DESIGN, MANUFACTURING, AND TESTING OF OFFSHORE OSCILLATING WATER COLUMN

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ABSTRACT

This report focuses on the comprehensive design, manufacturing, and testing of an offshore oscillating water column (OWC) system aimed at harnessing the power of ocean waves for electricity generation. The OWC system operates by exploiting the pressure fluctuations inherent in ocean waves, converting them into a continuous airflow that drives a turbine to produce electricity. The design phase of the OWC system encompasses meticulous selection of appropriate materials, structural design considerations, and accurate modeling of its performance characteristics. Meanwhile, the manufacturing process entails the fabrication and assembly of various components, including the wave chamber, turbine, and generator. The testing phase encompasses a series of rigorous assessments, encompassing laboratory testing, numerical simulations, and field testing.

The objective of this report is to contribute to the advancement of offshore OWC systems while shedding light on the challenges and opportunities inherent in their design, manufacturing, and testing. By offering practical insights into each aspect of the OWC system's life cycle, this work aims to address the current gaps in knowledge and facilitate the development of efficient and cost-effective solutions for electricity generation from ocean waves.

The offshore OWC system described in this report represents a promising avenue for generating electricity from a sustainable and renewable source. With the escalating demand for clean energy sources, this technology has the potential to make a significant contribution to the global energy transition. By utilizing the immense power of ocean waves, this system offers a practical and scalable solution for meeting electricity needs while reducing reliance on fossil fuels.

To validate the OWC system's performance, a comprehensive testing program is undertaken. Laboratory testing enables controlled experiments to evaluate the system's response under varying wave conditions, providing valuable data for performance analysis and refinement. Numerical simulations complement the experimental findings, offering a deeper understanding of fluid dynamics and aiding in the optimization of the system's design.

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“In the name of Allah, the Most Gracious and the Most Merciful.”

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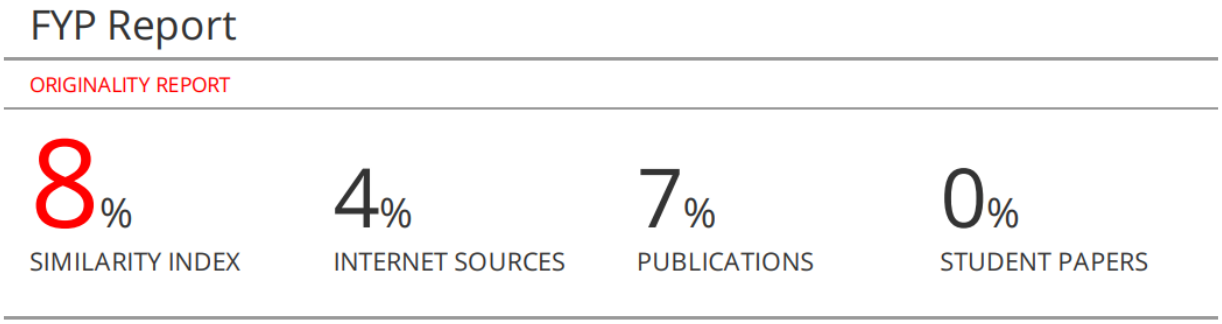

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Chapter 1 # INTRODUCTION

The utilization of renewable energy sources has become increasingly important in recent years due to the rising demand for energy, the depletion of fossil fuels, and the growing concern over climate change. Among the various forms of renewable energy, ocean energy has emerged as a promising source of clean, sustainable power. The oscillating water column (OWC) is a device that harnesses the energy of ocean waves to generate electricity. The OWC operates on the principle of capturing the pressure fluctuations of the ocean waves and converting them into a steady flow of air that drives a turbine to generate electricity.

This report focuses on the design, manufacturing, and testing of an offshore OWC system. The goal of this research is to develop a practical and cost-effective solution for generating electricity from ocean waves using an OWC. The design of the OWC system includes the selection of appropriate materials, structural design, and simulations using ANSYS Fluent. The manufacturing process involves the fabrication and assembly of the OWC wave chamber. Testing of the OWC system includes laboratory testing in available water tunnel, and numerical simulations.

Problem Statement:

Due to massive depletion of Natural Resources, it is extremely important to find a way towards the sustainable future of clean energy harvesting. This has caused an increase in the prices of energy. Moreover, Natural Resources of energy causes the greenhouse effect. The absence of a thorough understanding and optimization of offshore oscillating water column (OWC) designs for wave energy conversion is the issue this study attempts to solve. Current knowledge gaps limit the potential of OWC devices and prevent the efficient extraction of wave energy. This project seeks to close this gap by using CFD simulations to create an optimized OWC design, verifying the findings with a scaled-down physical model and measuring air pressure inside the chamber, all of which will progress the development of sustainable wave energy conversion technology.

Deliverables:

Although OWCs show potential for converting wave energy, the ideal design factors for maximizing energy extraction and efficiency remain poorly understood. Consequently, this project attempts to close this gap by concentrating on the following research goals and outputs:

Design of OWC

The creation of a thorough design for the offshore OWC system is the project's main output. To assure the system's integrity and functionality, this includes figuring out the proper proportions, geometrical arrangements, and structural issues. The design will be based on a thorough analysis of the current literature, pertinent regulations, and industry best practices.

CFD Simulations of OWC for Optimum Design

Advanced computational tools like Ansys Fluent are used in CFD simulations to assess and improve the OWC performance. These simulations will shed light on the system's hydrodynamic behavior, including its flow patterns, interaction with waves, and effectiveness in capturing energy. The iterative design process will be guided by the simulation findings, allowing for modifications and improvements to create the best OWC design.

Scaled Down Model based on Froude Number Similarity

A scaled-down physical model of the OWC will be built in order to verify the CFD simulation results and better understand the behavior of the system. To ensure that the flow conditions between the physical model and the actual offshore OWC are similar, the model will be built using the Froude number similarity design principles. The physical model will allow for experimental measurements and observations, providing useful information for contrasting with the outcomes of the simulation.

Measurement of Air Pressure in the Air Chamber

The project's measurement of air pressure inside the OWC system's air chamber is another crucial component. This calls for the creation and use of a manometer which approximately record the dynamic pressure changes that occur during wave interaction. The simulation findings will be verified using the measured pressure data, and the performance of the OWC under various wave circumstances will be evaluated.

Chapter 2 # LITERATURE REVIEW

By successfully capturing power from waves even in severe open-sea circumstances, Oscillating Water Column demonstrated its promise as a sustainable and renewable energy source. Extensive testing found that the effectiveness of power generation by the device was influenced by a variety of factors, including the height and frequency of the waves, as well as the device's orientation in relation to the direction of the waves. Notably, the gadget demonstrated a respectable ability to absorb a significant quantity of energy from the waves, with a maximum power absorption efficiency of around 50%. Furthermore, the device displayed remarkable stability and the ability to withstand wave heights of up to 6 meters, making it ideal for deployment in offshore sites. Overall, the findings suggest that the "Mighty Whale" wave power device has the potential to be an effective and reliable source of renewable energy in open-sea conditions, although further research and development may be needed to optimize its performance. **lii**

Extensive investigations into the Ocean Wave Energy Converter (OWC) device revealed its remarkable ability to efficiently convert wave energy into usable power. The device exhibited an increased power generation efficiency with higher wave height and period, highlighting its effectiveness in harnessing the energy potential of waves. Notably, optimal performance was achieved when the water column height was precisely tuned to match the prevailing wave conditions, resulting in maximum power absorption at resonance. Additionally, the incorporation of a central baffle within the OWC chamber proved to be a valuable enhancement, as it effectively reduced the air flow rate while simultaneously increasing the air pressure, further improving the device's performance. The water level within the OWC chamber was discovered to exert a significant influence on the overall performance of the device. Remarkably, a lower water level within the chamber corresponded to a higher power output, indicating the importance of careful calibration in achieving optimal results. These findings collectively suggest that the fixed offshore OWC device holds great promise as a reliable and effective renewable energy solution, particularly in regions abundant in wave energy resources. To fully realize its potential, further research and development efforts are warranted. Specifically, attention should be directed towards refining the design of the OWC chamber and exploring innovative approaches for tuning the water column height. These endeavors will aid in maximizing the device's performance and efficiency, ensuring its viability as a sustainable energy source for the future. By capitalizing on the significant advancements achieved thus far, we can pave the way for a greener and more resilient energy landscape powered by the immense potential of wave energy. [2]

The dual-chamber oscillating water column (OWC) technology outperforms the single-chamber model in terms of power generation efficiency. This is mostly due to improved air column calibration and the associated greater air pressure. Furthermore, the inclusion of a central baffle within the OWC chamber improves device performance by increasing air pressure and decreasing air flow rate. The study also demonstrates that wave height and duration influence the device's performance, with more power production recorded at greater wave heights and lower power output observed at shorter wave intervals. Numerical simulations are thought to be useful for precisely forecasting the hydrodynamic performance of OWC devices, allowing for design and functionality optimization. These findings imply that the dual-chamber OWC device with a central baffle has substantial potential as a dependable and efficient source of renewable energy, particularly in wave energy-rich regions. However, more research and development are required to improve the device's performance and efficiency, with a particular focus on the design of the OWC chamber and the fine-tuning of the air column. [3]

