DESIGN AND FABRICATION OF AN OTEC SYSTEM FOR POWER GENERATION.

BY

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A FINAL YEAR PROJECT SUBMITTED TO THE DEPARTMENT OF MARINE ENGINEERING, FACULTY OF ENGINEERING, NIGERIA MARITIME UNIVERSITY OKERENKOKO DELTA STATE, IN PARTIAL FUFILLMENT OF REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING [B.ENG] DEGREE IN MARINE ENGINEERING

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ABSTRACT

Fossil fuels are the main source of energy in many countries including Nigeria but the reservation of fossil fuel decreases over time coupled with their usage which has a negative impact on the ecosystem. Ocean Thermal Energy Conversion (OTEC) is an innovative and sustainable method for harnessing renewable energy from the temperature difference between the surface sea water and cold deep-sea water and it has the potential to meet energy demands and also reduce the negative environmental impacts caused by fossil fuels. Therefore, the purpose of this project is to design and fabricate an efficient OTEC system for power generation. The objective of this study is to develop an efficient an efficient and environmentally friendly OTEC system that can produce clean electricity with minimal impact on the marine ecosystem. The project outlines the design process, including the selection of heat exchangers, working fluids and system components. It also discusses the construction and assembly of the OTEC system. The temperature gradient gotten from the difference between the warm surface sea water and cold deep-sea water can be utilized to produce no emission of electrical energy via renewable energy sources. Practically, the design encompasses development of a dependable model using ASPEN HYSYS software program to carry out the analysis of date such as surface sea water temperature, sea water temperature at a given depth, mass flow rate of the refrigerant, pressure of the refrigerant etc, obtained from Burutu river. Experimental results and performance evaluations are presented, highlighting the system's efficiency and power generation capabilities. The findings of this project underscore the potential of OTEC as a reliable renewable energy source. The OTEC system demonstrates promising results, offering a sustainable solution for coastal regions with access to temperature gradients in the ocean. The implications of this research extend to reducing greenhouse gas emissions and addressing the growing demand for clean energy sources.

CERTIFICATION

This is to certify that this project was carried out by AGBER CALEB TERPASE. (ENGG/MAE/18/19/034), DAN-SAMUEL WILFRED (ENGG/MAE/18/19/056), DURU THEOFREDRICK U. (ENGG/MAE/18/19/059), ONU SIXTUS C. (ENGG/MAE/18/19/109), and TIMOTHY VICTOR OSAS (ENGG/MAE/18/19/059) of Marine Engineering Department, Nigeria Maritime University, Okerenkoko, Delta State, Nigeria. This project was supervised, approved and accepted at meeting the partial requirement for the award of Bachelor of Engineering [B.ENG] Degree in Marine Engineering.

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Supervisor

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DECLARATION

Agber Caleb Terpase, Dan-Samuel Wilfred, Duru Theofredrick U, Onu Sixtus C and Timothy Victor Osas hereby declare that this project work titled **"Design and fabrication of an OTEC system for power generation"** submitted to the department of marine engineering, faculty of engineering, Nigeria Maritime University represents our original work and has not been previously submitted elsewhere or in this University for the award of any similar degree.

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TIMOTHY VICTOR OSAS	**DATE**

DEDICATION

This project is dedicated to God Almighty for his unconditional love, protection, provision and grace throughout the course of this project.

ACKNOWLEDGEMENT

We appreciate God almighty for the grace and help to carry out this project.

We wish to appreciate the efforts of the following persons who contributed immensely to the success of this project work. We want to start by appreciating the efforts, contribution and dedication of our HOD and project supervisor, Engr. Nelson Igoma, the members of staff of the department of marine engineering, Nigeria Maritime University, Okerenkoko and other staff whose efforts have contributed to the success of this project work.

We wish to heartily appreciate Pst and Mrs Wilfred Dan, Mr Palmer Odigie, Pst Success Odigie, Mr Favour Odigie, Mr and Mrs Umile Jacob, Mrs Comfort Agber, Hon Peter Agu, Mrs Peter Agu.

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Fossil fuels form the cardinal power source utilized by many countries in the world including Nigeria. The reservation of the fossil fuel decreases overtime. Their usage pollutes our ecosystem with harmful substances that affects human being and lead to greenhouse gas (GHG) emissions. The rises in global energy consumption, environmental concerns and the increase in fuel prices over the last decade have strengthened interest in the exploitation of renewable energy. The design, together with the investigation of a suitable carbon free energy generation becomes very necessary to avoid harmful emissions and also cater for the increasing energy demands. Renewable energies are encouraging backups to fossil fuels that could settle human's energy requirements and are maintained without harmfully affecting the environment. (Koohi-Fayegh and Rosen, 2020).

Ocean energy is a maintainable energy source that has a very enormous capability for delivering a vast amount of the world energy demands. It contains a large quantity of energy and it covers over seventy per cent of the planet earth’s surface (SOPAC, 2009; Ressurreição et al., 2011). Ocean Thermal Energy Conversion (OTEC) System uses the difference in the temperature that exists between the shallow waters and the deep waters in the ocean to operate a heat or steam engine (Magesh, 2010). The ocean surface behaves like a solar collector and has the potential to capture the heat energy form the sun (Khan et al., 2017). Ocean energy has several merits when compared with other maintainable sources like biomass, solar and wind. It is abundant in nature, preferably accessible, gives a lesser impact on the environment when compared with other renewable sources, and it is predictable. These merits give it a capability for electricity generation (Melikoglu, 2018). Ocean energy could give energy independence, desalination of sea water and also serve as a means of job creation. The Ocean is the world biggest solar receiver and storage of energy system and in a day, sixty million squares kilometers (60, 000, 000Km^2) of equatorial seas absorb the total ratio of solar radiation that is equitable to heat proportion of approximately two hundred and fifty billion barrels of oil (Alkhalidi *et al.*, 2014). According to the International Energy Agency (IEA), there are five techniques of exploiting the ocean energy. Some of these techniques are already implemented but some are still in the design level and they include; tidal power, tidal or marine current, wave power, temperature gradient and salinity gradient. Tidal and wave energy conversion has remarkably gained attention globally coupled with the technology of the generation of portable drinking water through desalination, hydrogen generation by electrolysis together with the supply of compressed-air to aquaculture (SOPAC, 2009; IEA, 2017). The position of electrical power production from different kind of renewable energy sources like wind, solar, hydraulic, geothermal, biomass, and ocean thermal energy conversion which is the concern of this research work, is constantly chronicled and the design of possible renewable energies are frequently studied (Bouraiou *et al.*, 2020; Kuang *et al.*, 2016; Østergaard *et al*., 2020). The design of renewable energy sources encompasses integrating difference sources of energy into hybrid systems like solar or wind energies which in turn gives ameliorated optimized power doubled with its management, operation and control plans (Shivarama and Sathish, 2015; Chamandoust *et al.*, 2020).

Ocean thermal energy conversion (OTEC) system is a system which utilizes the temperature gradient between hot surface seawater and cold deep seawater to propel a working fluid in a Rankine cycle to produce electric power. Surface seawater have temperatures with the range of 24^0C to 30°C, depending on the season, while deep seawater often does not change meaningfully by season and remains moderately steady in the range of 5^0C to 9°C. The sea surface temperature of the Atlantic Ocean ranges from 27.1 - 29.4^0C and the temperature at depths of 1000m and is below 5^0C for all oceans globally as shown in Figure 1.1 (Bruce, 2008).

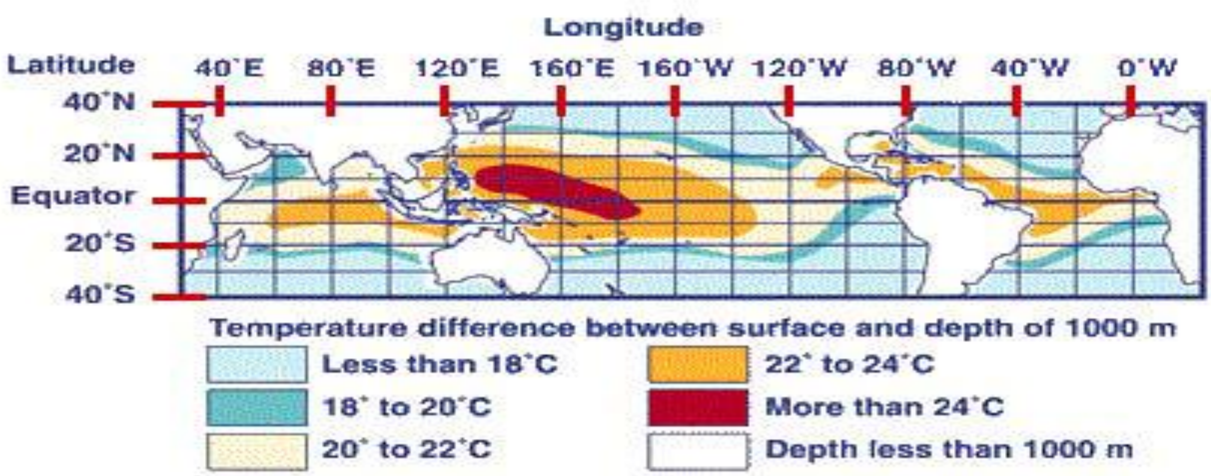

Figure 1.1: Worldwide Ocean Surface Temperatures (Yusuf and Lydia 2010)

The Ocean Thermal Energy Conversion is a solar energy likened renewable energy due to the conspicuous fact that the Ocean absorbs the sunlight daily and this is equitable to different thousand times the elementary energy need of the earth planet we are living (Avery and Wu, 1994). Precisely, this energy is reserved as heat in the upper surface of the Oceans and the equatorial coastal part of the surface of the earth has a mean temperature of between 27^0C and 29^0C and the deep temperature decreases from 4^0C to 5^0C as the depth rises to 1000m and above the depth of 1000m; the temperature decreases to another degrees even at a mean ocean of depth of 3650m as depicted in figures 1.2 (Hernández, 2021).

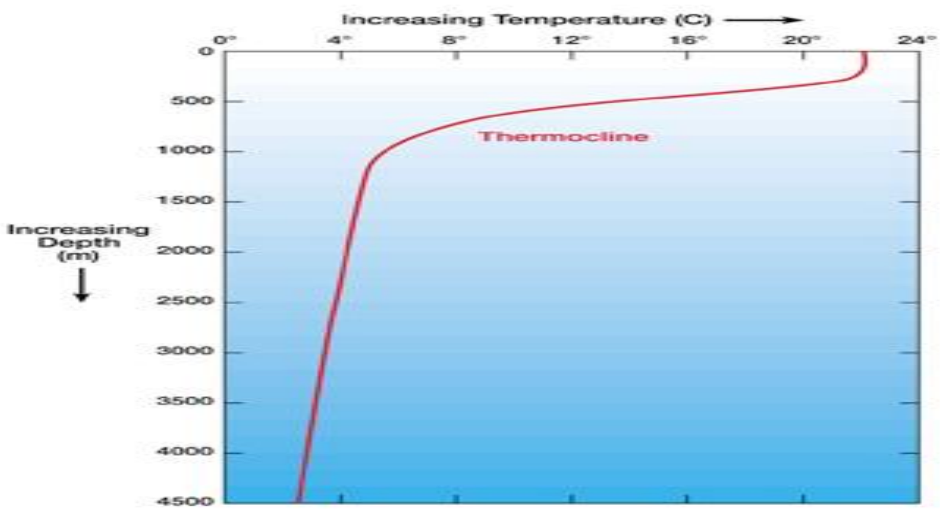

Figure 1.2: The temperature profile of ocean water (Walter and Farshid, 2014)

The Ocean Thermal Energy Conversion system produces electric power endlessly and it can be utilized as a base load power generating plant which is a considerable benefit comparable to other renewable powers like solar and wind (Ruud and Frank, 2014).

