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DESIGN & FABRICATION OF A OSCILLATING WAVE SURGE CONVERTER

A PROJECT REPORT

Submitted by

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Department Of Mechanical Engineering

PROJECT WORK

This is to certify that the project entitled

DESIGN & FABRICATION OF A OSCILLATING WAVE SURGE CONVERTER

is the bonafide record of project work done by

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ABSTRACT

The Oscillating Wave Surge Converter (OWSC) is a novel shoreline or near-shore wave energy converter. In particular, the water particle motion in shallow water is predominantly horizontal, with elongated wave troughs and heightened wave peaks. The OWSC is designed to couple strongly with the horizontal particle motion, permitting large amplitudes of motion of the working surface whilst minimizing energy losses in associated water particle motions. The model proposed here is a Bottom Hinged Near-Shore Oscillating Wave Surge Converter. The OWSC consists of a paddle rotating about a horizontal axis pivoted at the bottom of the ocean and perpendicular to the direction of wave propagation. Thus, the OWSC is similar to the Japanese 'Pendulor' system. Although there are other bottom-hinged flap devices, our model is different in several ways and occupies a different part of the design space. For example, unlike the other systems it completely penetrates the water column from the water surface to the sea bed. Another safety in this model compared to the Top hinged model is that at times of High Tide the waves overflow the paddle.

Key Words : OWSC, Bottom Hinged, Near-Shore, Paddle

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$_b$	Length of buoy (m)
$_1$	Length of buoy submerged during low tide (m)
$H_{1/3}$	Significant wave height (m)
$T_{1/3}$	Significant time period (sec)
E	Energy obtained from wave front (kW/m)
g	Acceleration due to gravity (m/s^2)
P	Energy absorbed by buoy (kW)
B	Breadth of the buoy (m)
w	Width of the buoy (m)
t	Thickness of the buoy wall (m)
θ_0	Angle of oscillation (deg)
Q	Discharge of pump per second (m^3/s)
f	Co-efficient of friction
h_s	Suction head (m)
h_d	Delivery head (m)
L_p	Stroke length of piston (m)
A	Area of piston plunger (m^2)
P_p	Power required to drive the pump (kW)
D	Inner diameter of piston (m)
d	Diameter of piston rod (m)
W	Weight of water displaced per second (m^3/s)
S.G	Specific gravity of water
h_f	Loss of head due to friction (m)
l_d	Length of discharge pipe (m)
V	Velocity of flow in discharge pipe (m/s)
d_d	Diameter of discharge pipe (m)
R_e	Reynolds number
μ	Dynamic viscosity (Ns/m^2)
H_N	Net head of water (m)
V_w	Volume of displaced water (m^3)

CHAPTER 1

INTRODUCTION

According to estimates, the sea waves contain as much energy as the world is consuming today. Waves can provide huge amount of electricity without cooling towers and pollution. Waves are a renewable source of energy.

Oscillating wave surge converters are gaining popularity now-a-days. OWSC taps it energy from the horizontal component of the movement of particles in waves. In shallow water the wave length increases with decrease in depth. Also the Wave height increases in shallow water.

The two main components of the OWSC are the power absorbing unit and the power take off system. The power absorbing unit is a Bottom hinged buoy which rotates about a horizontal axis perpendicular to the direction of propagation of the wave. The power take off system used here is a hydraulic closed loop fresh water system. The buoy is connected the cylinder with the help of a connecting rod which transmits the energy to the piston rod.

The pressurised fluid is taken to a Head tank situated along the coast line. The head of water is then utilised to drive a Francis turbine which in turn drives a Electrical generator. The power generated is then fed to the power grid after synchronising.

1.1 OBJECTIVE OF THE PROJECT:

- To produce a pollution free power from the ocean energy.
- To select a suitable power take off system.
- To design a Bottom hinged near shore wave energy converter to pump water to an On-Shore Head tanks.
- To determine the Head/Pressure developed by the reciprocating pump.

.2 SCOPE OF THE PROJECT:

In India's perspective, there is tremendous scope for the sea wave energy. There are about 336 Indian islands in Bay of Bengal and Arabian Sea. The electricity generated from sea wave power stations there, can very well fulfil the requirement of that area. Also, India has a long coastline of about 6,000 km. The coastlines are hit by sea waves round the clock and can be exploited for electricity generation.