The underwater geometry of the OWC device has a significant impact on its hydrodynamic performance. Notably, devices with flared design outperform their cylindrical counterparts in terms of effectively capturing wave energy. This discovery emphasizes the significance of carefully evaluating the geometry and design of the OWC device while attempting to maximize wave energy conversion. Furthermore, the OWC device's position relative to the sea surface appears as a crucial component influencing energy acquisition. Devices that are placed closer to the sea surface are more effective at capturing wave energy. This study shows the need of careful device placement and the potential for maximizing energy extraction by strategically positioning the OWC device in respect to the dynamic features of the waves. Furthermore, the inclusion of a center baffle within the OWC chamber has been recognized as a vital component that improves the device's overall performance. This baffle design increases air pressure within the chamber while decreasing the rate of air flow. The center baffle adds to increased energy conversion and enhances the overall efficiency of the OWC device by optimizing these factors. To fully optimize the device's performance and efficiency, more research and development are required. Particular attention should be paid to the device's positioning in respect to the sea surface and the design of the OWC chamber. These paths have enormous promise for progressing the field and realizing the full potential of OWC devices as a reliable and sustainable source of renewable energy. [4]

A unique oscillating water column (OWC) design that outperforms existing OWC designs in terms of power production and energy conversion efficiency. This outstanding performance can be attributed to the device's unusual design and the use of a dual chamber mechanism. The experimental analysis demonstrated that the OWC device captures wave energy well across a wide range of wave frequencies and amplitudes. Furthermore, higher wave heights and longer wave durations were shown to improve the device's power output, suggesting its versatility and reactivity to changing wave circumstances the inclusion of the central baffle aided in optimizing energy conversion, increasing the overall efficiency of the OWC device. The experimental results were in great agreement with numerical simulations performed using computational fluid dynamics (CFD), demonstrating CFD's effectiveness as a dependable method for forecasting the hydrodynamic performance of OWC devices. The successful correlation of actual and simulated data highlights the importance of using CFD simulations to optimize device design and fine-tune performance parameters. These findings highlight the unique OWC wave energy converter's significant potential as a reliable and effective source of renewable energy, particularly in places with extensive wave energy resources. Nonetheless, additional research and development are required to properly maximize the device's performance and efficiency, with a particular emphasis on refining the architecture of the OWC chamber and fine-tuning the water column height. Addressing these issues could lead to even greater breakthroughs in the device's ability to harness wave energy and contribute to sustainable energy generation.[5]

The form and size of the OWC chamber were discovered to have a significant impact on device efficiency. Tapered chambers were found to be more effective than cylindrical chambers, whereas larger chambers produced more power. These findings emphasize the significance of carefully adjusting the geometric properties of the OWC chamber in order to improve energy conversion and overall device performance. Furthermore, the position of the OWC device relative to the sea surface was discovered to be an important factor influencing energy acquisition. Proximity to the sea surface was discovered to improve the effectiveness of wave energy capture, indicating that the positioning of OWC devices should be carefully considered to maximize their energy-harvesting capacity. The study also acknowledged the need of including a center baffle within the OWC chamber. This design aspect was seen to improve the device's performance by managing air flow rate and regulating air pressure. The center baffle enhanced energy conversion and device efficiency by successfully increasing air pressure while decreasing air flow. Furthermore, the study demonstrated the effectiveness of numerical simulations as a tool for estimating the hydrodynamic performance of OWC devices. These simulations, which make use of advanced computational fluid dynamics (CFD) techniques, provide useful insights and allow researchers to optimize device design and performance. By utilizing numerical simulations, researchers can explore a wide range of parameters and scenarios to enhance device efficiency and energy conversion. Considering the collective findings, it becomes evident that optimizing the shape, size, and positioning of the OWC chamber plays a crucial role in elevating the hydrodynamic performance of OWC devices. Through careful design considerations and parameter adjustments, such as implementing tapered chambers, positioning devices closer to the sea surface, and incorporating central baffles, it is possible to achieve higher power output and greater energy conversion efficiency. [6]

The research reveals significant discoveries about the hydrodynamic performance of oscillating water column (OWC) devices in conjunction with an offshore detached breakwater. The incorporation of this breakwater was discovered to offer considerable improvements in device efficiency by reducing the amount of wave energy reaching the devices, resulting in a more stable environment. This improvement improved the overall performance of the OWC devices, allowing for more energy conversion and usage. The analysis also revealed that the spacing and orientation of the OWC devices within the array had a significant impact on their performance. Devices that were placed closer to each other and aligned parallel to each other produced more power. This discovery highlights the significance of carefully adjusting the layout of devices inside the array in order to improve energy capture and overall array efficiency. In keeping with the prior discussion, numerical simulations have proven to be an effective technique for forecasting and optimizing the hydrodynamic performance of both OWC devices and offshore detached breakwaters. These simulations, which make use of advanced computational methodologies, let researchers to evaluate alternative design parameters and performance scenarios, allowing them to optimize device and breakwater design to improve efficiency and reliability When the total data are considered, it is clear that the combination of an offshore detached breakwater with an array of OWC devices has tremendous promise as a reliable and efficient source of renewable energy, particularly in locations rich in wave energy resources. This integrated system has various benefits, including greater performance, stability, and cost-effectiveness. However, more research and development are required to fully optimize the design of both the OWC devices and the offshore detached breakwater. Researchers may accelerate breakthroughs and support wider acceptance of these integrated systems as a feasible and sustainable alternative for renewable energy generation by focusing on refining the device and breakwater design and examining the economic feasibility of offshore deployment. Finally, combining an offshore detached breakwater with an array of OWC devices represents a great opportunity to improve device performance and efficiency, resulting in a more reliable and cost-effective source of renewable energy. The findings highlight the importance of continuing research efforts to optimize the design of these systems and assess their economic viability for offshore deployment. The full potential of integrated OWC devices and offshore detachable breakwaters can be achieved through these efforts, considerably contributing to a cleaner and more sustainable energy future. [7]

The device's design, size, and number of chambers all have an impact on its performance. Larger devices with several chambers were found to capture wave energy more effectively, emphasizing the need of optimizing these design characteristics to enhance energy conversion and overall device performance. Furthermore, the position of the OWC device relative to the sea surface was discovered to be an important predictor of energy capture. Devices placed closer to the sea surface were found to be more effective at capturing wave energy. This study emphasizes the need of optimizing the location of OWC devices in order to maximize their energy-harvesting capability and overall performance. The study also highlighted the value of the modeling approach used, which proved to be a useful tool for forecasting the hydrodynamic performance of OWC devices. This modeling approach aided in the optimization of device design and performance characteristics, providing insights on how to improve efficiency and overall effectiveness. Furthermore, the data strongly imply that including a multi-chamber floating OWC device has enormous potential to considerably improve the performance and efficiency of OWC systems, providing a more reliable and cost-effective source of renewable energy. Researchers can achieve higher power output and increased energy conversion efficiency by refining the device design and embracing the concept of multi-chamber floating devices. It should be noted that additional research and development efforts are required to properly optimize the design of OWC devices and assess the economic feasibility of offshore deployment. Researchers can increase the viability and broad adoption of OWC devices as a prominent and sustainable alternative for renewable energy generation by refining the device's design and addressing economic concerns. Finally, the findings emphasize the importance of improving the design of OWC devices, notably in terms of shape, size, and number of chambers. Furthermore, the incorporation of multi-chamber floating devices has enormous promise in terms of increasing the hydrodynamic performance of OWC systems, resulting in increased power output and improved energy conversion efficiency. [8]

The study throws light on several critical discoveries concerning the hydrodynamic performance of oscillating water column (OWC) devices. One noteworthy observation is that the geometry of the device is critical to its performance. Larger water column height and chamber width devices were shown to be more successful in capturing wave energy. This emphasizes the importance of improving the geometric parameters in order to maximize energy extraction and improve overall device performance. In addition, the study investigated the use of a turbine to induce damping inside the water column. This approach was discovered to improve the hydrodynamic performance of OWC devices. The turbine improved the device's efficiency and overall energy conversion capacities by reducing the air flow rate and raising the pressure difference between the chamber and the atmosphere. The incorporation of such dampening methods demonstrates the possibility for additional performance enhancements in OWC systems. Another interesting observation is the asymmetry of the OWC devices. Horizontal asymmetry was shown to provide more power than vertical asymmetry. This highlights the importance of carefully examining the symmetry of the device during the design process in order to optimize its hydrodynamic performance and energy collecting capabilities. The research also emphasized the need of numerical simulations as a trustworthy method for forecasting the hydrodynamic performance of OWC devices. These simulations, which make use of computational models, allow researchers to experiment with different design configurations and parameters, allowing them to optimize device performance and efficiency. Increasing the hydrodynamic performance of OWC devices by optimizing their geometry and utilizing the benefits of turbine-induced dampening. This optimization results in increased power output and improved energy conversion efficiency. Nonetheless, more research and development is required to properly optimize the design of OWC devices and determine the economic feasibility of deploying them offshore. [9]