The significance of studying OTEC systems extends beyond energy generation. OTEC systems offer the potential to produce fresh water through desalination processes (Pandey et al., 2020). By utilizing the temperature gradient between warm surface water and cold deep water, OTEC systems can generate distilled water, addressing the global water scarcity challenge. The integration of water production capabilities with power generation makes OTEC systems a versatile and sustainable solution for coastal regions with limited freshwater resources. The significance of this study lies in its contribution to the further development and optimization of OTEC systems by focusing on the design, fabrication, and performance appraisal of OTEC systems used for power generation,

1.2 Statement of the Problem

In light of Nigeria's expanding population, the escalating demand for energy and electricity has become increasingly pronounced. The existing energy requirements in Nigeria far outstrip the available supply which is primarily from fossil fuels. However, persistent supply shortages, volatile pricing, and uncertainty surrounding future availability of these fossil fuels underscore a critical imperative – the development of a sustainable and reliable renewable energy source.

Therefore, the need for clean sustainable energy supply via ocean renewable energy necessitated this project work. Hence, this work proposes a closed cycle type of ocean thermal energy conversion (OTEC) plant thereby giving the enablement for clean and stable energy production.

1.3 Aim of the Study

The aim of this study is to develop, fabricate an OTEC prototype and analyze the performance of OTEC system that will be used for clean power supply in the Niger Delta.

1.4 Objectives of the Study

The selected objectives of the research work include to:

i. Study and design a dependable model for the ocean thermal energy conversion (OTEC) plant utilizing appropriate thermodynamic principles and assumptions.

ii. Fabricate a prototype of the ocean thermal energy conversion plant.

iii. Carry out a performance appraisal of the ocean thermal energy conversion (OTEC) model with ASPENHYSYS and EXCEL Software Programs.

1.5 Scope of the Research

The ocean thermal energy conversion plant works on the principle of using temperature gradient to produce electrical energy. However, the energy which it generates is achievable at a significant depth that needs the usage of refrigerant which in turn emanated the proposal of this study. Also, in this work, engineering mechanics together with the appraisal of the operation doubled with influence of environment on the OTEC system are not part of the work excepting the thermodynamic assessment.

Hence, this work will look at ocean thermal energy conversion system that will be utilized for electric power generation using Burutu offshore waters and its useful environmental conditions.

1.6 Significance of the Research

Precisely, the rate at which electricity is consumed in Nigeria is very high so the need for renewable energy emanated. Therefore, investigation of the performance of ocean thermal energy conversion is looked as another avenue of meeting the power demand of day –to-day living.

Presently, epileptic electricity supply is what we are experiencing with the national grid and this have negative effect on the businesses that needed it for smooth operation and this investigation will work as a precursory assessment into OTEC potentiality in the Nigeria coastal region.

Hence, this study is directed at ameliorating the thermodynamic performance like power output and the efficiency of the ocean thermal energy conversion and this work is narrowed down to Burutu offshore water sea region and it will also serve as a framework for government if they want to invest in ocean thermal energy conversion system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Maren et al. (2013) noted that energy plays a vital role in supporting human survival and progress. The exploration and utilization of energy have greatly contributed to the advancement of the global economy and human civilization. One significant example is the indispensable use of fossil fuels (such as coal, oil, and gas) for generating electricity, facilitating transportation, providing heating, and serving various other needs. The progress witnessed in the global economy and technology is intricately connected to the transformation and development of energy sources.

A review by The Outlook for Energy (2012) clearly indicates a rising need for energy to power various aspects of modern life, including factories, industries, transportation systems, and residential heating. The demand for energy in these sectors is continuously increasing, as evidenced by the estimated average growth rate of 2.3% per year, as reported in The Outlook for Energy (2012). This data underlines the significance of energy in sustaining and propelling the global economy and technological advancements. The global demand for energy, particularly electrical energy, has experienced significant growth over the years. As societies become more industrialized, technology-dependent, and interconnected, the reliance on electrical power has become paramount.

The global consensus on the urgency of addressing climate change is clear. Renewable energy sources, such as solar, wind, hydroelectric, geothermal, and bioenergy, offer a viable alternative to fossil fuels. According to the Intergovernmental Panel on Climate Change (IPCC), renewable energy can significantly reduce greenhouse gas emissions and help limit global warming to well below 2 degrees Celsius above pre-industrial levels. By transitioning to renewables, the world can mitigate the adverse impacts of climate change and protect the planet for future generations (IPCC, 2018).

As the world economy experiences rapid growth, the energy crisis and environmental concerns have emerged as crucial challenges for humanity. To address these issues, the development and utilization of renewable and clean energy sources have been recognized as an effective solution. The sun provides daily energy that is more than sufficient to meet the global energy demand for an entire year (Chapo, 2008), with approximately 80% of this solar energy being absorbed by the ocean.

Consequently, ocean energy has gained significant attention due to its abundant resources and clean, stable characteristics (Malik et al., 2020).

Muralidharan, (2012), in his work, highlighted the history of Ocean Thermal Energy conversion system. According to his work, Ocean Thermal Energy Conversion (OTEC) system was propounded by a French Engineer Jacques Arsene d'Arsonval, in 1881. Conceiving the tropical oceans as a possible source of energy, through the natural temperature gradients between the ocean's surface water and deep water, D'Arsonval built a closed-cycle OTEC system, with ammonia as the working fluid that powered an engine. Ammonia was taken as the best fluid obtainable to fit the pressure gradients between the two temperatures of water assuming that the temperature of the boiler was 30^{o}C and the condenser was 15^{o}C. The pressure gradient in the ocean thermal energy conversion system design was one of the requirements D'Arsonval had to surmount. Ammonia was picked due to the fact that it had a low boiling point thereby allowing it to become vaporized by the small temperature differences when pressurized by the pumps in the system. Also, in the same cycles where the Rankine cycle is followed there is usually a higher pressure difference in which to generate energy i.e. combustion driven engines. In the case of OTEC the temperature gradients are maximum 22^{o}C therefore a working fluid that was able to change phases with such a small gradient was chosen. This proposed technology was never tested by d'Arsonval himself. A student of d'Arsonval named George Claude soon took on the challenge of properly designing and building a working OTEC system. Claude, however, took a different approach to the design. He stated that corrosion and bio-fouling of the heat exchanger in an OTEC system would be a problem in the closed-cycle design. Claude suggested using the warm seawater itself as the working fluid in an open-cycle, now better known as the Claude cycle. OTEC systems were not investigated again on a serious scale until 1956 when a team of French scientists and engineers designed a 3 megawatt (MW) power plant. This design project had to be abandoned due to the expenses associated with the components of the OTEC system. It was not until 1985 that Saga University managed to construct a larger version of their experimental OTEC system, capable of producing 75 kW. In order to move the technology forward and attempt to attain economically feasible power, a group of 25 of Japan's top companies spanning a variety of fields (engineering, manufacturing, ship building, power generation) were brought together in 1988 to form an organization to study OTEC. The same year, Hamuo

Uehara and his team managed to optimize a hybrid cycle that combines the energy production of OTEC with the desalination of seawater to bolster the efficiency of ocean thermal energy.

However, the working principle of ocean thermal energy conversion system is actually very simple. It is when warm water on the surface of the ocean is collected and pumped by warm seawater pump. Then, the water is pumped through the boiler/evaporator and the water vapor is used to heat ammonia, the working fluid. The ammonia vapors then expand through a turbine combined with a generator to produce power. To ensure the ammonia vapor return back to a liquid state, cold water from the deep ocean water is pumped into the condenser to cool the working liquid. The fluid is pumped back into the evaporator. The net power of the system is counted by the turbine power minus the specific energy consumption from all pumps. There are three types of OTEC design namely closed cycle, open cycle and hybrid cycle as earlier mentioned.

2.2 Operation and components of OTEC system

Ocean thermal energy conversion system comprises of a comprehensive array of methods, approaches, and advanced technologies, all dedicated to harnessing, transforming, and producing power by utilizing the solar thermal energy stored within the vast oceanic bodies. (Felsics, 2023).

The primary source of energy comes from warm surface water. This warm water is harnessed to facilitate the conversion of low boiling point liquid working fluid into its gaseous state. This crucial step serves as the initial energy transfer mechanism within the system. (Byju's, 2023). Subsequently, the generated vapor of the working fluid, now at high pressure, is directed to spin the turbines of generators. These turbines are specially designed to efficiently convert the ocean thermal energy carried by the vapor of the working fluid into electricity, making it a sustainable and environmentally friendly power generation process. (Byju's., 2023)

In order to ensure a continuous and uninterrupted production of electricity, the used vapor of the working fluid is then directed to pass through a condenser. In this stage, cold water is pumped from the deeper parts of the ocean to facilitate the condensation of ammonia vapor back into its liquid state. This recycling process helps to restore the ammonia to its original form, allowing it to be used again and again in the OTEC plant's energy generation cycle. Also, by repeatedly implementing the condensation and evaporation process, the OTEC plant can maintain a steady production of electricity, harnessing the vast thermal energy potential present in the ocean. This approach not only provides a sustainable alternative to traditional fossil fuel-based power generation but also offers the benefit of being an eco-friendly solution with a significantly lower carbon footprint. (Byju's., 2023).

It operates through a straightforward process consisting of three key stages: capturing thermal energy, conducting thermo-mechanical conversion, and finally, generating electricity. These sequential steps are grounded in the principles of the Rankine Cycle, a well-established thermodynamic model for transferring energy. By employing uncomplicated conversion mechanisms, OTEC efficiently transforms thermally-energized fluids into electricity, making it an effective and sustainable power generation method. (Yang, M.-H., and Yeh, R.-H. 2014). Thermal Energy Capture is the initial phase of the OTEC process, where the system harnesses thermal energy from the ocean's shallow, warm surface waters, typically ranging from 20-50 °C. This energy results from continuous solar heating, causing temperature to decrease as depth increases, creating an inverse hydrothermal gradient within the oceans.

An OTEC power plant comprises various components, including the working fluid, heat exchanger/evaporator, pumps, turbine, electric generator, and flow-pipes. However, the key elements involved in thermal energy capture are the working fluid, heat exchanger or evaporator, and pumps.