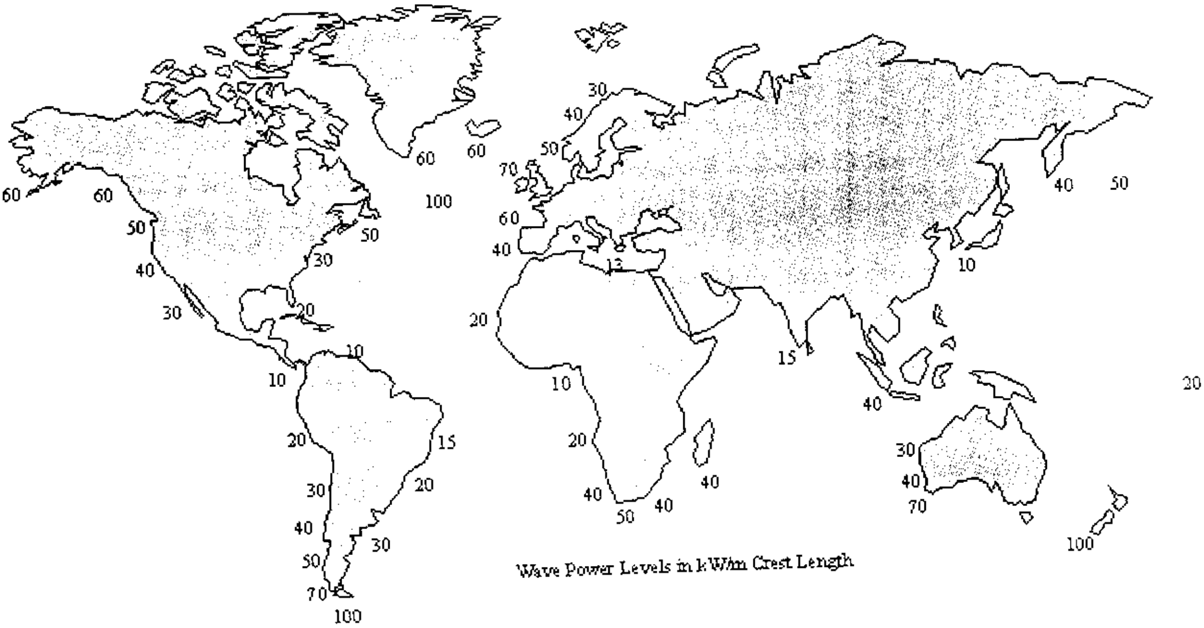


Figure 1.1 Wave power levels

In India the research and development activity for exploring wave energy started in 1982. Primary estimates indicate that the annual wave energy potential along the Indian coast is between 5 MW to 15 MW per meter. Hence theoretical potential for a coast line of nearly 6000 Km works out to 60000 MW approximately. However, the realistic and economical potential is likely to be considerably less and 47 kW/m is available off Bombay during Southwest monsoon period. Based on the wave statistics for the southern tip of India, a mean monthly wave power of 4 - 25 kW/m is estimated. The average wave potential along the Indian coast is around 5-10 kW/m. India has a coastline of approximately 6500 km. Even 10% utilization would mean a resource of 3750 –7500 MW.

CHAPTER – 2

LITERATURE REVIEW

The literature review section will give an insight on the Source of energy from the ocean in particular the wave energy, types of wave energy collectors, wave farm configuration and also the environmental impact of a WEC.

2.1 SOURCE OF ENERGY FROM OCEAN:

The oceans cover 70 percentage of the world and harbour a vast untapped source of renewable energy that can be transformed into electricity. There have been many ideas to try to extract some of the energy potential from the ocean through the years. The oldest ones are several hundred years old, and on a global basis there are more than 1000 patents on different constructions to harness this potential.

The forms of ocean renewable sources can be broadly categorized into: a) Ocean Tides b) Ocean Waves c) Ocean current d) Ocean Thermal Energy Conversion (OTEC) and e) Salinity Gradient. Of these, the three most well developed technologies are ocean tides, ocean waves and OTEC.

2.1.1 OCEAN TIDES:

Tidal energy is harnessed from the rise and fall of seawater caused by the gravitational action of the Sun and the Moon. As tide ebbs and flows, underwater turbines spin like windmills. The turbines are mounted on a gearbox shaft, which generates electricity. There are three different generating methods of tidal energy: tidal stream generator, tidal barrage and dynamic tidal power.