The study offered compelling conclusions about the hydrodynamic performance of oscillating water column (OWC) devices, using both numerical simulations and experimental measurements to support the numerical model's correctness. The concordance between the two methodologies adds confidence to the numerical simulations and underlines their usefulness in anticipating the OWC device's hydrodynamic behavior. Furthermore, the properties of the incoming waves have a considerable influence on the operation of the OWC device. Higher wave heights and longer wave periods were found to correspond to higher power production, underscoring the need of taking wave circumstances into account when measuring and optimizing OWC device performance. The OWC device's shape and size emerged as crucial aspects in its hydrodynamic performance. A greater chamber diameter and a smaller throat diameter were discovered as design elements that influenced power output positively. Researchers can improve the device's energy conversion efficiency and overall effectiveness by improving these dimensions. The OWC device has a lot of potential as a dependable and efficient source of renewable energy, especially in areas with a lot of wave energy resources. OWC devices can play a critical role in reaching renewable energy targets and lowering reliance on conventional energy sources with proper design optimization and smart deployment. Furthermore, investigating the deployment of OWC devices on land may bring further benefits. By contemplating the deployment of these devices in terrestrial environments, researchers may be able to harness specific traits and environmental variables to boost their hydrodynamic performance even more. This technique allows for innovative integration with existing infrastructure and maximizes the possibility for OWC devices to be widely adopted as a viable renewable energy alternative. While the findings provide interesting insights, more research and development is required. It is critical to optimize the OWC device's design in order to realize its full potential and analyze the economic feasibility of land-based deployment. Researchers can advance OWC technology into commercial viability and speed its inclusion into the renewable energy market by tackling these issues.[10]

Numerical simulations are used to anticipate the hydrodynamic behavior of oscillating water column (OWC) devices, demonstrating their potential for optimizing device design and performance. The capacity to precisely mimic the intricate interactions between waves and the OWC device is critical in advancing renewable energy technology. Furthermore, the importance of wave conditions and the arrangement of the OWC device in relation to the incoming waves in influencing its performance. The gadget produced the most power when it was perfectly aligned with the waves, demonstrating the importance of understanding wave characteristics during deployment and operation. Researchers can maximize energy capture and overall efficiency by carefully situating the OWC gadget. Furthermore, the advantages of a partially stationary, partially floating architecture for the OWC gadget. This novel strategy improves hydrodynamic performance by reducing horizontal forces operating on the device and boosting the system's natural frequency. This revolutionary design idea opens up new options for improving the effectiveness and stability of OWC devices, reinforcing their promise as reliable renewable energy sources. The ability to adjust the design of the device and use the benefits of a partially stationary and partially floating configuration can result in significant increases in power output and energy conversion efficiency. Additional research and development activities are required to fully harness the capabilities of OWC technology. The device's performance can be improved by optimizing its design parameters, which include chamber dimensions, wave characteristics, and location. Furthermore, determining the economic feasibility of installing such devices in offshore environments will be critical in encouraging their widespread adoption and integration into the renewable energy landscape. Researchers can advance the transition to sustainable energy sources and speed the realization of a cleaner and more environmentally friendly future by exploiting these findings and continuing to develop OWC device design and deployment tactics. [11]

The study found that numerical simulations accurately reflected the complicated and nonlinear hydrodynamic behavior of the oscillating water column (OWC) platform, giving a dependable tool for assessing its performance under diverse wave circumstances. The precision of these simulations demonstrates their value in determining the platform's efficiency and effectiveness in turning wave energy into electricity. Furthermore, the analysis emphasized the benefits of utilizing numerous OWC chambers inside the platform. This arrangement improved energy conversion efficiency by allowing for the capture and utilization of a greater amount of the wave energy. The platform shows increased potential as a renewable energy solution by optimizing the exploitation of wave resources. The position and size of the OWC chambers have a significant impact on the platform's performance. The best results were obtained when the chambers were placed at the platform's edges and had a reasonable aspect ratio. These findings highlight the significance of thorough process design and optimization for optimal performance and energy conversion efficiency. Researchers can realize the full potential of the OWC platform by carefully examining the strategic placement and proportions of the chambers. These effects, which are inherent in wave interactions, have significant significance and must be carefully considered during the design and optimization phases. Accounting for and effectively simulating these nonlinear impacts is critical to ensuring the platform's dependability and efficiency. Researchers may fully utilize the platform's capabilities by precisely developing and optimizing the platform's geometry, as well as strategically positioning the OWC chambers. To achieve optimal performance and enable the integration of OWC technology into the renewable energy environment, the study underlines the significance of precisely accounting for and modeling nonlinear hydrodynamic effects throughout the design and evaluation stages. [12]

The use of numerical simulations to evaluate the performance of oscillating water column (OWC) devices under different wave situations, offering precise predictions of their hydrodynamic behavior. These simulations were useful for assessing the efficiency of OWC devices and their responses to various wave types. Furthermore, the utilization of several chambers in OWC devices resulted in large increases in power output. Devices having a wide chamber aspect ratio and a tight gap between the chambers performed very well. This conclusion emphasizes the significance of improving chamber design in order to optimize power generating potential. The performance of the OWC devices was discovered to be significantly reliant on incident wave properties such as wave height, period, and direction. These criteria were critical in determining the devices' energy conversion efficiency. As a result, building OWC systems that can effectively adjust to changing wave conditions is critical for reaching peak performance. Furthermore, the effect of various design parameters on OWC device performance. To further understand the impact of chamber size, shape, and turbine positioning on energy extraction efficiency, these variables were explored. The findings highlighted the importance of carefully selecting these design parameters to create a balance between optimizing energy extraction efficiency and reducing device wave reflection. Numerical simulations play an important role in analyzing the performance of offshore OWC devices. It stressed the importance of thorough design and optimization methods that consider a variety of elements such as wave conditions, chamber design, and turbine placement. Researchers can efficiently increase energy extraction efficiency while decreasing wave reflection by taking these aspects into account, hence improving the overall performance and viability of OWC devices as a renewable energy solution in offshore areas. [13]

Air turbines are critical components of oscillating water column (OWC) wave energy systems because they transform the oscillating air pressure generated by waves into useful mechanical or electrical energy. However, optimizing the design of air turbines in OWC systems necessitates careful study of the numerous elements that influence their performance. The characteristics of the waves at the specific area are a crucial driver of air turbine design. The wave characteristics, such as wave height, period, and direction, have a direct impact on the turbine's working circumstances. Furthermore, the intended output power and overall efficiency of the turbine are critical design factors. Researchers used a variety of approaches, including numerical simulations, experimental tests, and analytical models, to build efficient air turbines for OWC wave energy systems. These methodologies enable a thorough understanding of the turbine's performance under various conditions and aid in optimizing its design. Another key component determining the performance of OWC systems is the type of turbine used. Horizontal and vertical axis turbines are extensively utilized, and each has its own set of benefits and drawbacks. The most appropriate turbine type is determined by characteristics such as efficiency, dependability, and ease of maintenance. Aside from turbine type, implementing variable pitch or variable speed control systems can improve air turbine efficiency in OWC wave energy systems. These control systems allow the turbine to adjust to changing wave conditions, hence improving energy extraction. Furthermore, integrating numerous turbines inside an OWC system can boost overall energy collection efficiency dramatically. To avoid interference or inferior performance, the spacing and configuration of the turbines must be carefully considered. It underlines the importance of more research and development to improve the performance of these systems. Researchers can continue to develop the design of air turbines by using numerical simulations, experimental testing, and analytical models, taking into account elements such as wave characteristics, output power needs, turbine type, and control systems. Ultimately, these efforts will contribute to the advancement of efficient and reliable OWC wave energy systems, supporting the transition to sustainable and renewable energy sources.[14]

SRTs distinguish themselves as a form of turbine with the unusual capacity to work in both directions, allowing them to harness the positive and negative flows of water generated by waves. SRTs differ from standard unidirectional turbines in that they can efficiently capture energy from both the upward and downward strokes of waves. As a result, they hold the prospect of improved energy conversion efficiency in wave power generation. SRT designs can be adapted to individual purposes, resulting in the development and testing of numerous designs. This versatility enables customization based on variables such as intended use case and desired performance characteristics. As a result, researchers have investigated a variety of SRT designs in order to maximize their efficiency and versatility. Multiple factors influence the efficiency of SRTs, including the turbine's design, the particular features of the waves at the installation site, and the current operational conditions. These parameters have an impact on the performance and energy conversion capacities of SRTs as a whole, stressing the need of taking them into account during the design and implementation stages. Furthermore, SRTs provide versatility in terms of integration into many types of wave energy systems. They work well in a variety of systems, including point absorbers, oscillating water columns, and overtopping devices. This adaptability allows SRTs to contribute to a variety of wave energy conversion methods. Despite SRTs' great potential, difficulties exist that demand additional research and development. To guarantee optimal performance, the complex dynamics associated with these turbines must be properly understood and accounted for. Furthermore, the ability of SRTs to survive high wave conditions without being damaged is a crucial matter that must be carefully considered. It explains the design and performance considerations for these turbines. Continued SRT-focused research and development activities have the potential to make major improvements in the efficiency and reliability of wave energy systems. The renewable energy sector may utilize the tremendous potential of wave power for a sustainable future by investigating the complexities of SRTs and addressing present difficulties. [15]