2.3 Literature Review of Literary works on OTEC system

Xinguo et al., (2012) carried out a thermodynamic analysis of Organic Rankine Cycle (ORC) with Ejector. In order to increase the power output capacity and its efficiency, an Organic Rankine Cycle with Ejector (EORC) was proposed in their paper. In the EORC, an ejector and a second-stage evaporator were added to the ORC. The vapor from the second-stage evaporator worked as the primary fluid for the ejector, to suck the exhaust from the expander so as to decrease the expander backpressure and increase the pressure difference through the expander, which resulted in an increase of the power output capacity. A Double Organic Rankine Cycle (DORC) was also introduced in order to analyze and compare the EORC with the ORC and DORC in the thermal performance. The output capacity was increased by EORC and DORC compared to the ORC. The thermal performance of DORC was superior to EORC, but another expander-generator and its auxiliary equipment were required for the DORC led to increase the investment and operation management compared to the EORC.

Yuan, et al., (2015), in their research proposed an ocean thermal energy conversion (OTEC) based solar-assisted combined power and refrigeration cycle, which could be used for both electricity generation and fishery cold storage application. In their proposed combined cycle, ammonia/water was selected as the working fluid and warm/cold seawater was utilized as the heating/cooling source. A two-stage ejector system was introduced, the turbine was used to produce power and the evaporator was used to produce refrigeration output. A flat-plate solar collector was utilized to increase the heating source temperature. To evaluate the performance of the proposed cycle, the developed a mathematical simulation program; the performance comparison between their proposed cycle and a previous two-stage ejector OTEC cycle was made, which showed that solar-assisted cycle has a slightly lower power-production efficiency of 2.27% but a much higher comprehensive-production efficiency of 7.89% under the given working condition. Furthermore, they performed a parametric analysis to guide the theoretical performance of their proposed combined cycle. The results showed that the generator pressure, solar collector outlet temperature and rich solution concentration all affect the cycle performance.

Tobal et al., (2022) showed how an OTEC Ecopark could provide comprehensive, sustainable, and quality products that satisfy the diverse needs of coastal communities in Mexico. An offshore 60 MW hybrid Ocean Thermal Energy Conversion (OTEC) plant was proposed, which would provide products that will not only fulfill the water, energy, and food needs of the coastal communities, but also energize the local blue economy. An assessment of the financial feasibility of the plant as well as a comparative analysis against other forms of energy generation was carried out. The methodology they employed included a market description, literature review for the technical design, methods for mitigating socio-environmental risks, and an analysis of operational risks. To determine financial feasibility, the CAPEX, OPEX and annual revenue, including the sale of CELs and carbon credits, were evaluated. Based on their findings, the Internal Rate of Return suggested that the system would pay for itself in year 5 of the system’s 30-year life.

Bin et al., (2021) Using R134a as the cycle working fluid, developed the calculation programs of the working fluid thermodynamic properties and OTEC single-stage Rankine cycle thermodynamic performance. The thermodynamic performances of single-stage Rankine cycles and their applicability in OTEC power plants were studied. Their studies showed that in the simple Rankine cycle, when the condensation temperature is 9℃ and the maximum temperature is limited to 26℃, the cycle thermal efficiency increases from 0 to 5.3%. Under the condition that the isentropic efficiencies of pump and expander in simple Rankine cycle both are 0.85, the pressure drop of working fluid either in condenser or evaporator should not be higher than 136kPa. The reheat measure reduces the cycle efficiency in most working conditions and is not suitable for OTEC power plants. However, the maximum thermal efficiency of the regenerative cycle can reach 5.45%, which is about 2.83% higher than the simple Rankine cycle. From their results, they recommended the use regeneration measures to improve cycle efficiency in OTEC power plants.

Muralidharan, (2012) carried out an assessment of OTEC. His study used a method of bringing together a broad overview of the technology, market locations, technical and economic assessment of the technology, environmental impact of the technology and a comparison of the levelized costs of energy of this technology with competing ones. He also provided an analysis and discussion on application of this technology in water scarce regions of the world, with a case study of the economic feasibility of this technology for the Bahamas. He found that current technology exists to build OTEC plants except for some components such as the cold water pipe which presents an engineering challenge when scaled for large-scale power output. The technology is capital intensive and unviable at small scale of power output but can become viable when approached as a sustainable integrated solution to co-generate electricity and freshwater, especially for island nations in the OTEC resource zones with supply constraints on both these commodities. He recommended that, to succeed, this technology requires the support of appropriate government regulation and innovative financing models to mitigate risks associated with the huge upfront investment costs. If the viability of this technology can be improved by integrating the production of by-products, OTEC can be an important means of producing more electricity, freshwater and food for the planet's increasing population.

Kim et al., (2017) conducted a study on Solar-boosted Ocean Thermal Energy Conversion (SOTEC) that utilizes not only ocean thermal energy, but also solar thermal energy as a heat source. The study performed exergy analysis on cycles based on SOTEC. Their analysis showed that RE245fa2 has the best thermodynamic performance among the working fluids tested. The exergy efficiency of RE245fa2 was 64.76% in the simple Rankine cycle and 67.79% in the Rankine cycle with an open feed liquid heater. In the Rankine cycle with an open feed liquid heater, an increase in thermodynamic performance could be expected in a SOTEC system, compared to the simple Rankine cycle.

Hernández, (2021) in her work, proposed the study and optimization of OTEC power cycles to generate electricity considering technical, economic, environmental and social aspects. However, the design and control of these systems involves multiple factors associated with the treatment of energy demand, environmental conditions, technology design, energy market costs and environmental impact. The generated models allow determining the technological configuration and sizing of the system, as well as the operation policy. The results show how to trade-off system design and operation with conflicting objective functions.

Adiputra et al., (2019) aimed at reducing the capital cost of OTEC. Their paper introduced a concept design of the floating structure from a converted oil tanker ship. To propose the design process, they was adapted the general principles of designing a converted tanker FPSO and then modified it to deal with ocean thermal energy conversion (OTEC) characteristic. In the design process, the arrangement of the OTEC layout was carried out by constraint satisfaction method and the prospective floating structure size is varied using Monte Carlo simulation. The variables in the design process consist of the velocities of cold water and warm water transport, the size of the plant ship, and the location of the OTEC equipment to the seawater tank. Constraints they introduced were allowable border to determine the acceptability for particular case including the provided space and buoyancy, and the net power output estimation. The results showed that the 'typical' size of a Suezmax oil tanker ship was the optimum one for the plantship with the velocity of the water transport of 2–3 m/s.

Fan and Chen, (2023) developed a thermo-economic OTEC model and conducted a sensitivity analysis of the OTEC system concerning its thermodynamic and economic performances. Specifically, the impact of warm-seawater temperature and cold-seawater pumping depth on the net thermal efficiency and the total investment cost were investigated by them. The results indicated that, an increase in warm-seawater temperature and cold-seawater pumping depth can improve the net thermal efficiency and a higher installed capacity was beneficial to the system economics. Building on these, a design optimization method with considering the on-design and off-design conditions was proposed in their work and the dynamic variation of warm-seawater temperature were considered in. In multi-objective optimization procedure, with the objective functions being the average net thermal efficiency and unit power cost within the operational cycle, the non-dominated sorting genetic algorithm II (NSGA-II) was employed by them to maximize the net thermal efficiency and minimize the unit power investment cost, resulting in the Pareto front. The net thermal efficiencies of OTEC systems using ammonia and R245fa as working fluids were gotten to be 4.13% and 3.8%, respectively which represented an improvement of 19.4% and 57.0%, respectively, compared to traditional optimization methods that do not account for off-design conditions.

Amir-Sina and Sadegh, (2017) in their research work, made use of worldwide experience, all sections of a conceptual design including site selection, technical specifications and cost estimation for an designing an Iranian OTEC power plant. A 5 MW closed cycle floating plant with an annual average temperature difference of 22°C was chosen at a 33 km distance from Chabahar harbour. Deep seawater was be extracted from 1000 m depth which would result in 3.52 MW of net power. According to cost calculations, the leveled cost of electricity of the plant was estimated to be approximately 0.117 $/kWh, which was an acceptable level compared to other renewables. The conceptual OTEC design presented in their paper demonstrated a thermal potential in the Oman Sea which could assist with meeting the power demand for the southern coast of Iran.

2.4 Possibility of Ocean Thermal Conversion Plant Energy Production

The ocean holds a wealth of renewable resources, with primary methods of utilization including tidal energy, wave energy, and ocean thermal energy (OTE). OTEC, one of these ocean energies, is a renewable source that causes no harm to the environment and boasts several advantages over other ocean energy options. It absorbs a significant amount of solar energy, far exceeding global total energy consumption, indicating its vast reserves. Moreover, its energy output remains stable and unaffected by day or night, reducing grid fluctuations or intermittence. Additionally, OTEC offers various conversion forms beyond just power generation, making it a versatile option. As a result, OTEC shows promise as a potential replacement for traditional power plants. (Ma et al 2022).

According to U.S. Department of Energy, (2002), collectively, an approximate amount of 10 terawatts (equivalent to 10 trillion watts or 10 billion kilowatts) of energy, which is roughly comparable to the current worldwide energy consumption, has the potential to be generated by Ocean Thermal Energy Conversion (OTEC) without causing any disturbance to the ocean's thermal makeup.

Felsics. (2023) noted that OTEC has the potential to produce an impressive amount of energy, estimated to exceed 80,000 TWh per year, considering the ocean's energy storage rate and capacity. On average, the oceans possess a thermal energy capacity of up to 0.8 Watts per square meter, with variations based on geographical location. Regions near the equator experience the highest levels of stored thermal energy.

2.5 Research Gap

The literature review carried out in the above section indicates that there is a lot of interest in the renewable energy technology. From the review carried out, it is seen that authors and researchers like Xinguo et al., (2012) carried out a thermodynamic analysis of Organic Rankine Cycle (ORC) with Ejector in order to increase the power output capacity and its efficiency, an Organic Rankine Cycle with Ejector (EORC), on the other hand, Yuan, et al., (2015), in their research proposed an ocean thermal energy conversion (OTEC) based solar-assisted combined power and refrigeration cycle, which could be used for both electricity generation and fishery cold storage application. Similarly, Kim et al., (2017) conducted a study on Solar-boosted Ocean Thermal Energy Conversion (SOTEC) that utilizes not only ocean thermal energy, but also solar thermal energy as a heat source. The study performed exergy analysis on cycles based on SOTEC. Tobal et al., (2022) showed how an OTEC Ecopark could provide comprehensive, sustainable, and quality products that satisfy the diverse needs of coastal communities in Mexico, proposing an offshore 60 MW hybrid Ocean Thermal Energy Conversion (OTEC) plant, Amir-Sina and Sadegh, (2017) in their research work, made use of worldwide experience, all sections of a conceptual design including site selection, technical specifications and cost estimation for an designing an Iranian OTEC power plant. A 5 MW closed cycle floating plant with an annual average temperature difference of 22°C was chosen at a 33 km distance from Chabahar harbour.