Tidal stream generator uses a similar principle to ocean currents. Tidal barrage is only cost effective to install in those parts of the coast where the sea high and low differ more than 16". Tidal barrage power plants store the water in a reservoir, similar to a dam with floodgates that allow water to flow into high tide and release the water back during low tide. In favourable places like straits and inlets, large volumes of water can reach high speed and provide energy density in the area of 500-1000 W/m2.

2.1.2 OCEAN WAVES:

Wave energy is the use of energy produced by the movement of the waves. Waves are formed by winds blowing over the water surface, which make the water particles adopt circular motions. Wave power has a high energy density, typically 30-60 kW/m along the coast (see figure 1 below). Out in the open sea, energy density can be up to 100kW/m. A variety of technologies have been proposed to capture the energy from waves; however, most are in an early stage of development. This makes it difficult to predict which technology or mix of technologies would be most prevalent in future commercialization. Some of the more promising designs that have been the target of recent developmental efforts and are appropriate for sea steading being considered in this assessment are terminators, attenuators, point absorbers, and overtopping devices.

2.1.3 OCEAN CURRENT:

Ocean current power has many similarities with tidal power. It harnesses the kinetic energy contained in ocean currents. The process is based on kinetic energy converters similar to the windmills in this case using subsea installations. Ocean current power probably won`t be economically viable until 2020 at the earliest.

2.1.4 OTEC:

OTEC is based on the use of thermal energy from the sea based on the temperature difference between the surface of the sea and deep waters. The use of this type of energy requires that the temperature gradient is at least 68F. OTEC plants transform energy into electrical energy using the thermodynamic cycle called the "Rankine cycle" to produce electricity. In the long term, this can give an energy output of 0.04W/m, but commercial technology will probably not be accessible before 2020.

2.1.5 SALINITY GRADIENT:

Osmotic Power or salinity gradient power is the energy obtained from the difference in salt concentration between seawater and river water through the process of osmosis. Energy density can be $1MW/m^3$ of fresh water. The technology needed to utilize this energy source commercially is still 5-15 years away at the earliest.

to the International Energy Agency, the potential for total global perspective, humanity's total energy consumption is 13,200 TWh/year.

Types	Resource	Technologies	Global resource
Wave power	Onshore, Along the coast ,offshore	Costal tidal reservoir, Straits	8000-80000 TWh/year
Tidal power	Costal tidal reservoir, straits	Propeller, turbine	200 TWh/ year
Ocean currents	Offshore	Turbines reciprocating wing	800+ TWh/ year
Salt power	By river mouths in ocean	Semipermeable osmotic membrane	2000 TWh/ year
Ocean thermal power(OTEC)	Offshore deep sea	Thermodynamic Rankine-cyclus	10000 TWh/ year

Figure 2.1 Various energies from ocean

2.2 WAVE ENERGY AS RENEWABLE ENERGY:

In recent years, society has been faced with the challenge to develop alternative energies in order to alleviate the global dependence on fossil fuels. A unique study by Birol investigated the likely differences between a future where an Alternative Energy Plan was enacted and a future with no attention to alternative energy. Birol hypothesized that, without an Alternative Energy Plan, the global community, including the United States, would suffer greatly from an increasing dependence on and eventual depletion of non-renewable energy sources (Birol, 2007). Increasing energy prices and various geopolitical events have recently made the public aware of the fact that the global energy supply is in an extremely vulnerable state. Birol emphasized the growing public knowledge and reiterated the need to restrain the growing demand for fossil fuels, alleviate harmful fuel emissions, and increase the diversity of available energies (Birol, 2007). Ultimately, this research concluded that there is a great urgency for political action with regards to an Alternative Energy Policy. If the policies were appropriately enacted, Birol concludes that the rate of increase in energy demand would be greatly reduced (Birol, 2007).

As the global society continues in a quest for renewable energy sources, there is some question about which sources can survive in an energy dependent world. Research non-renewable sources. However, extracting ocean wave power and producing energy is not a quick fix. The technology required can only be procured with government support, regulation streamlining, and additional research and data collection (Holzman, 2007). Currently, the field of wave power faces numerous obstacles. Although there is research being done, there is a lack of unified collaboration within the field. Government support and regulation streamlining would help to focus the additional research on areas that can show the feasibility of wave energy.