The use of a Savonius rotor in an Oscillating Water Column (OWC) system to increase power output by absorbing energy from oscillating air flow caused by waves. It includes a number of critical discoveries that shed light on the performance and implications of an OWC system using a Savonius rotor. The incorporation of a Savonius rotor into an OWC system has been shown to improve its power generation capabilities. The rotor effectively collects energy from the system's oscillating air flow, resulting in higher power production. Multiple parameters influence the performance of an OWC system using a Savonius rotor, including rotor size and shape, wave characteristics, and OWC chamber design. These characteristics contribute to the system's overall efficiency and power output. The experimental results showed that the OWC system with a Savonius rotor consistently outperformed the system without a rotor, with the rotor contributing to a 75% increase in power production. This advancement demonstrates the Savonius rotor's tremendous potential for improving the energy conversion efficiency of OWC systems. Furthermore, the spacing between the rotor and the OWC chamber was discovered to affect the system's power production. Smaller space between the rotor and the chamber resulted in better power production, underscoring the necessity of optimizing component design and arrangement for best performance. While the Savonius rotor can enhance power output, its efficiency was found to be quite low, with a maximum efficiency of around 20%. This shows that there is still potential for improvement and highlights the importance of continued research and development efforts to increase the overall efficiency and efficacy of OWC systems with Savonius rotors. It also underlines the importance of ongoing research to improve the design and performance of these systems. [16]

The most important characteristics of the device's structural integrity, stability, and resilience. The structural integrity of the OWC device is preserved under normal working conditions. It is known, however, that damage can occur as a result of the influence of extreme environmental pressures. The study proposes employing measures to assure the device's survivability, such as incorporating a strong and redundant design, to mitigate this. Changes in mooring line tension affect the device's stability. An active tensioning system can be used to manage and alter the mooring line tension to ensure stability. This allows the gadget to resist a variety of climatic conditions while maintaining functionality and operational efficiency. The OWC system's resiliency is one prominent feature. Even if a component fails, the OWC chamber can continue to function. This feature improves the device's durability and operating continuity, reinforcing its appropriateness for offshore conditions. In order to improve the device's survivability, redundancy was built into the design. This is possible by combining numerous OWC chambers and redundant mooring lines. Such redundancy techniques add structural support and redundancy in crucial components, increasing the device's overall survivability in harsh environments. It underlines that the width of the OWC chamber should be less than 0.2 times the width of the testing tank in order to accurately recreate ocean wave conditions and ensure the validity and reliability of experimental results. These devices can provide better dependability and operating efficiency in demanding offshore settings by addressing structural integrity, stability control, system resilience, and redundancy methods. These findings highlight the importance of thorough design considerations in ensuring the long-term success and viability of offshore floating moored OWC devices. [17]

Chapter 3 # METHEDOLOGY

The project consists of designing and testing an offshore oscillating water column. The whole project is divided into two domains. The first one is manufacturing of the testing model and the second one is the verification of the results through CFD analysis.

Manufacturing

The manufacturing process can only be done when the design calculations along with the material selection are finalized. The design calculations and the material selection are an important step in the manufacturing of the testing model.

Design Selection

There are many designs of the oscillating water column along with many configurations notably Single chamber, Double chamber, Multiple chambers, Fixed oscillating water column, Oscillating water column with mooring lines. The literature review was done to get a good understanding of the design prospects along with different configurations.

A single chamber oscillating water column was selected with two configurations for testing, one is fixed with a mount and the other is with mooring lines. The chamber has a front draft, along with a base plate attached to the rear draft of the chamber. An orifice at the top of the chamber is given to measure the pressure generated at the top with each incoming wave.

Design Calculations

The size of the testing model is restricted to the size of the testing apparatus. As the conditions resemble sea wave conditions, there are several constraints which are to be dealt with.

1. Effect of side walls
2. Waves Back pressure

3. Wave turbulence

The effect of the side walls of the testing section is minimized by making the ratio of model width to chamber width less than 0.2. This value is obtained from literature review in the following paper.

The Back pressure of the waves is dealt with by making outlet damping zone in the testing rig and using Outlet plenum. The purpose of the Outlet Plenum is to connect the wide-angle diffuser with the piping system to drain out the flow. The geometry of the Outlet Plenum is designed properly to avoid any type of irregularities occurring in the model which leads to the reverse flow or back pressure in the system which will disturb the results in the test section.

The wave turbulence is controlled using honeycomb before the start of the testing section and contraction chamber is also used to attain the high velocities.

Different parameters of Testing Chamber*:*

The wave flume testing section has the following dimensions of length, width, and height.

Table 3-1 Wave Flume Parameters

Sr. No.	Parameters	Symbol	Value
1	Testing Section Length	L	$2\ m$
2	Testing Section Width	W	$0.4\ m$
3	Testing Section Height	H	$0.5\ m$
4	Water depth range	h	$0 - 0.4\ m$
5	Flow Velocity Range	V	$0 - 0.5\ m$

Design Calculations:

The schematic diagram is given below:

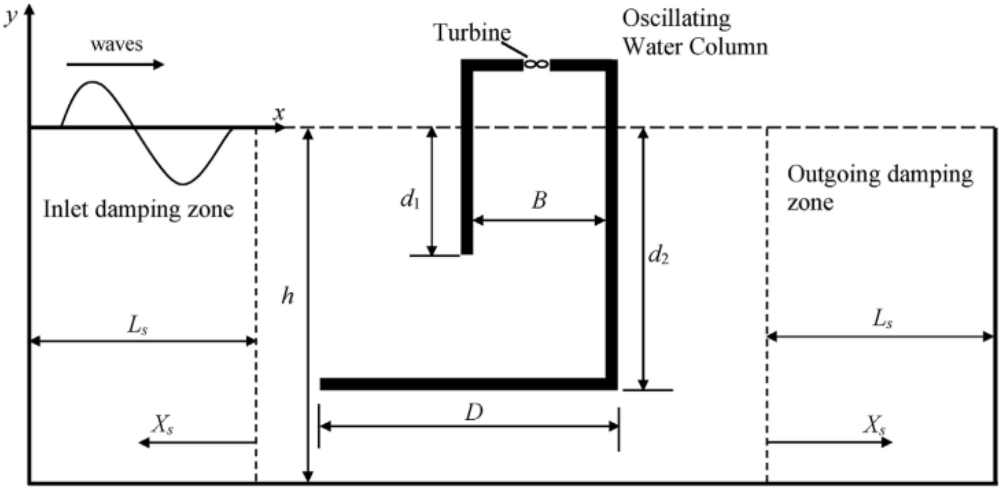


Figure 3-1 Schematic Diagram

Table 3-2 Model Parameters

Sr. No.	**Parameters**	**Description**	**Symbol**
1	Front wall draft	Depth of front wall	d_1
2	Rear wall draft	Depth of rear wall	d_2
3	Water depth	Depth of water	h
4	Model length	Length of Model	B
5	Base plate length	Length of base plate	D
6	Model width	Width of model	w

The optimal values for the ratios of front draft and rear wall draft to water depth along with length of base plate to length of model are taken from **[13]** and model width to tank width from **[17]**.

$$\frac{d_1}{h} = 0.25 \tag{1}$$

$$\frac{d_2}{h} = 0.5 \tag{2}$$

$$\frac{D}{B} = 2 \tag{3}$$

$$\frac{w}{W} \leq 0.2 \tag{4}$$

Model Dimensions Calculations:

To neglect the effect of side walls on the model the ratio given in **[17]**, the width of model is calculated as:

$$\boldsymbol{w} = \boldsymbol{W}(0.18)$$

$$w = (0.4\,m)(0.18)$$

$$\boldsymbol{w = \ 0.072\,m}$$

Now the front draft value is calculated using equation 1 ,

$$Front\ draft = d_1 = 0.25(h)$$

$$Frontdraft = d_1 = 0.25(0.4m)$$

$$\boldsymbol{Front\ draft = d_1 = 0.1\,m}$$

Now the rear draft value is calculated using equation 2,

$$Rear\ draft = d_2 = 0.5(h)$$

$$Rear\ draft = d_2 = 0.5(0.4\ m)$$

$$\boldsymbol{Rear\ draft = d_2 = 0.2\ m}$$

The value of the chamber length is calculated using equation 3.

The value of B is taken as 0.16 m, which is in accordance with our testing section whose length is 2 m.

$$\frac{D}{B} = 2$$

$$\frac{D}{0.16} = 2$$

$$D = 0.16 \times 2$$

$$\boldsymbol{D = 0.32\ m}$$

Froude Number Similarity:

The Froude number similitude law is used to make a 1:50 model whose dimensions are calculated above. The flow with 0.4 m water depth represents 20 m water depth flow of an open channel. The average speed of the flow is 0.25m/s.

The Froude number is:

$$Fr = \frac{V}{\sqrt{gh}}$$

$$Fr = \frac{0.25\ m/s}{\sqrt{9.81 m/s^2 0.4 m}}$$

$$Fr = 0.126$$

Material Selection:

The initial material proposed was plexiglass but there are a few issues associated with it.

1. The manufacturing must be done by hand.
2. Cutting of plexiglass must be done by hand so the dimensions are not as accurate.
3. The sheets are then to be assembled by glue whose joints are subjected to leakages.

The finalized material is PLA or Polylactic Acid because the model will be 3D printed and it is more rigid as compared to the plexiglass one.

