5.