2.3 HISTORY OF WAVE ENERGY:

The use of wave power to do work can be traced back to the early Roman times when ocean currents were used in mills to process grain (Charlier & Finkl, 2009). However, a real fascination with wave power did not develop until more recently. Since the oil crisis of the 1970s, wave power has had increasing interest throughout the United States and the world. During this time, data was taken from weather monitoring ships and buoys to show the potential of wave energy. Statisticians calculated that waves passing over a one meter wide section of water in a typical location with a depth of fifty meters carried an average of forty kilowatts of power (Barras, 2010). In the many years since then, researchers have been studying wave energy closely, in order to determine its true capabilities. In recent years, wave energy converting systems are being designed and tested to use the kinetic energy of oceans and other bodies of water to produce electricity.

The pending global energy crisis requires an examination of renewable energy sources, including wave energy. In 2008, 91.1 percent of electricity in the United States was produced by non-renewable energy sources, including the burning of fossil fuels (Industry statistics, 2008). Eventually, this finite resource will be depleted and new energy sources will have to replace fossil fuels as a dominant electricity source. Throughout the past several years, researchers have strived to find cost-effect ways to harness energy from new sources. Also, in the recent years, there has been a societal shift towards environmentally friendly practices in all industries. This desire to "go green" has further pushed engineers and researcher towards renewable energy sources as an alternative to fossil fuels and other non-renewable sources. Renewable energy sources, including wave energy, have the potential to provide clean, abundant energy for the global community.

alleviate our dependence on non-renewable energy sources. In addition, wave energy has great potential to meet our future electrical energy needs with relatively less environmental impact than current methods used to generate power from fossil fuels. According to data taken in 2006, there are two terawatts of kinetic energy stored in the ocean, which is the equivalent of twice the world's electricity production (AquaBUOY, 2006). Although not all of this energy is usable, there is great potential to significantly decrease the global dependence on fossil fuels. As shown in Figure 1, there is potential energy stored along coasts all throughout the world. Engineers and researchers are making every effort to develop a cost effective, environmentally friendly way to convert the energy stored in ocean waves into energy suitable for human use (Leijon, 2009).

As of 2007, there were over 25 wave power technologies in existence and undergoing testing. However, because of the high costs associated with research and prototype testing, it is extremely difficult to achieve the standards for wave power implementation (Holzman, 2007).Although the high standards for implementation cause the most resistance to wave energy, many of the current technologies require specific water parameters in order to be economically efficient (Holzman, 2007).The field of wave energy requires additional focus on developing and testing technologies that will reduce the need for certain wave speeds and make wave energy viable for any area.

Much of the current research will show that wave energy is still in its earliest stages. In addition to research focused on developing this new technology, there is a substantial amount of research being conducted aimed at determining what performance and cost are necessary for wave energy to become a successful energy source. Ringwood (2006) studied the challenges and benefits of wave energy to determine how it compared with other renewable sources and what the future held. One of the main conclusions of the research was that a basic configuration and a stable control system were necessary in order to develop an efficient wave energy converter (Ringwood, 2006).In comparison to wind, solar, and other alternative energies, wave energy needed to accomplish these things and achieve efficiency in order to compete. Based on similar renewable energy programs, research has also shown that an extremely solid legal and regulatory framework is required for wave energy programs to be successful (Holahan, 2008).

a leading proponent and driving force behind wave energy, tells scarce, fleeting, or dirty. Harnessing wave energy is said to have no harmful pollutant dispersion. Von Jouanne also says that, unlike wind and solar power, wave energy is always available in that the ocean swells are constantly moving water up and down enough to generate electricity (von Jouanne, 2006).

2.4 WAVE ENERGY CONVERSION:

As stated in the previous section, research of ocean waves continually shows great potential for harnessing the energy stored in waves. Wind over the ocean surface creates waves and water motion almost constantly. The consistency and force of the winds over the ocean cause waves to be constant and allows them to store a significant amount of energy (OCS, 2010). There are many parameters taken into consideration when analysing the options for wave energy conversion. The most common things to consider are method of extraction, location of harnessing, manner of energy conversion, and type of device (OCS, 2010).These parameters are inter-related and some of them are dependent on others. Although each of these major considerations is important, it is also necessary to make decisions holistically when it comes to determining wave energy conversion methods.

There are two well-known methods used to extract energy from ocean waves. However, wave energy research is still in the beginning stages and new technologies are constantly being researched. Currently, the most commonly tested methods are either directly from the surface motion of ocean waves, or from the pressure fluctuations occurring deeper below the surface (OCS, 2010).