Manufactured Model:

The model was 3-D printed with the selected material. Its mounts were drilled with an M6 drill and then reamed to smooth surface. The mounts were made from wood. The manufactured part

Figure 3-2 3D Printed Model

was then covered with Matt black paint for better visualization of waves. The final part is shown below:

CAD Model:

The 3D CAD model was designed for 3D printing of the chamber. The following CAD model was designed using SolidWorks.

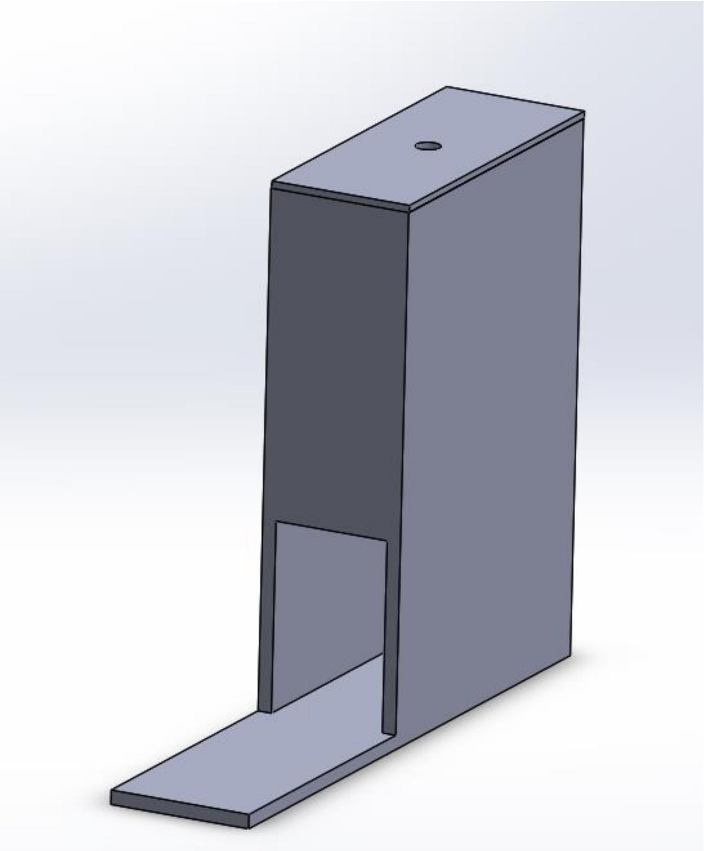


Figure 3-3 3D CAD Model for 3D Printing

Simulations:

To verify the result of experimentation and the selection of optimum design parameters simulation was done on ANSYS Academic 2023. Since it was a Multiphase flow, so Volume of Fluid (VOF) method was used for simulation. The Volume of Fluid (VOF) method is well-suited for simulating offshore oscillating water columns (OWCs) due to its ability to accurately track free surface flows and model the interaction between air and water. The VOF method captures the dynamic behavior of the water column inside the OWC, accurately representing the changing shape and position of the water-air interface affected by incident waves. It handles multiphase flow, allowing for the accurate modeling of the water and air phases. The method's robust framework captures interface dynamics, including wave breaking and reforming, reflections, and air compressibility effects. Additionally, the VOF method can be coupled with structural solvers to account for fluid-structure interaction.

Model Sketching:

The model was sketched on ANSYS Design Modeler. The sketched model for simulations was as follows:

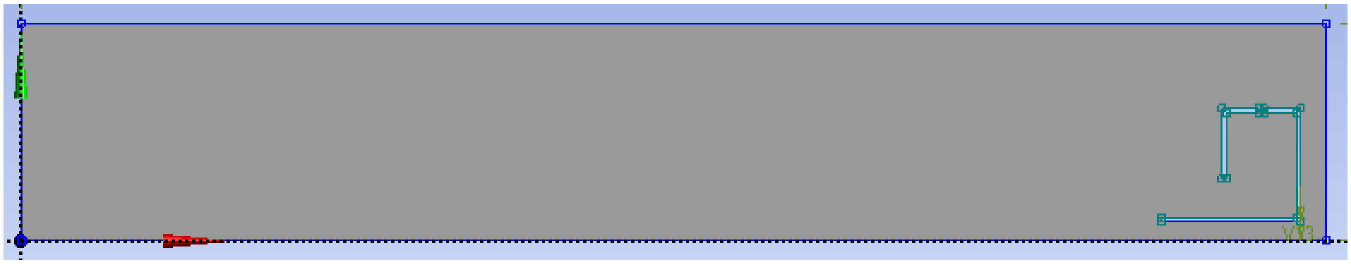


Figure 3-4 Sketch of Flow Domain and Chamber

The flow domain set was of 3 x 0.5 m. The dimensions of the chamber were collected from the CAD Model. Closeup view focusing on the chamber is shown as follows:

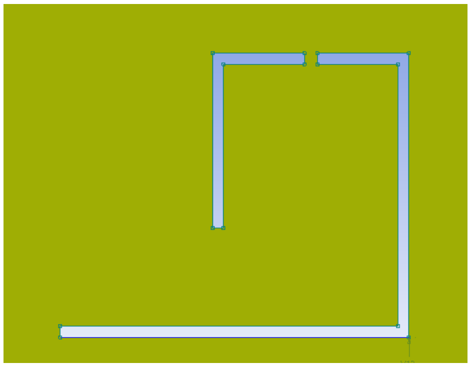


Figure 3-5 Chamber close-up view

Meshing:

After calculation of dimensions and designing geometry on the ANSYS Design Modeler the mesh was generated. Mesh was generated by adding refinement and edge sizing to improve mesh quality. There was a total of 38693 nodes and 37998 elements. The final mesh was as follows:

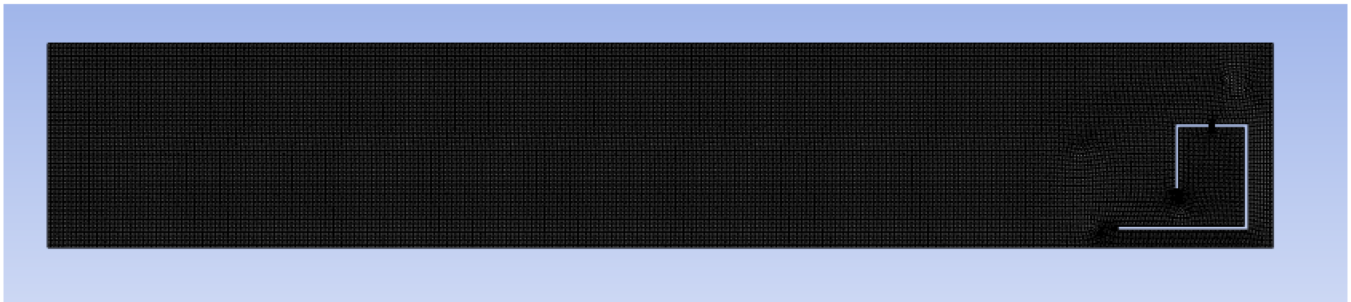


Figure 3-6 Mesh Generated for CFD

The named selection was generated for easy application of boundary conditions in Ansys Fluent. The following named boundary conditions were used.