It can be seen that in the research works and studies sampled above, even though the authors bothered themselves with design, modeling, optimization, performance appraisal aspects of OTEC systems and plants, their scope encompassed regions outside the territory of Nigeria, and making used of data peculiar to their regions of interest. This research work now bothers itself with the Nigerian territory, precisely using data acquired from Burutu offshore waters of the Niger Delta region.

CHAPTER 3

MATERIAL AND METHODS

3.1 Introduction

The approach adopted in this study encompasses the design and modeling together with performance appraisal of close cycle ocean thermal energy conversion plant for power generation. Since it is known that the ocean thermal energy conversion is a technological renewable energy which utilizes temperature difference between the surface and the depth ocean to generate electrical power as a result of the operation of a low pressure turbine. Notwithstanding, as cited earlier, the OTEC influences a temperature gradient betwixt the upper - surface part of the sea water and the deep-sea water. The temperature gradient could be utilized to produce no emission of electrical energy via renewable energy technologies. Precisely, in this coastal region the surface temperature levels at daylight is between 24^0C to 30^0C and these temperatures goes deep down to the range of 4^0C to 6^0C at 500m to 1000m below the surface level thereby making the intermediate temperature difference to be about 26^0C.

There are temperature variations with the depth of Atlantic Ocean water. About 5m to 50m depth, it is relatively warm with about 25ºC to 30^0C. This temperature drops rapidly to about 4ºC at 1000m and an average of 3.2^0C is maintained at sea bed. This made the average temperature difference about 26^0C. This variation in temperature has made the coastal regions in Nigeria a viable location for the installation of an OTEC plant.

The design encompasses development of a dependable model via utilization of pertinent data such as surface sea water temperature, sea water temperature at a given depth, mass flow rate of the refrigerant, pressure of the refrigerant etc., and these data will be obtained from the Burutu offshore waters of the Niger Delta region and from standard tables and graphs. Also, appropriate thermodynamic principle will also be applied in developing the model equations coupled with ASPEN HYSYS and EXCEL Software Programs will also be used to carry out the analysis. The proposed OTEC is depicted in Figure 3.1. Validation is being carried out to know the closeness of the experimented and simulated results with OTEC that is fabricated.

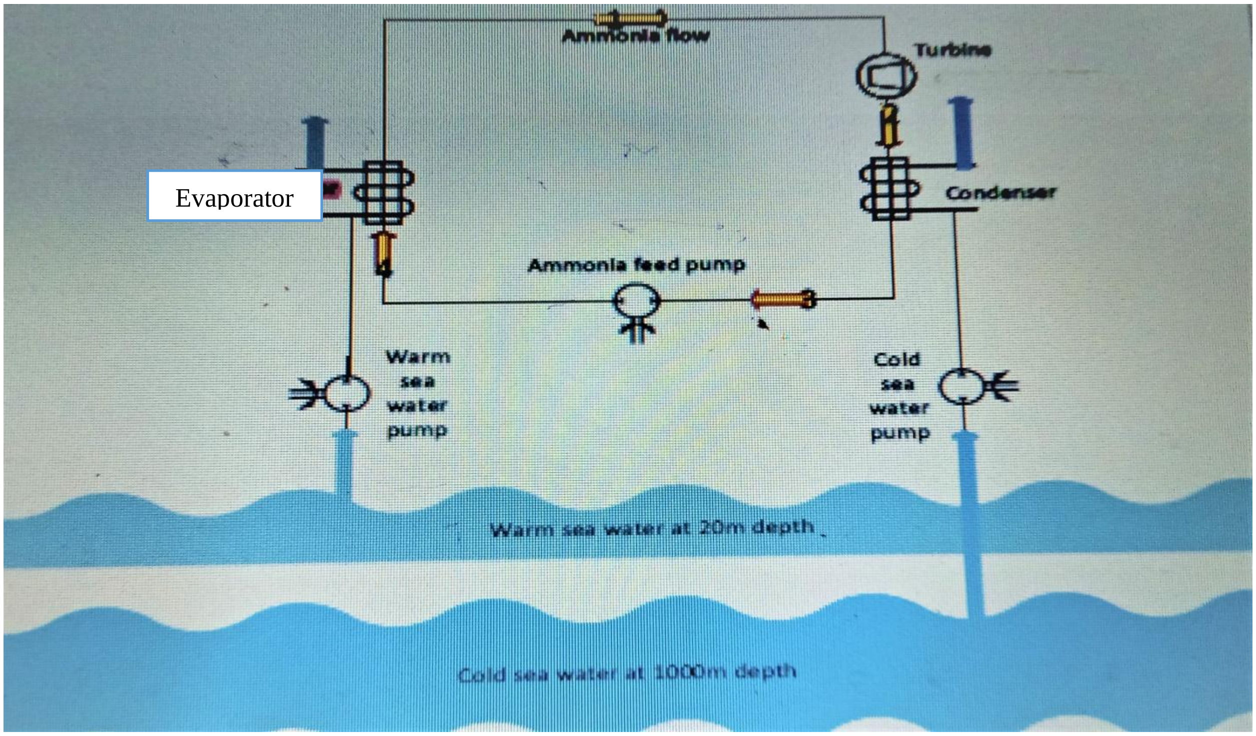

Figure 3.1: Closed Cycle OTEC Plant (Ahaotu *et al.*, 2018)

3.2 Fabrication of the Prototype OTEC

3.2.1 Material Used

The materials used during the fabrication process are as follows:

i. 11/2 Stainless Sheet Plate
ii. 316 L Stainless tube Round Pipes
iii. 20 Pieces of Stainless Coupling Plugs
iv. 12 Kg Cylinder Storage Tank
v. Heat Exchanger Accessories: Stainless Sheet and Stainless tubes
vi. Condenser Accessories: Stainless Sheet and Stainless tubes
vii. Turbine Accessories: Impeller made of Stainless Steel and cylindrical compartment
viii. Six Digital Temperature Control Gauge
ix. Six Digital Pressure Control Gauge
x. 0.5KW pump
xi. Valve

xii. 2.5KVA Alternator
xiii. Control Dashboard
xiv. 10 packet of Electrodes
xv. 5 lengths of 1.5 inches Angle Steel Iron
xvi. 3 lengths of 1.5inches Square Pipe Steel Iron
xvii. R134a Refrigerant
xviii. Small 0.5KVA Generator for Initial Start-up
xix. Ice Block
xx. Water

3.2.2 Fabrication Process

The Heat Exchanger and the Condenser were fabricated utilizing stainless steel sheet plates. The fabrication of the Turbine was also done using the stainless steel plates. The fabrications of these three components were done on air and water tilt basis. That is, they were fabricated in such a way that there should be no leakages of air and water. The angle steel and square pipe steel was used to construct the housing of all the components of the Prototype OTEC. These components includes: heat exchanger, condenser, turbine coupled with impeller, coupling plugs, valve, pump, gas cylinder, alternator and the dash board which is also known as the multi- components board houses the temperature and the pressure gauges.

Practically, the fabrication encompasses the cutting, welding, milling, grinding and installations. Figure 3.1 to Figure 3.6 depicts a pictorial demonstration of how the fabrication was performed.

Figure 3.2: Pictorial View of the Fabricated Heat Exchanger

The Heat Exchanger main function is to heat the water so as to enable quick circulation of the refrigerant. This heat help the to turn the turbine that is connected to the alternator to rotate thereby make it to generate power. Without the heat exchanger, it will be practically impossible for the OTEC plant to generate power.

Figure 3.3: Fabricated Condenser under Measurement

The condenser and the heat exchanger lookalike but there differences is that while the heat exchanger is for heating, the condenser is for cooling of the refrigerant so as to start the process again with the help of the pump.

Figure 3.4: Pictorial View of Welding Operation

Figure 3.5: Welding Operation of the frame

Figure 3.6: Pictorial View of Cutting Operation

Figure 3.7: Pictorial View of Measurement of the Housing Casing of the Prototype OTEC Plant.

Figure 3.8: Installation of the Heat Exchanger and Condenser

3.2.3 Experimental Procedure

The experiment was carried out after the installation of all the components of the OTEC. The heat exchanger was provided with artificial heater to heat up the water while ice block were used at the condenser to bring the temperature of the water to at least 10^0C. Practically, this is done in order to get a temperature difference thereby generating power in turn because the OTEC system uses temperature difference of the surface sea water and the cold deep seawater to generate energy. Also, the temperatures and the pressures gauges were fitted at every temperature and pressure interval. All the gauges are connected to the display component dashboard. These gauges were installed to take reading at any given interval. The cylinder gas bottle contains the refrigerant which is Ammonia and a pump of 0.5KW is attached to it so that it can pump it via the valve and a small generator of about 0.5KWA was used for the startup operation.

The experiment is carried out and power was generated and the temperatures and the pressures were taken at every interval and recorded.

3.3 The System Model

The close cycle OTEC plant being propounded as depicted in **Figure 3.8** operates similar to the conventional Rankin cycle power plant. It comprises of a turbine, a condenser, the working fluid (Ammonia), ammonia feed pump, an evaporator, and two auxiliary pumps for warm sea surface water and cold sea water at a depth of 1025m.

Practically, **Figure 3.9**, depict the thermodynamic process involved. The saturated ammonia vapour is generated in the evaporator, (4-1), due to the heat exchange between the warm surface sea-water (entering the evaporator through the auxiliary pump for warm sea surface water) and the liquid ammonia entering the evaporator at the saturated pressure, Pe. The saturated ammonia vapour then enters a turbine, (1-2), where it does some shaft work with the impingement of the ammonia vapour on the turbine blades. The turbine rotates driving an electric generator to generate electricity. The wet vapor exiting the turbine at a pressure, P_k is channeled to a condenser, (2-3), where it condenses, loosing heat to the cold water being pumped into the condenser from a depth of 1025m below sea level. The low pressure low temperature liquid ammonia leaving the condenser is then further pressurized via a working fluid feed pump, (3-4), to repeat the cycle

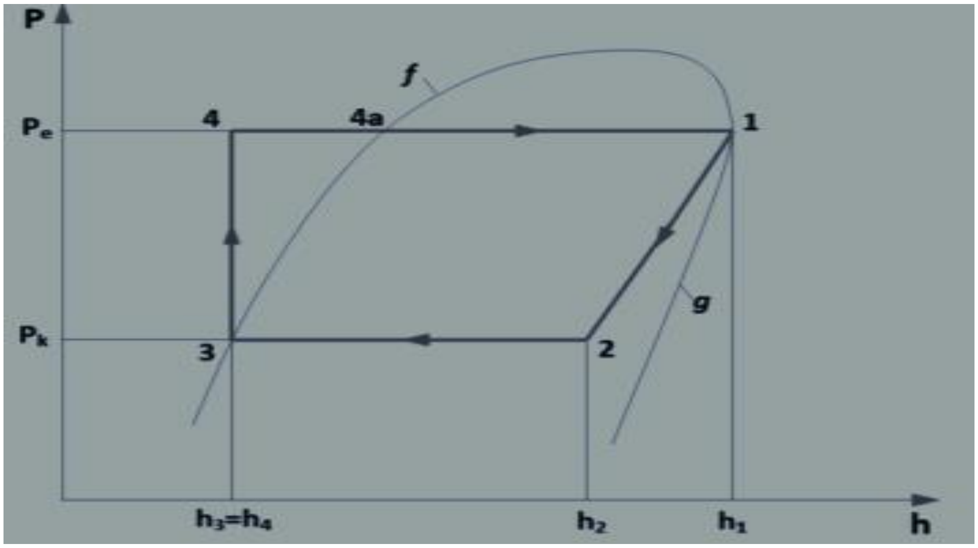

Figure 3.9: Pressure and Enthalpy (P-H) Diagram of the Proposed OTEC Plant

Meanwhile, the thermodynamic processes of a closed cycle ocean thermal energy conversion system utilizing Ammonia as working fluid are modeled as the saturated Rankine cycle and the appraisal is on the basis of the Figure 3.9 depicted (Ahoatu *et al.*, 2018):