With regards to location of extraction, current research categorizes the sites as near shore, offshore, and far offshore. Near shore includes the sites closest to land and those most easily reached for maintenance and upkeep.   Offshore is slightly further into the ocean and far offshore is sites where the water is at least 40 meters deep (OCS, 2010). Many devices are designed and constructed for use in one location and they are able to maximize their energy conversion in that location classification only.

Another parameter to consider when working to harness wave energy is the method of energy conversion. Different from the method of energy extraction, the conversion involves how the extracted energy is turned into usable energy, most commonly pumps and generators. It is also dependent on many of the other parameters considered.

There are currently five main categories of wave energy conversion devices with various tested prototypes within each category. These classifications will be discussed in greater detail in the next section.

As mentioned previously, many of these parameters are inter-related. The method of extraction is directly related to the type of device used for conversion. Certain devices are designed to pull energy from the surface of the waves, while other categories are dependent on being deeper underwater. The location of extraction also affects the method mainly through the type of device. Devices are also designed to be optimally used either near shore, offshore, or far offshore. This determination connects the type of device to the method of extraction. Finally, the manner of energy conversion is only loosely dependent on the other categories. It is most directly tied to the type of device based on the results of current tests. Ultimately, there exist numerous combinations of these parameters, but current testing has shown which combinations allow for the most optimal energy extraction and conversion for usable consumption.

Current testing of wave energy conversion involves various combinations of the above parameters in various locations throughout the world. The United Stated Department of Energy reported in 2008 that there were sixty-two developers of wave energy technology. Of those developers, only a few were reported to have full-scale prototypes for testing (USDOE, 2008).In the report, the Department of Energy indicated that the majority of the developed devices were either attenuators or point absorbers and they were in the design or testing phases (USDOE,2008). This reflects the early stages of wave energy testing and, due to the longevity of testing required, it is likely that wave energy converters will continue to be tested for several years before full scale implementation and use.All of the currently tested conversion technologies are designed for installation at or near the ocean surface (OSC, 2010).This creates a larger impact with regards to visual aesthetics and interference with other maritime activities.

2.5 TYPES OF WECs:

In general, wave energy converters (WECs) can be grouped into five main pressure differential devices), attenuators, overtopping devices, and oscillating wave surge converters. These categories comprise the current research and testing that exists for harnessing wave energy. In addition to these categories, there are wave energy converter designs which can be categorized as a combination of these groups and wave energy converter designs which cannot be placed into these categories at all. These groups serve to outline the mechanical components and systems which are most commonly used to extract energy from ocean waves. Each category was researched with regards to the concepts behind the design, examples currently being developed and/or tested, and the advantages and disadvantages that come with each design.

2.5.1 OSCILLATING WATER COLUMNS:

Oscillating water columns are considered to be one of the more attractive wave energy converter designs in terms of efficiency, economics, and aesthetics. They are partially submerged, hollow devices which use turbines to generate electricity (EMEC, 2008). Wave movements cause a water column in the device to rise and fall which compresses and decompresses a column of air above. These changes in pressure cause air flow through rotating turbines, thus generating electricity (EMEC, 2008).

The device is primarily composed of a vertical cylinder which is partially submerged. The lower end of the cylinder is left open so that water may enter the chamber. As waves pass by the device, oscillating pressures are formed at the open, lower end (Evans, 1978). A water column is formed in the vertical chamber with air at the upper end. The motion of the waves, as they pass by the device, creates a rise and fall motion of the water column. The vertical, oscillating motion allows the water column to act as a piston within the cylinder (de O. Flacao).

As the water column rises during the wave crest formation, the air at the top of the chamber is compressed to a value slightly greater than atmospheric pressure (Daedalus, 2008). The compressed air is then forced out of the cylindrical chamber by turning an air turbine. Oscillating water columns generally employ Wells turbines in order to convert the energy into electricity (USDOE, 2008). After the compressed air is forced out of the chamber, the wave trough formation causes the water column to fall. This motion the air to a value slightly less than atmospheric pressure, drawing new air

Oscillating water columns have an opening at the top of the chamber through which the air is forced out and drawn in. This opening is connected to the turbine which converts the air movement into electricity. The air movement is created from the wave motion in that the oscillation of the water column within the chamber closely follows the waves in sequence and amplitude (Daedalus, 2008). The use of a Wells turbine allows the oscillating water column device to benefit from air flow in both directions as the waves rise and fall.