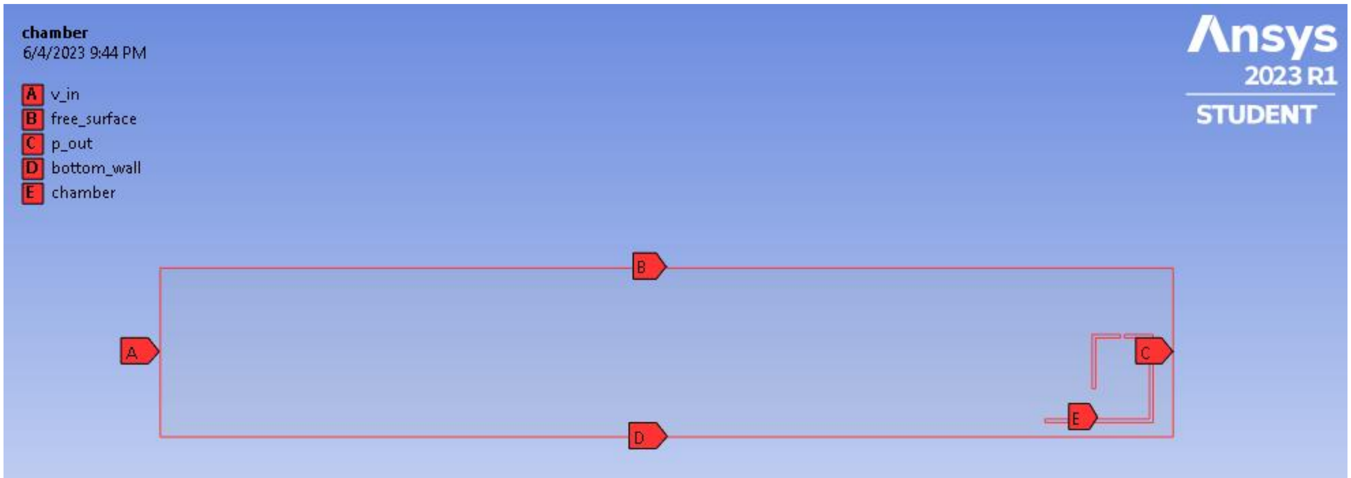


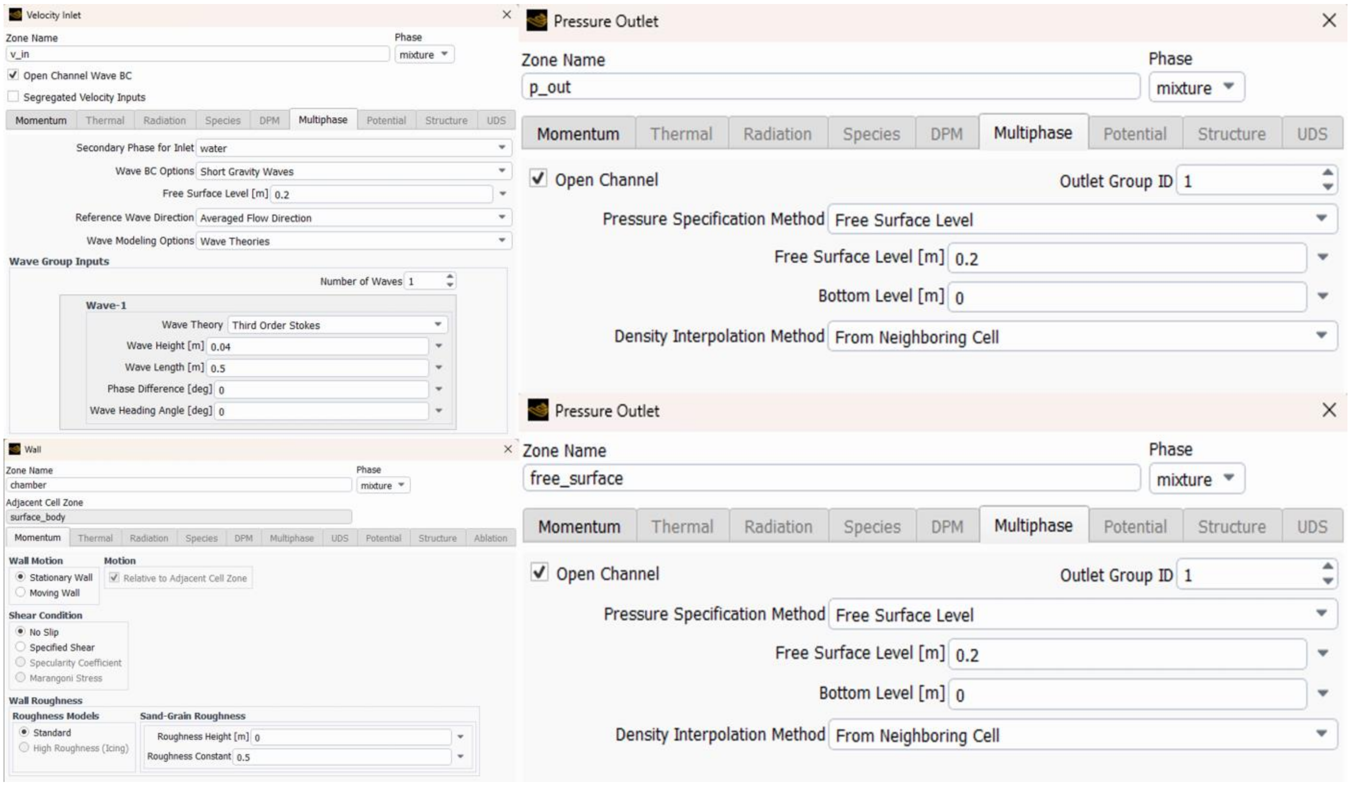
Figure 3-7 Named Selections

Starring the Simulations:

After meshing was done the ANSYS Fluent setup was made. As our flow was multiphase so the simulation model selected was VOF Model. We preferred the use of k-epsilon model as for oscillating water column (OWC) simulations it is suitable due to its computational efficiency, robustness, simplicity, and ability to capture the turbulent flow characteristics relevant to OWCs. Its efficiency makes it suitable for large computational domains and long simulation times, while its extensive validation and established empirical coefficients ensure reliable results. The model's simplicity facilitates implementation and calibration for OWC-specific data, and it can accurately capture turbulence effects under unsteady flow conditions. Although more advanced turbulence models may be necessary for highly complex flows, the k-epsilon model strikes a balance between accuracy and computational resources in OWC simulations.

The Boundary Conditions were set for v_in as velocity inlet, chamber and the bottom wall as standard walls while the free_surface and p_out were categorized as Pressure outputs.

The option of numerical breach enabled to neglect the effect of reflecting waves from the wall.



Velocity Inlet

Zone Name: v_in

Phase: mixture

☑ Open Channel Wave BC

☐ Segregated Velocity Inputs

Secondary Phase for Inlet: water

Wave BC Options: Short Gravity Waves

Free Surface Level [m]: 0.2

Reference Wave Direction: Averaged Flow Direction

Wave Modeling Options: Wave Theories

Wave Group Inputs

Number of Waves: 1

Wave-1

Wave Theory: Third Order Stokes

Wave Height [m]: 0.04

Wave Length [m]: 0.5

Phase Difference [deg]: 0

Wave Heading Angle [deg]: 0

Pressure Outlet

Zone Name: p_out

Phase: mixture

☑ Open Channel

Outlet Group ID: 1

Pressure Specification Method: Free Surface Level

Free Surface Level [m]: 0.2

Bottom Level [m]: 0

Density Interpolation Method: From Neighboring Cell

Wall

Zone Name: chamber

Phase: mixture

Adjacent Cell Zone: surface_body

Wall Motion

● Stationary Wall

○ Moving Wall

Motion

☑ Relative to Adjacent Cell Zone

Shear Condition

● No Slip

○ Specified Shear

○ Specularity Coefficient

○ Marangoni Stress

Wall Roughness

Roughness Models

● Standard

○ High Roughness (Icing)

Sand-Grain Roughness

Roughness Height [m]: 0

Roughness Constant: 0.5

Pressure Outlet

Zone Name: free_surface

Phase: mixture

☑ Open Channel

Outlet Group ID: 1

Pressure Specification Method: Free Surface Level

Free Surface Level [m]: 0.2

Bottom Level [m]: 0

Density Interpolation Method: From Neighboring Cell

Figure 3-8 Boundary Conditions Applied

The solution was then initialized to obtain the results of the simulation.

Chapter 4 # RESULTS AND DISCUSSION

Experimentation:

Experiments on the 3D printed model were done in the water flume. The wave flume serves as a controlled environment where scaled-down models or prototypes of the OWC can be tested under various wave conditions. This experimentation helps researchers and engineers understand the complex interactions between waves and the OWC, providing essential data for design optimization and performance evaluation. Within the wave flume, waves are generated to mimic real ocean conditions. These waves interact with the OWC's structure, causing the water column inside to oscillate. By measuring the resulting wave-induced motion, scientists can evaluate the device's efficiency in extracting energy from waves.

Experimental Setup:

The model was mounted on the water tunnel with the help of Studs and Nut **M6.** A U-Tube manometer was used to measure the pressure head at the orifice of the OWC. The parameters which were held as constants are shown below:

Table 4-1 Wave Parameters

Sr. No.	Parameters	Symbol	Value
1	Wave Amplitude	A	4 cm
2	Wave Period	T	0.98 s
3	Wave Frequency	ω	6.4 rad/s
4	Front Wall Draught	d_1	Variable

Test 1:

The test was conducted at $\boldsymbol{d_1 = 1\ cm = 0.01\ m.}$ Measured Water head = **1.7 cm**

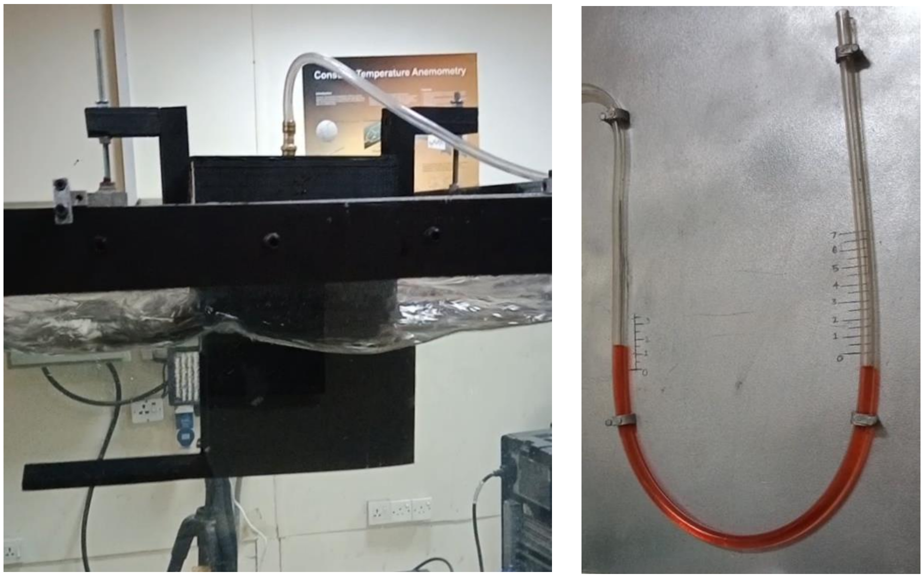


Figure 4-1 Test Trial 1

Test 2:

The test was conducted at $\boldsymbol{d_1 = 2\ cm = 0.02\ m.}$ Measured Water head = **1.5 cm**