3.3.1 Modeling of the Heat

Heat added to the System (Process 4-1)

$$\text{Heat added} = Q_{\text{added}} = h_1 - h_4 \tag{3.1}$$

Heat rejected from the System (Process 2-3)

$$\text{Heat rejected} = Q_{\text{Rejected}} = h_2 - h_3 \tag{3.2}$$

However for Heat Exchanger (HE) that is satisfied with its operations, the heat transfer rate in the Evaporator is expressed as:

$$Q_a = \dot{m}_{hw} C_{pw} \Delta T_h = \dot{m}_a (h_1 - h_4) \tag{3.3}$$

Where $\Delta T_h = T_{hi} - T_{ho}$

Also, the rate of heat rejected in the main Condenser is expressed as:

$$\mathrm{Q_c} = \dot{\mathrm{m}}_{\mathrm{hw}}\mathrm{C}_{\mathrm{pw}}\Delta\mathrm{T_c} = \dot{\mathrm{m}}_{\mathrm{a}}(\mathrm{h}_2 - \mathrm{h}_3) \tag{3.4}$$

Where $\Delta\mathrm{T_c} = \mathrm{T_{ci}} - \mathrm{T_{co}}$

3.3.2 Modeling of the Work

Process (1-2) is the Turbine Work while Process (3-4) is the pump work which is expressed as follows:

$$\text{Turbine Work} = \mathrm{W_T} = \mathrm{h}_1 - \mathrm{h}_2 \tag{3.5}$$

$$\text{Pump Work} = \left|\mathrm{W_p}\right| = \mathrm{h}_4 - \mathrm{h}_3 \approx \vartheta_3(\mathrm{P}_4 - \mathrm{P}_3) \tag{3.6}$$

$$\text{Net Work} = W_{net} = \mathrm{W_T} - |\mathrm{W_P}| = \mathrm{h}_1 - \mathrm{h}_2 - \mathrm{h}_3 + \mathrm{h}_4 \tag{3.7}$$

The power output of the Ranking power plant is expressed as:

$$\dot{W}_{net} = \dot{m}W_{net} = \dot{m}(h_1 - h_2 - h_3 + h_4) \tag{3.8}$$

The actual mechanical Net Work after putting into consideration the cycle efficiency is expressed as:

$$\dot{W}_{net} = \dot{m}_a W_{net}\eta_{c\,eff} \tag{3.9}$$

3.3.3 Modeling of the Head Loss and Power Loss

Work is required to move large quantity of warm water (WW) and cold water (CW) around the plant against friction.

The Head Loss due to friction at different section of the pipe is expressed as:

$$h_{fi} = \frac{2fl_iU_i^2}{d_ig} \tag{3.10}$$

The power loss due to at the different sections is expressed as:

$$P_{iw} = h_{fi}m_{iw}g \tag{3.11}$$

The Net Power generated by the ocean thermal energy conversion system after due consideration of the suction pumps is expressed as:

$$\dot{W} = \dot{W}_{net} - P_{iw} \tag{3.12}$$

Where, $P_{iw} = P_{hw} - P_{cw}$

i = signifies for both warm-water and cold-water respectively.

3.3.4 Modeling of the Efficiency of the System

The Cycle Efficiency of the system is expressed as:

$$\eta_{c\,eff} = \frac{\dot{W}_{net}}{Q_{added}} = 1 - \frac{h_2 - h_3}{h_1 - h_4} \tag{3.13}$$

The Thermal Efficiency of the System is expressed as:

$$\eta_{thermal} = \frac{T_1 - T_3}{T_3} = 1 - \frac{T_3}{T_1} \tag{3.14}$$

3.3.5 Modeling of the Speed

The mean speed of the sea water for cold and warm water is expressed as:

$$U_i = \frac{V_i}{A_i} \tag{3.15}$$

3.4 Ocean Thermal Energy Conversion Flow-Chart of Simulation

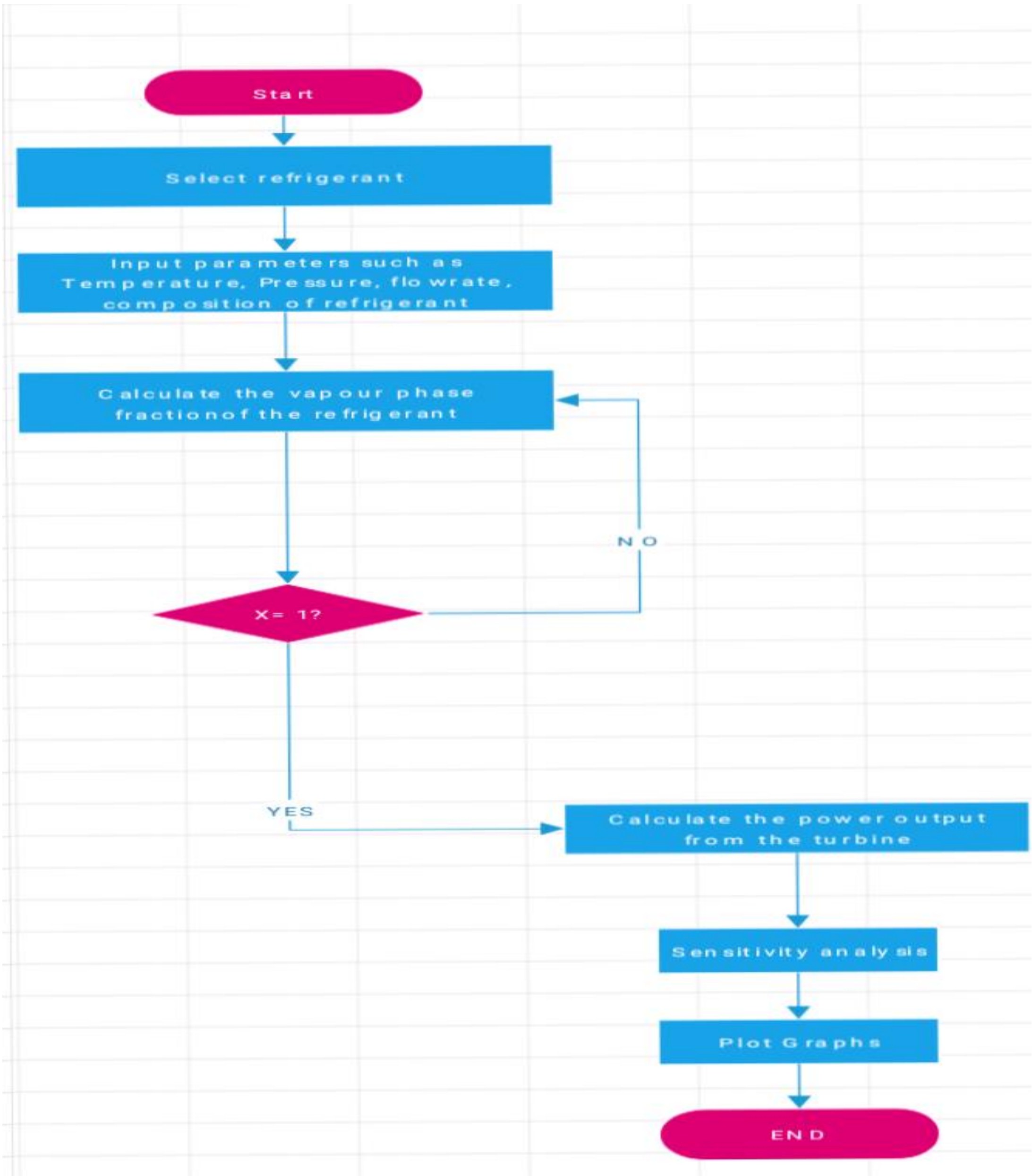

Figure 3.10: Flow Chart simulation of the OTEC using ASPEN HYSYS Software.