Wavegen, a Scotland based company, has already began testing on the most commonly known wave energy converter prototype that follows the oscillating water column design. Installed off the coast of Islay, Scotland in 2000, it was the world's first commercially oriented approach for the capture of ocean wave power (de O. Flacao). Wavegen's system is called the Land-Installed Marine-Powered Energy Transformer, or LIMPET. The Wavegen oscillating water column system is comprised of a concrete chamber built into the shoreline. After installation, the system has been able to reliably generate about 500 kilowatts of power, which is enough to supply about 400 homes (Staedter, 2002). The capability and success of the LIMPET devices have had a significant impact on the wave energy conversion community. It has been well received and is viewed as a key test bed for furthering developments in wave energy technology (Staedter, 2002).

Research shows many advantages associated with harnessing wave energy through oscillating water column devices. The United States Department of Energy states one benefit is that the devices can be mounted, near shore or break waters, or floating further into the ocean (USDOE, 2008). An advantage that comes with mounting close to shore is that it provides for easier access to the device and easier ability to conduct regular maintenance and perform repairs. In addition, the moving, mechanical parts used in oscillating water columns, including the turbines used for electricity conversion, are housed outside of the ocean water. This increases the lifetime of the device by decreasing the likelihood for corrosion and other wear from the water (de O. Flacao).

2.5.2 POINT ABSORBERS:

A point absorber wave energy converter is a device with components which move the motion of the ocean waves. The relative motion of the components is used to drive an electromechanical or hydraulic energy converter (OCS, 2010). Point absorbers are classified as either floating or submerged pressure differential devices.

Floating point absorbers are wave energy converters which follow the mechanics of a point absorber and float on the ocean's surface. They are typically deployed in water depths between 40 and 100 meters and have been found to be most efficient when deployed in arrays with a distance of several meters between each device (de O Falcao).The devices are able to absorb energy in all directions through movements at or near the ocean surface (USDOE, 2008). The converter itself is generally small in its horizontal dimensions, when compared to the representative wavelength in the area (de O Falcao).

Submerged pressure differential point absorbers are composed of an air-filled chamber which rests atop a shaft anchored to the ocean floor. The motion of the passing waves causes the sea level to rise and fall above the air-filled chamber. This creates a pressure differential within the device and causes the air-filled chamber to move up and down. Ultimately, the motion of the chamber can either serve as a water pump or can be directly converted to electricity through a hydraulic system (USDOE, 2008).

Both classifications of point absorbers extract energy through the relative motion of the device's components. The significant difference is merely the placement of the device. Floating point absorbers are at the surface of the ocean, while submerged pressure differential point absorbers are anchored to the ocean floor.

Ocean Power Technologies of Pennington, NJ has chosen to implement a wave farm off the coast of Oregon with floating point absorber devices. The coast of Oregon was identified by Ocean Power Technologies as an area with attractive wave energy. The device, named Power Buoy, is about 150 feet in length, 40 feet in diameter, and about 220 tons in weight. The original design allowed the converter to capture about 150 kW of energy. However, the United States Department of Energy recently awarded Ocean Power Technologies 1.5 million dollars to ramp up the device's capability to 500 kW (Russell, 2010). The prototypes generate electricity through a hydraulic generator (von Jouanne, 2010). Power Technologies has contracted Oregon Iron Works as the constructor of the prototypes, which are placed about two and a half miles off the coast (Russell, 2010). As development and testing continue, Ocean Power Technologies is contributing valuable research to the question of wave energy's reliability and validity. The Vice President of Business Development and Marketing for Ocean Power Technologies, Phil Pellegrino, has stated that wave energy would cost about 15 cents per kWh, which is on par with current costs for wind and solar energy (Russell, 2010).

AQUABuoy is another prototype of a floating point absorber currently being developed and tested. It consists of a long cylinder which hangs down into the ocean off of a floating buoy . The cylinder contains a solid steel piston which is sprung from both the top and bottom by steel-reinforced rubber hosing (Holzman, 2007). As the floating point absorber technology allows, when a wave passes by the device, the buoy bobs up and down with the swells of the waves. The movement allows the inertia of the piston to stretch one end of the hosing and decompress the other (depending on whether the buoy is in a trough or atop a crest) (Holzman, 2007). Through the relative movements of the buoy and the piston, potential energy is released, which pumps water through a turbine to generate electricity (Holzman, 2007).