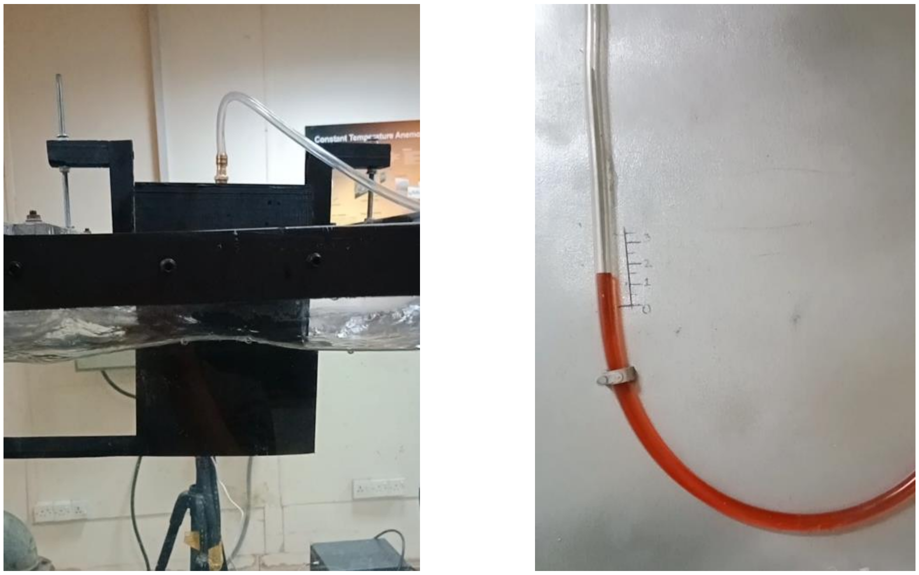


Figure 4-2 Test Trial 2

Test 3:

The test was conducted at $\boldsymbol{d_1 = 6\ cm = 0.06\ m.}$ Measured Water head = **0.8 cm.**

Figure 4-3 Test Trial 3

Test 4:

The test was conducted at $\boldsymbol{d_1 = 8\ cm = 0.08\ m.}$ Measured Water head = **0.6 cm.**

Figure 4-4 Test Trial 4

Experimental Results

The values of pressure head and velocity are calculated using the following equations.

$$\boldsymbol{P} = \boldsymbol{\gamma}\mathbf{h_w} \tag{5}$$

$$\boldsymbol{V} = \sqrt{\frac{\boldsymbol{2P}}{\boldsymbol{\rho}}} \tag{6}$$

The value of velocity is calculated using dynamic pressure.

Table 4-2 Experimental Values

Sr. No.	**Test**	**Front wall Draft**	**Water head**	**Pressure**	**Velocity**
		d_1	**h_w**	**P**	**V**
		m	**m**	**Pa**	**m/s**
1	1	0.01	0.017	167	0.578
2	2	0.02	0.015	147	0.542
3	3	0.06	0.008	78	0.396
4	4	0.08	0.006	59	0.343

Plots:

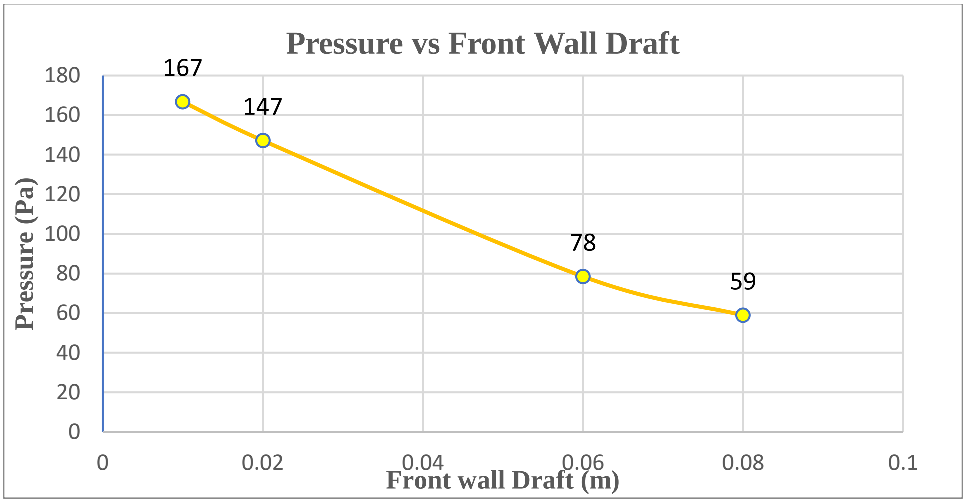


Figure 4-5 Graph between Pressure & Front Wall Draft

The following graph illustrates the relationship of pressure and front wall draft. The value of pressure decreases as the front wall draft increases. It is inversely related to the value of front draft.

The reason is that as the front wall draft increases, the volume of air enclosed in the oscillating water column decreases. Thus, effectively decreasing the mass flow rate and the pressure generated at the orifice.

To keep the pressure at an optimal rate an oscillating water column with varying height can be used to maximize the efficiency of OWC.

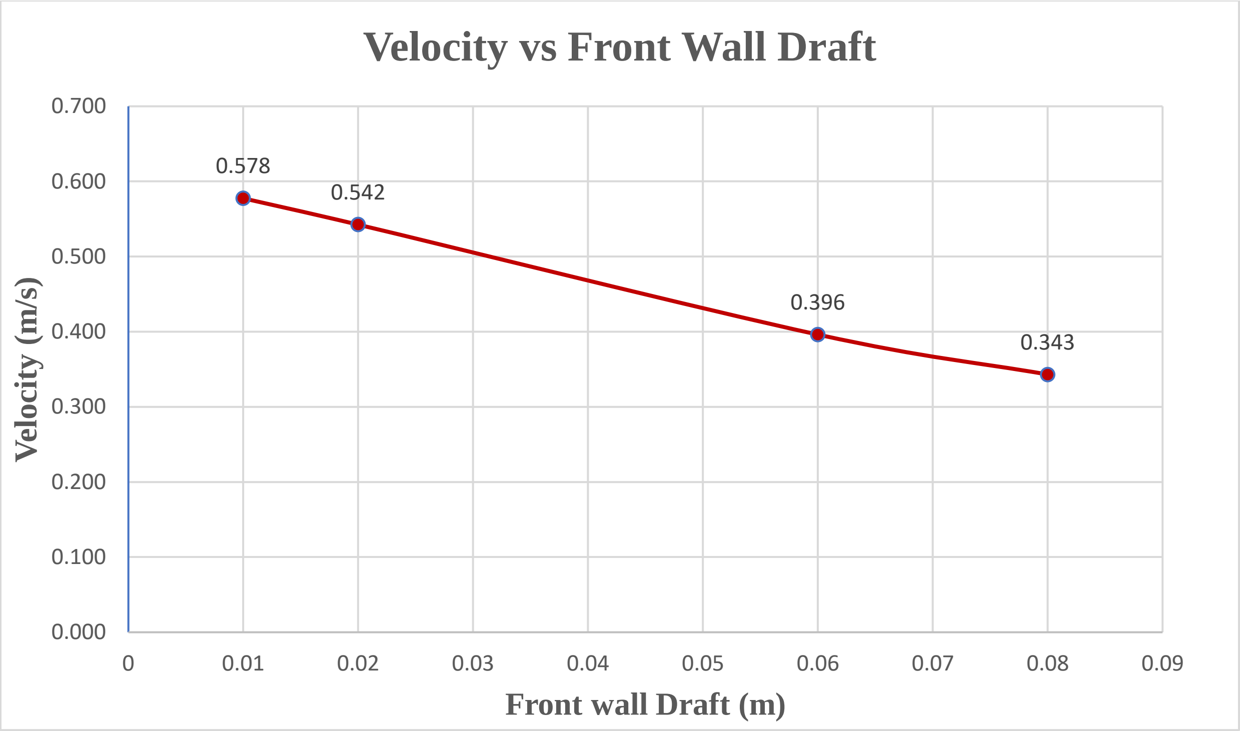


Figure 4-6 Graph between Velocity & Front wall Draft

The following graph illustrates the relationship of velocity and front wall draft. The value of pressure decreases as the front wall draft increases. It is inversely related to the value of front draft.

The reason is that as the front wall draft increases, the volume of air enclosed in the oscillating water column decreases. Thus, effectively decreasing the mass flow rate and the velocity generated at the orifice.

To keep the velocity at an optimal rate an oscillating water column with varying height can be used to maximize the efficiency of OWC.