3.5 Proposed Ocean Thermal Energy Conversion Process Flow Diagram

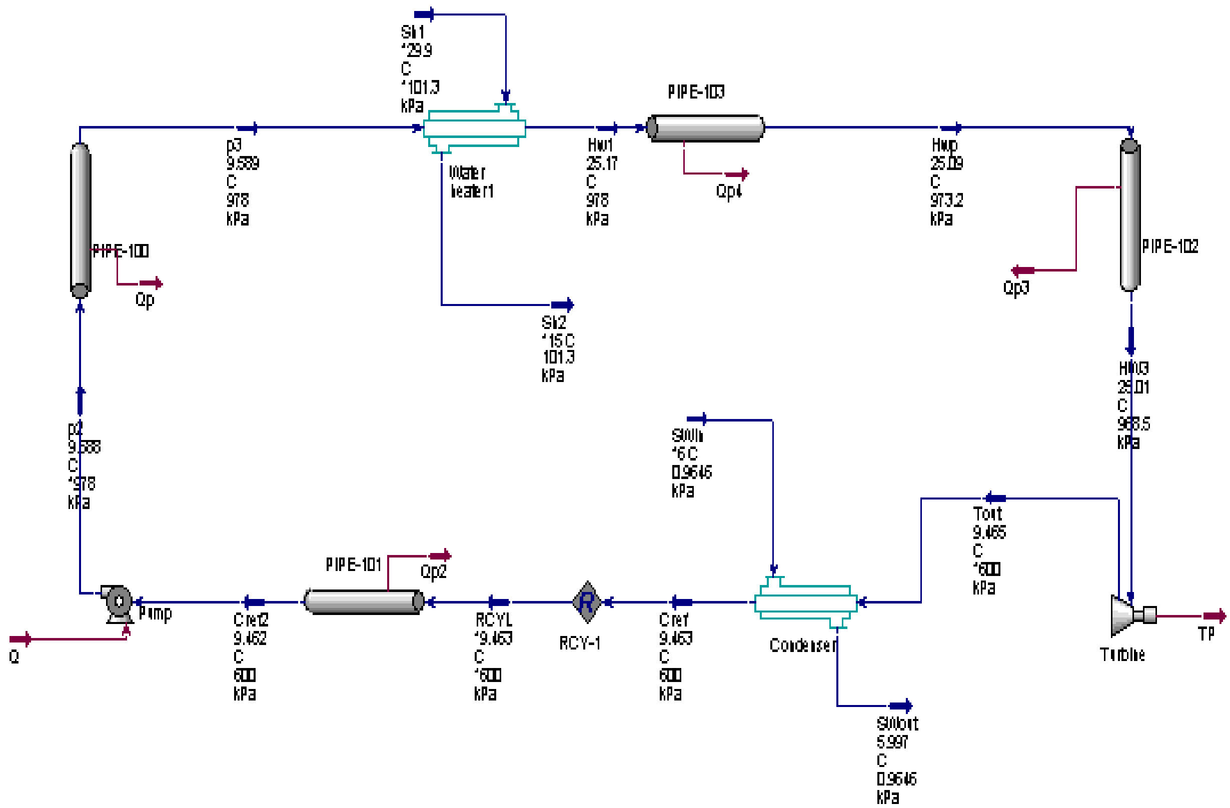

Figure 3.11: The Process Flow Diagram of the Proposed OTEC using ASPEN HYSYS

Table 3.1: Initial Proposed Working Design Data for the 50MW OTEC Plant

Parameters	Values	Unit
Working fluid	Ammonia	
Ammonia Density	597.908	Kg/m^3
Ammonia Specific heat capacity	4.87	KJ/KgK
Turbine Efficiency	0.796	%
Turbine Rated Power	50	MW
Generator Efficiency	0.946	%
Pumps Efficiency	0.895	%
Warm seawater inlet temperature	25.2 and 29.9	^oC
Cold seawater inlet temperature	4 and 6	^oC
Pipe length of warm seawater	100	m
Pipe diameter of warm seawater	103	m
Pipe length of cold seawater	1025	m
Pipe diameter of cold seawater	101	m
Heat exchangers conductivity	14	W/m K
Surface sea water temperature	29.9	^oC
Deep cold water temperature	4	^oC
Water Density	1025	Kg/m^3
Water Specific Heat Capacity	4.182	KJ/KgK

Evaporator Pressure	9.78	Bar
Condenser Pressure	6	Bar
Friction loss factor	0.02	

Table 3.2: Monthly Average Sea Surface Temperature of Burutu River, Delta State.

Months	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mini-Temp. (^{0}C)	26.2	26.6	27.6	27.5	27.8	26.1	25.7	25.2	25.4	26.6	27.5	26.9
Max. Temp. (^{0}C)	28.6	29.7	29.3	29.9	29.8	28.8	27.6	26.2	27.5	28.3	29.3	29.3

Table 3.3: Enthalpies of Ammonia

h1 (KJ/Kg)	h2 (KJ/Kg)	h3	h4
1624.7	1564.8	378.	378.59

Table 3.4: Generated Turbine Power via Simulation

State	Tout - Pressure	TP – Power
Case 1	300	95.67
Case 2	400	75.13

Case 3	500	57.85
Case 4	600	43.87
Case 5	700	30.76

Table 3.5: Generated Vapour Phase Fraction via Simulation

State	Sh1 - Temperature	Hw1 - Vapour Fraction
Case 1	20	0.2975
Case 2	22	0.4398
Case 3	24	0.582
Case 4	26	0.7242
Case 5	28	0.8664
Case 6	30	1

Table 3.6: Generated Turbine Power and Net Work via Simulation

State	**Sh1 - Temperature**	**TP - Power**	**Pump - Power**	**Wnet**
Case 1	20	14.41	0.2037	14.2063
Case 2	25	29.13	0.3565	28.7735
Case 3	30	44.21	0.5092	43.7008

Case 4	35	73.92	0.662	73.258
Case 5	40	99.49	0.8148	98.6752

Table 3.7: Generated Pump Power via Simulation

State	p2 - Pressure	Pump - Power
Case 1	700	0.2037
Case 2	775	0.3565
Case 3	850	0.5092
Case 4	925	0.662
Case 5	1000	0.8148

Table 3.8: Generated Evaporator Heat Duty via Simulation

State	p2 - Pressure	Water heater1 - Performance Table (Tube) (Heat Flow-Heat Flow_2)	Water heater1 - UA
Case 1	800	38	6.57E+05
Case 2	850	46.44	7.01E+05
Case 3	900	54.54	7.53E+05
Case 4	950	62.36	8.16E+05

Case 5	1000	69.89	8.96E+05

Table 3.9: Generated Net Work and Cycle Efficiency via Simulation

p2 - Pressure	Water heater	Turbine Power	Pump - Power	Wnet	neff
800	38	15.08	0.2037	14.8763	39.14816
850	46.44	18.5	0.3565	18.1435	39.06869
900	54.54	21.92	0.5092	21.4108	39.25706
950	62.36	25.34	0.662	24.678	39.57344
1000	69.89	28.76	0.8148	27.9452	39.98455

Table 3.10: Generated Condenser Heat Duty via Simulation

State	Tout - Pressure	Condenser - Performance Table (Tube) (Heat Flow-Heat Flow_2)
Case 1	400	1133
Case 2	500	1150
Case 3	600	1163
Case 4	700	1173
Case 5	800	1183

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

Table 3.1 Initial proposed working design data for the 50MW OTEC plant, **Table 3.2** is the Monthly Average Sea Surface Temperature of Burutu River, Delta State and **Table 3.3** which is Ammonia utilized enthalpies. The maximum average surface (hot) sea water temperature was utilized and the deep cold seawater temperature was taken as $4^0C - 6^0C$. Precisely, the ASPENHYSYS Software was utilized via the process flow diagram (PFD) putting the atmospheric conditions into considerations and all other thermodynamic data couple with principles: **equations 3.1 -3.15** to generate the following parameters in **Tables 3.4 – 3.10** respectively. While the EXCEL Software program was utilized to get the characteristics features of the performance of the OTEC plant and it is depicted in Figures 4.1 – 4.10 respectively.