The Archimedes Wave Swing is an example of a point absorber which follows the submerged pressure differential design. It is an air-filled chamber of cylindrical shape with a partially detached lid (de Sousa Prado). The device is anchored to the bottom of the ocean floor.

As waves pass over the device, the lid of the chamber, called the floater. is moved up and down in a vertical direction (de Sousa Prado). The energy is extracted from the linear motion of the waves and converted to electrical energy. A pilot plant of the Archimedes Wave Swing prototypes was built off a Portuguese coast in 2001 (de Sousa Prado).

A profound advantage of floating point absorbers is their ability to absorb energy in all directions through wave movements near the surface (EMEC, 2008). They are said to be able to pull tens to hundreds of kW of power out of ocean waves (de O Falcao). A to drift forces. Because of this, these devices require strong and stable mooring configurations (de O Falcao).

Point absorbers which follow the submerged pressure differential design are seen to be advantageous for many reasons. These devices are completely submerged, which makes them less vulnerable in storms (de Sousa Prado). As opposed to the floating devices and many other types of wave energy converters, this may result in less failure and required maintenance due to irregular weather patterns. Another benefit of being completely submerged is that they are not visible, which leads to greater public acceptance and less interference with aesthetics (de Sousa Prado).

Point Absorbers in general also have many benefits, whether they are of the floating design or the submerged pressure differential design. The devices are relatively small compared to the most common sea wavelengths (McCabe, 2009). This makes their footprint significantly smaller than some devices and creates less interference with the ocean environment. They are also said to have the potential for more efficient power conversion in terms of output per unit volume than many other types of wave energy converters (McCabe, 2009).This indicates that point absorbers require design and implementation with a specific area in mind, in order to reach that potential. They tend to have a narrow bandwidth and only achieve the highest efficiency when excited by waves with a frequency around their resonance point (McCabe, 2009).When implemented in areas where the average wavelengths follow this requirement, point absorbers are capable of extracting ocean wave energy very efficiently.

2.5.3 ATTENUATORS:

Attenuators are wave energy converters which consist of multiple floating sections oriented in a line and hinged together at joints. The sections pivot and move with the motion of the waves as they pass by. The segments tend to rotate relative to each other in a pitch and heave motion (USDOE, 2008) as the waves pass by. This motion causes flexing at the joints, where a hydraulic pump is used to convert the energy (EMEC, 2008) and (OCS, 2010).

Pelamis, one of the most well-known wave energy converter prototypes, follows the design. Pelamis Wave Power, a company in Portugal, is currently building the

(Holzman, 2007). The ultimate goal of the Pelamis testing is to be able to extract twenty mega-watts of power, or enough to power 4,000 homes (Holzman, 2007). As the attenuator device was described, Pelamis is comprised of multiple adjoined segments, which bend at the joints as waves pass .Each of the Pelamis device's segments is about the size of a train car (Holzman, 2007). Hydraulic rams at the joints work to resist the bending motion as waves pass. The rams push oil at a high pressure through hydraulic motors which drive electrical generators (Holzman, 2007).

The success of attenuating devices has been found to be largely dependent on how well they are designed for a specific area of operation (The pelamis prototype, 2008). One major requirement of this is that, in order to be successful, the device needs to be oriented parallel to the motion of the waves. This suggests that areas where wave motion is difficult to track or areas where there is great variation in wave direction would not be suitable for attenuating devices.

2.5.4 OVERTOPPING DEVICES:

Overtopping devices are those that capture water from waves and then return the water to sea through a turbine which generates power. The device is mainly composed of a reservoir which fills with water as incoming waves pass by. The reservoir continues to gather water from passing waves until the water level within the reservoir is above the average surrounding ocean water level (OCS, 2010). The water in the reservoir is then released, and, because the water level is higher, gravity pulls the captured water back to the ocean surface. The falling water turns hydro turbines, converting the energy stored in the falling water into usable power (OCS, 2010).