Simulation Results:

The simulation results were obtained as expected for the simulations performed. At the start the simulations were not that stable but after the 70 iteration the simulation gained stability and the solution met the convergence criteria. The solution at the 115th time stamp is taken as follows:

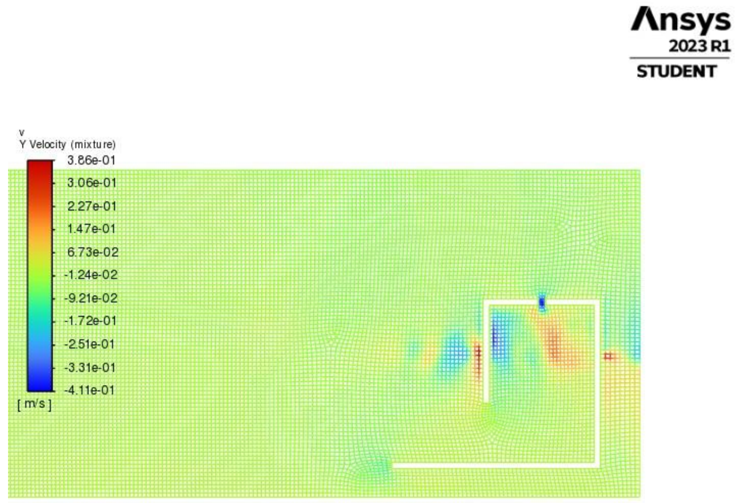


Figure 4-7 Y-velocity contour at 115th time stamp

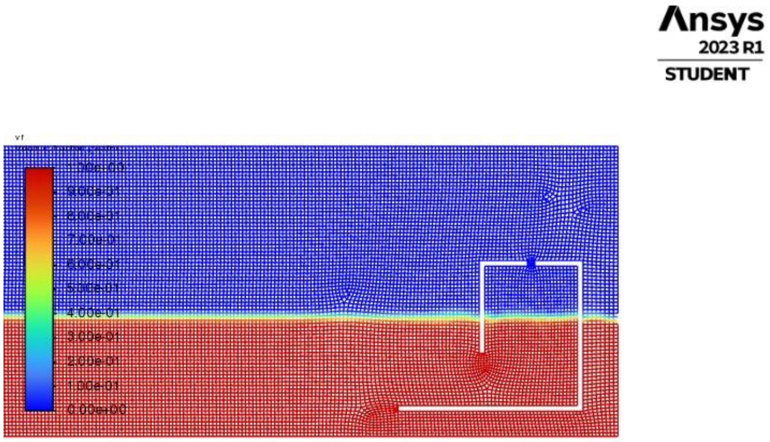


Figure 4-8 Volume Fraction Contour at 115th time stamp

It can be observed that at the orifice the velocity is negative and indicates that the decreasing wave has reached the orifice. The velocity at the outlet is found to be -0.411 m/s. It is to be noted that red area in volume fraction tells us that it is water, while blue area is the air region. The intermediate green region in between is the numerical error. Also, at the 175th time stamp the rising wave reached which caused the positive air velocity. The following shows the result of the simulation at 175^{th} time stamp:

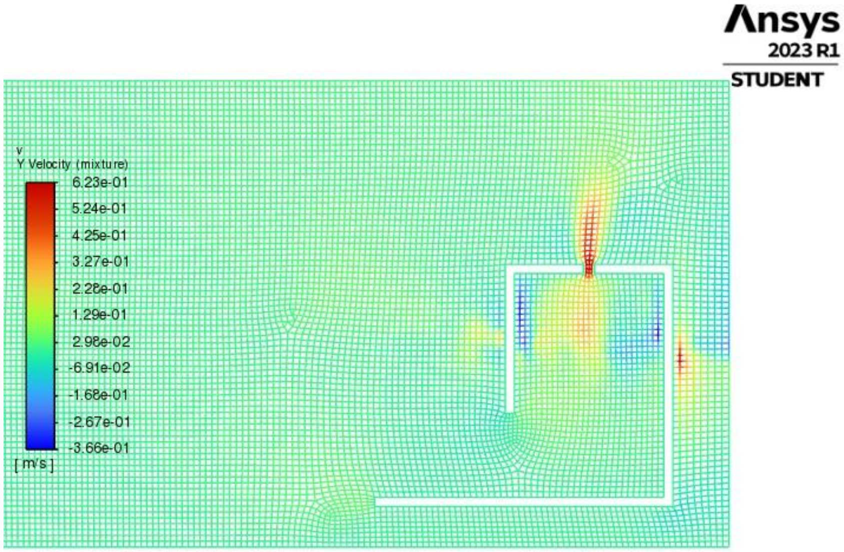


Figure 4-9 Y-velocity contour at 175th time stamp

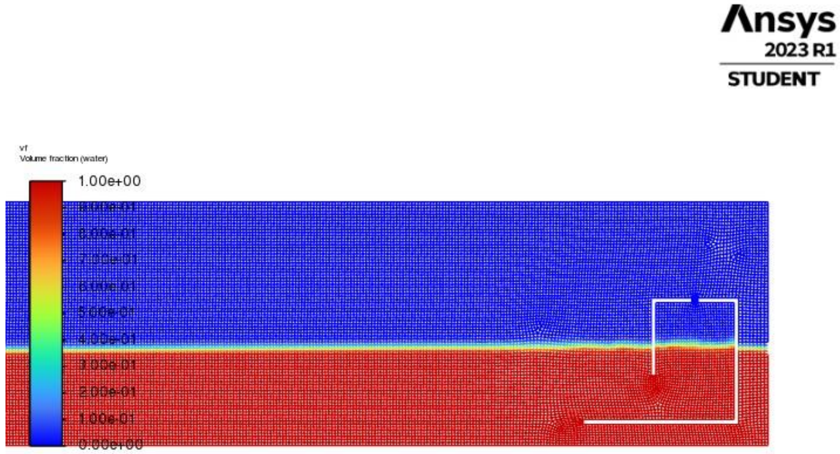


Figure 4-10 Volume Fraction at 175th time stamp

The output air velocity at the orifice for the rising wave is positive and has a value of 0.623 m/s.

Chapter 5 # CONCLUSION AND RECOMMENDATIONS

Conclusion:

This report focuses on the comprehensive design, manufacturing, and testing of an offshore oscillating water column (OWC) system aimed at harnessing the power of ocean waves for electricity generation. The OWC system operates by exploiting the pressure fluctuations inherent in ocean waves, converting them into a continuous airflow that drives a turbine to produce electricity. The design phase of the OWC system encompasses meticulous selection of appropriate materials, structural design considerations, and accurate modeling of its performance characteristics. Meanwhile, the manufacturing process entails the fabrication and assembly of various components, including the wave chamber, and its clamping mechanism. The testing phase encompasses a series of rigorous assessments, encompassing laboratory testing, and numerical simulations.

The objective of this report is to contribute to the advancement of offshore OWC systems while shedding light on the challenges and opportunities inherent in their design, manufacturing, and testing. By offering practical insights into each aspect of the OWC system's life cycle, this work aims to address the current gaps in knowledge and facilitate the development of efficient and cost-effective solutions for electricity generation from ocean waves.

The offshore OWC system described in this report represents a promising avenue for generating electricity from a sustainable and renewable source. With the escalating demand for clean energy sources, this technology has the potential to make a significant contribution to the global energy transition. By utilizing the immense power of ocean waves, this system offers a practical and scalable solution for meeting electricity needs while reducing reliance on fossil fuels.

To validate the OWC system's performance, a comprehensive testing program is undertaken. Laboratory testing enables controlled experiments to evaluate the system's response under varying wave conditions, providing valuable data for performance analysis and refinement. Numerical simulations complement the experimental findings, offering a deeper understanding of fluid dynamics and aiding in the optimization of the system's design.

Several proposals can be made for the future of the Offshore Oscillating Water Column (OWC) project to improve its efficiency, electricity generation potential, and pave the road for a sustainable energy future. One important suggestion is to incorporate a Wells turbine into the design, as they are specifically intended for OWC applications and can efficiently extract power from the oscillating air flow within the system. By adding a Wells turbine, the project may make use of its inherent self-rectifying properties, allowing power extraction from both the up and down strokes of the waves, increasing energy capture.

In order to improve the performance of the Wells turbine, extensive research and development are required. Computational fluid dynamics (CFD) simulations, among other things, can be used to examine and fine-tune the blade profile, chord length, and pitch angle. This iterative design method will aid in the attainment of optimal turbine performance, ensuring effective energy conversion from oscillating air pressure to electrical power.

It is proposed that larger-scale models of the OWC system be manufactured and tested to demonstrate scalability and real-world performance. To improve performance, durability, and convenience of manufacture, new manufacturing techniques such as additive manufacturing or advanced composite materials can be used. The project can overcome the limits presented by the size of the accessible water tunnel during the initial testing phase by leveraging this cutting-edge technology.

Integration with the electrical grid becomes critical as the OWC system progresses toward practical application. Working with electrical engineering specialists would be beneficial in building efficient power conversion and control systems. These systems will ensure that the electricity generated by the OWC system is seamlessly integrated into the existing power grid infrastructure, allowing for the effective distribution and consumption of renewable energy.

In addition to technical concerns, the environmental impact and economic feasibility of the OWC project must be considered. An environmental impact assessment will aid in determining the potential implications of large-scale OWC system deployment on marine ecosystems, coastal areas, and other pertinent aspects. This assessment will guarantee that the project is in accordance with sustainable practices and environmental legislation.

Furthermore, a detailed cost analysis is required to assess the economic sustainability of the OWC system. This study should take into account a variety of elements, including production costs, installation costs, operational and maintenance costs, and predicted revenue from electricity generated. Stakeholders may make educated judgments and find possibilities for enhancing the project's economic feasibility by precisely estimating the expenses and possible returns. Collaboration with academic institutions, industry professionals, and government organizations is strongly advised in order to benefit from their experience, resources, and support. Partnerships can provide access to advanced testing facilities, financial opportunities, and regulatory compliance guidance, hence expediting the development and deployment of the OWC system.

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