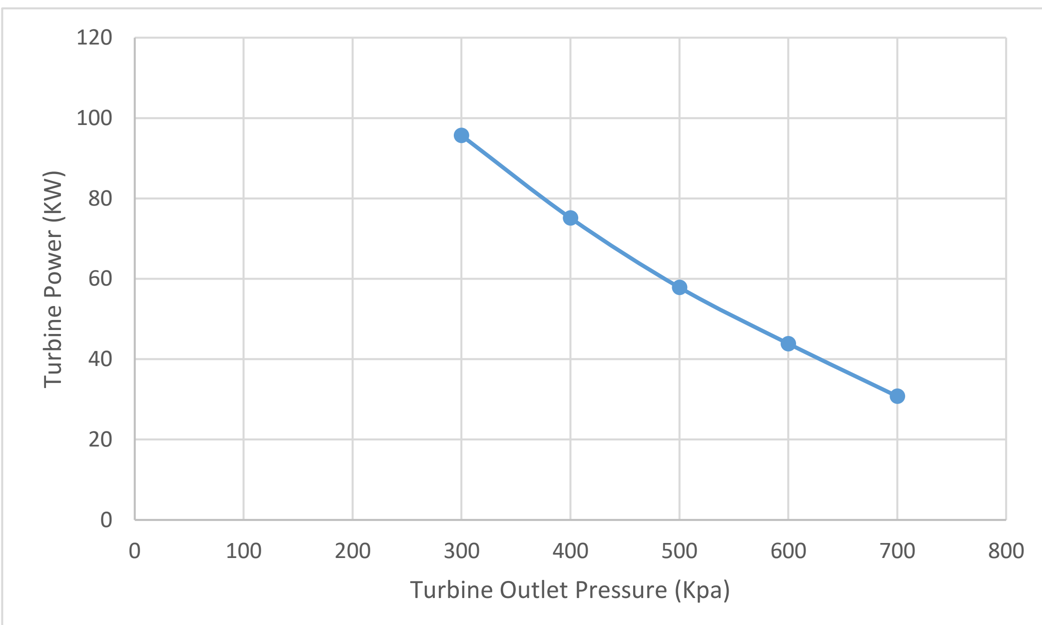

Figure 4.1: **Turbine Power against Turbine Outlet Pressure**

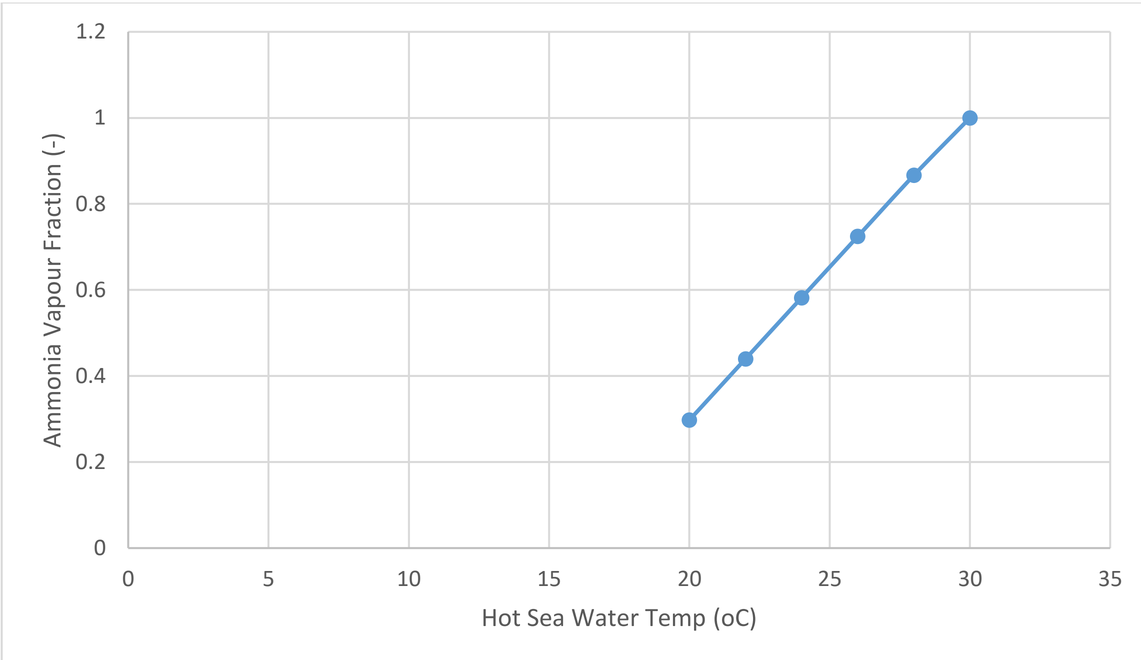

Figure 4.2: Ammonia Vapour Fraction against the Hot Sea Temperature

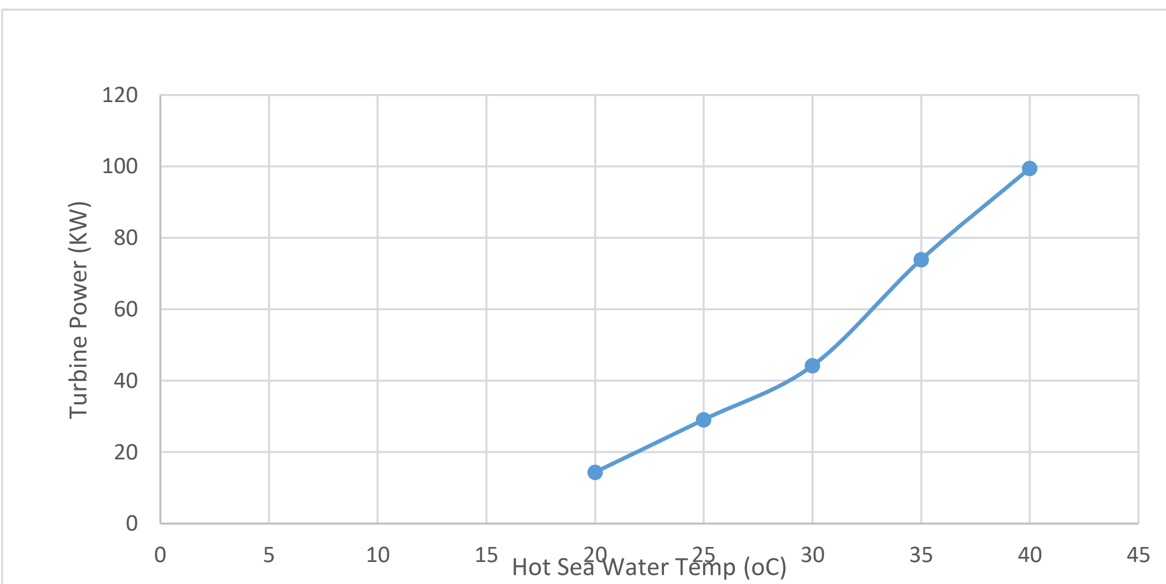

Figure 4.3: Turbine Power against the Hot Sea Temperature

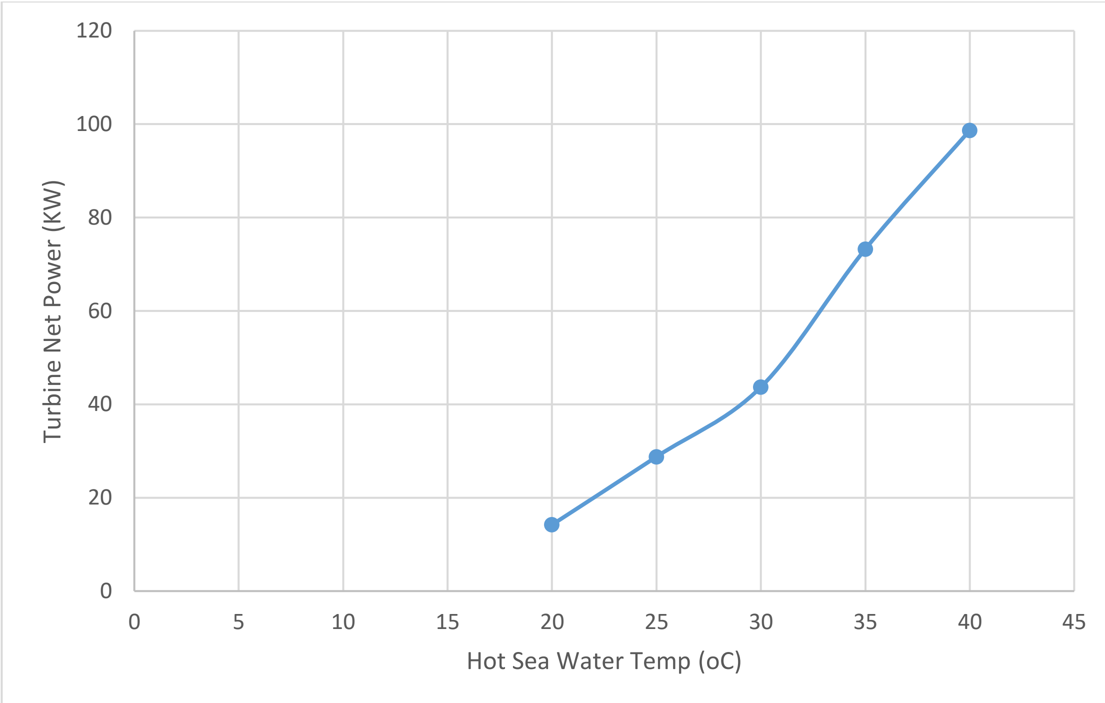

Figure 4.4: Turbine Net Power against Hot Sea Water Temperature

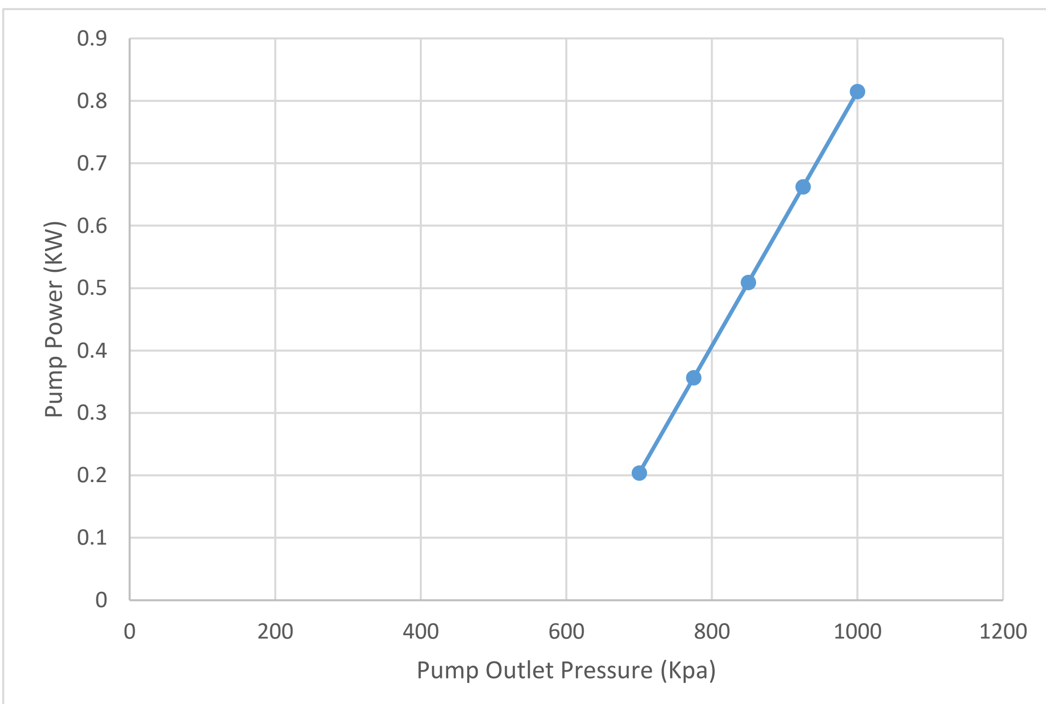

Figure 4.5: Pump Power against Pump Outlet Pressure

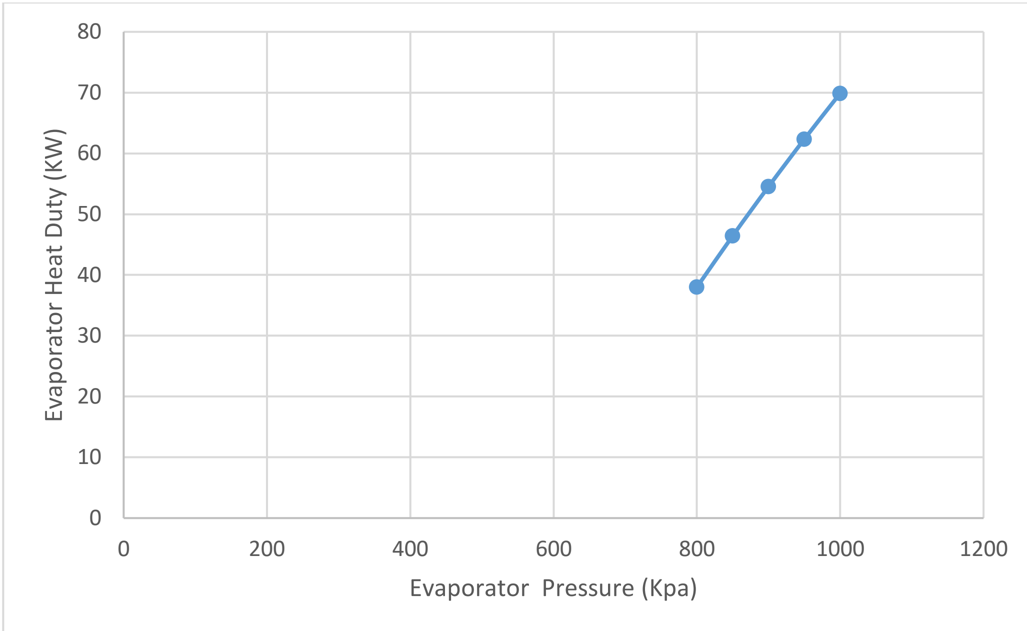

Figure 4.6: Evaporator Heat Duty against Evaporator Pressure

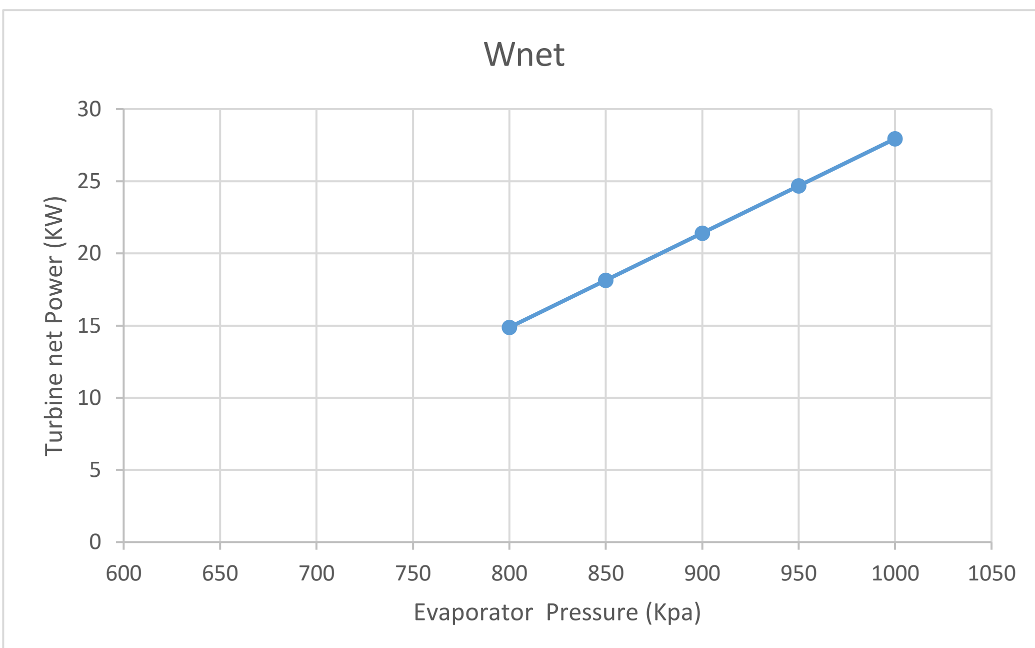

Figure 4.7: Turbine Net Power against Evaporator Pressure

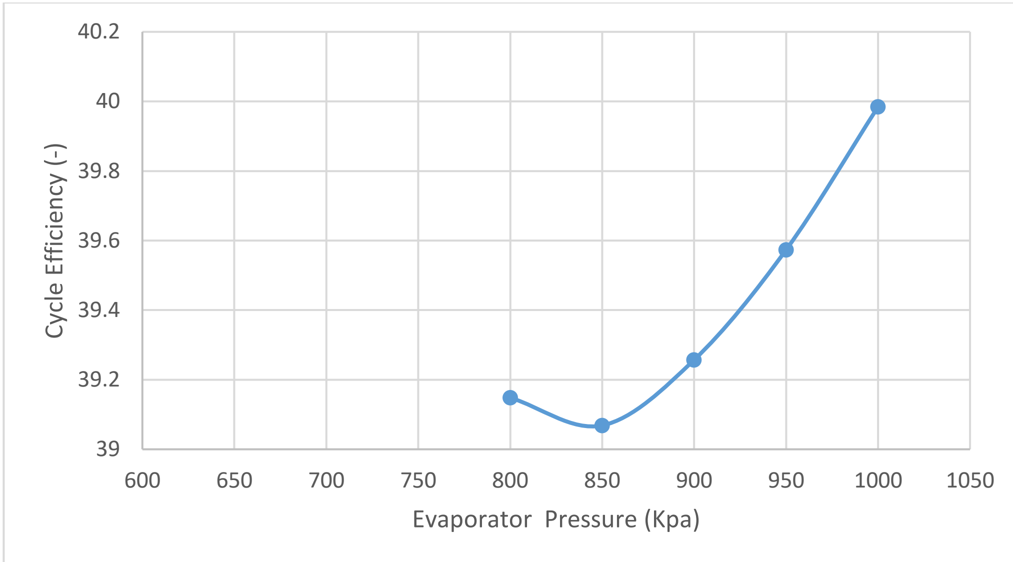

Figure 4.8: Cycle Efficiency against Evaporator Pressure

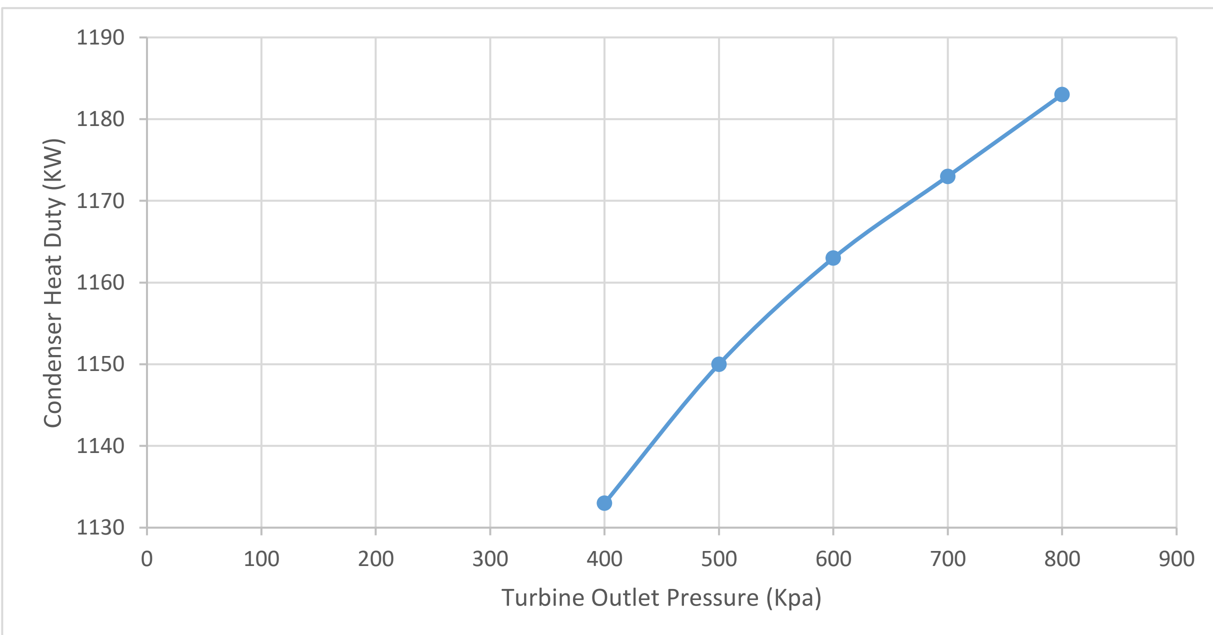

Figure 4.9: Condenser Heat Duty against Turbine Outlet Pressure

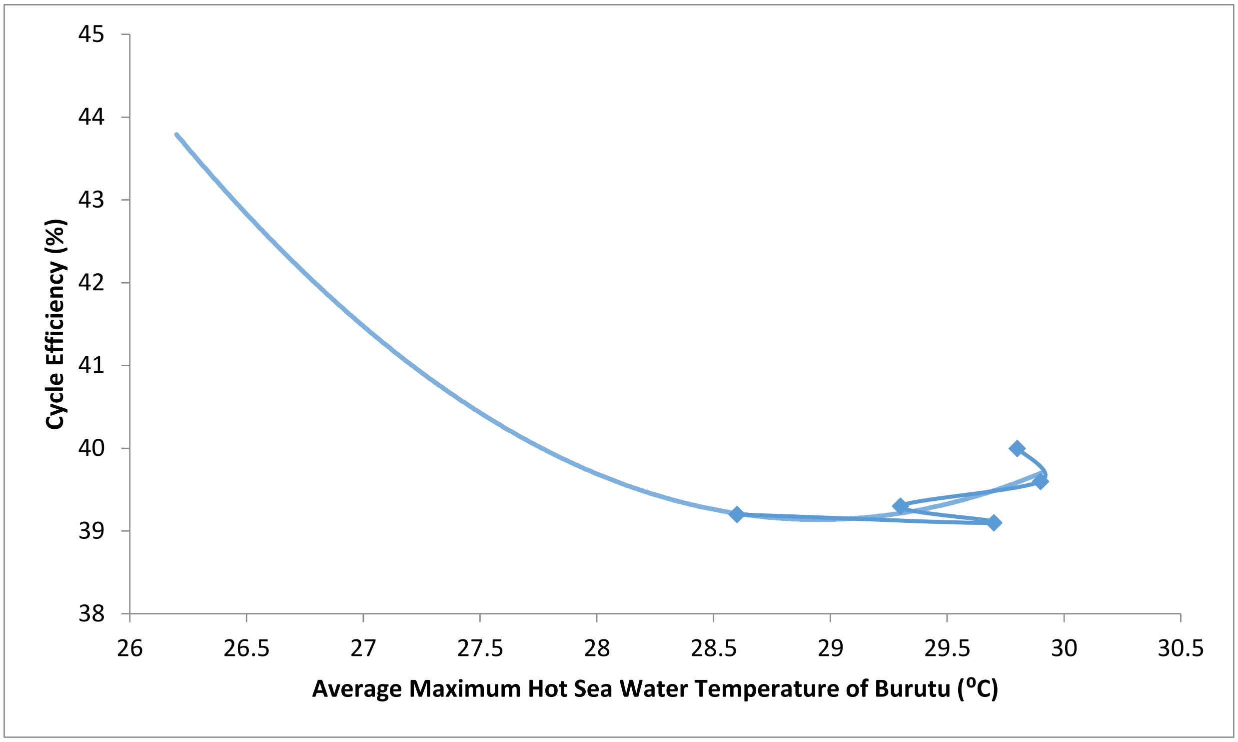

Figure 4.10: Cycle Efficiency against Average Maximum Hot Sea Water Temperature of Burutu offshore waters

4.2 DISCUSSION

Figure 4.1 represents turbine power against turbine outlet pressure showing that the higher the turbine power gives a decrease in the turbine outlet pressure and this means that the OTEC perform normal at a decrease turbine outlet pressure. **Figure 4.2** is ammonia vapour fraction against the hot sea temperature depicts that as the hot sea water temperatures increases via the aid of the heat exchanger, the concentration of ammonia vapour rises thereby exhibiting enough energy to propel the turbine to turn the alternator for power generation. **Figure 4.3** is turbine power against the hot sea temperature and **Figure 4.4** is turbine net power against hot sea water temperature. The two diagrams represent that as the hot sea water temperature increases via the heat exchanger, the turbine power and the turbine net power increases thereby depicting that the OTEC operation is normal since there is enough temperature difference. **Figure 4.5** is pump power against pump outlet pressure. It shows that as the pump outlet pressure increases, the power to pump the OTEC pump in order for the circulation of the refrigerant in the OTEC system increases. **Figure 4.6** is evaporator heat duty against evaporator pressure. The graph represents that the heat at the evaporator rises correspondingly with respect to the pressure. **Figure 4.7** is turbine net power against evaporator pressure figure and **Figure 4.8** is the Cycle Efficiency against Evaporator Pressure respectively. Theses diagrams depicts that as the evaporator pressure increases, the turbine net power increases with a corresponding increase in the cycle efficiency. It also indicate that the cycle efficiency of the OTEC plant increase with appropriate increase in the evaporator temperature. **Figure 4.9** is condenser heat duty against turbine outlet pressure. The figure illustrates that that the turbine outlet pressure increases, the condenser assumption of heat increases in a parabolic proportion and stop at 1183KW. Furthermore, **Figure 4.10** is cycle efficiency against average maximum hot sea water temperature of Burutu offshore waters. This is the climax of all depict that there is potentiality in the citing of the proposed OTEC plant because the mean maximum hot sea water temperature and the cycle efficiency increases proportionally. Also, the cycle efficiency is at normal operational performance in the twelve months of the year.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONs

5.1 CONCLUSION:

The study of how to fabricate and analyze the performance of ocean thermal energy conversion that will be used for clean power supply in the Niger Delta, Burutu offshore waters, Delta State, Nigeria has been conducted. The study indicates that there is potentiality of citing the proposed OTEC because there is enough temperature difference to give rise to a workable cycle efficiency which also indicates normal operational performance.

Precisely, **Figures 4.2 – 4.10** depict that the OTEC will perform well. Also, the temperature difference is 26.5^0C and this is above the recommended 22^0C for OTEC plant citing. The cycle efficiency is at normal operational performance in the twelve months of the year considering **Figure 4.10** and **Table 3.2** respectively.

5.2 RECOMMENDATIONS

The following recommendations are hereby projected:

1. A solar Booster should be incorporated in the heat exchanger to increase the heat
2. Study of environmental impact on the OTEC on Burutu offshore waters should be conducted
3. Study of Structural Work of the OTEC should be conducted.

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