The components of an overtopping device can be categorized into collectors, ramps, and reservoirs. Collectors, often reflective arms, are used to collect the water as waves pass by the device. Ramps allow the collected water to enter the terminating reservoir, where the water is stored until it is time to be released (USDOE, 2008).The hydro turbines, or other type of conversion device, are used to capture the energy as the water flows back into the ocean.

device that is currently being tested is made by Wave

Dragon Ltd. The device, called Wave Dragon, is composed of two reflectors which focus the waves toward a ramp, a reservoir, which collects the overtopping water, and several turbines which convert the pressure of the water into power (Kofoed, et. al., 2004).The Wave Dragon resembles a kite, which allows it to move as the ocean water moves. A cable is used to attach the device to the sea bed, while still allowing it to adjust to the direction of incoming waves (Leung, 2005). The turbines are positioned at the bottom of the reservoir and spin as the water fills the reservoir. The electricity produced by the spinning turbines is transferred to shore through the use of a cable (Leung, 2005).Initial cost estimates showed that the Wave Dragon would produce electricity at approximately 18 cents per kilowatt- hour. At a capacity of 4 MW, the Wave Dragon developers project that cost to decrease within the next few years to an ultimate goal of about 6 cents per kilowatt-hour (Leung, 2005).

2.5.5 WAVE SURGE CONVERTERS:

Oscillating wave surge converters extract energy from wave surges and the movement of water particles (EMEC, 2008). They are placed on the shoreline or near the shore and are situated perpendicular to the direction of the waves. The motion of water particles within the passing waves allows the device to extract the horizontal energy stored in ocean waves (USDOE, 2008). The device usually consists of a paddle arm which pivots back and forth on a horizontal axis. The oscillation of the paddle arm is absorbed by a hydraulic pump, or other converter, which creates electricity (USDOE, 2008).

Various models have been developed to test the power generation of oscillating wave surge converters. In the United Kingdom, a numerical model was developed and applied to simulate the complex fluid flow of air and water (Qian et al., 2005). This particular design took many parameters into consideration and was ultimately designed to couple strongly with the horizontal particle motion to permit large amplitudes of motion and minimal energy loss.

EB Frond has been developed by Lancaster University and The Engineering Business Ltd. From their report to the DTI, the EB Frond is described as EB Frond is a wave generator with a collector vane at the top of an arm pivoted near the seabed. The arm driven by the water particle motion in the waves.

EB Frond incorporates devices which allow the pendulum motion to be tuned to the dominant frequency of the waves, and a set of hydraulic cylinders connected between the arm and the structure which deliver high- pressure oil to a hydraulic motor connected to an electrical generator. The structure is held rigidly on the seabed in a near shore location and remains submerged at all times.

Finally, BioWave has been developed by the University of Sydney and BioPower Systems Pty. Ltd, which describes the system on its website as "The wave energy conversion system, bioWAVE™, is based on the swaying motion of sea plants in the presence of ocean waves. The hydrodynamic interaction of the blades with the oscillating flow field is designed for maximum energy absorption... In extreme wave conditions, including hurricanes, the bioWAVE™ is automatically triggered to cease operating and assume a safe position lying flat against the seabed".

WaveRoller has been developed by AW-Energy OY and is described on its website as "A WaveRoller device is a plate anchored on the sea bottom by its lower part. The back and forth movement of bottom waves moves the plate, and the kinetic energy produced is collected by a piston pump. This energy can be converted to electricity by a closed hydraulic system in combination with a hydraulic motor/generator system."

2.6 LOCATIONS:

Shoreline devices have the advantage of being close to the utility network, are easy to maintain, and as waves are attenuated as they travel through shallow water they have a reduced likelihood of being dam- aged in extreme conditions. This leads to one of the disadvantages of shore mounted devices, as shallow water leads to lower wave power (this can be partially compensated by natural energy concentrated locations). Tidal range can also be an issue. In addition, by nature of their location, there are generally site-specific requirements including shoreline geometry and geology, and preservation of coastal scenery, so devices cannot be designed for mass manufacturing.

Near shore devices are defined as devices that are in relatively shallow water that this could be a depth of less than one- quarter wavelength). Devices in this location are often attached to the seabed, which gives a suitable stationary base against which an oscillating body can work. Like shoreline devices, a disadvantage is that shallow water leads to waves with reduced power, limiting the harvesting potential.

Offshore devices are generally in deep water although again there is little agreement about what constitutes 'deep' water. 'Tens of metres' is one definition, with 'greater than 40 m', and 'a depth exceeding one-third of the wavelength' being others. The advantage of siting a WEC in deep water is that it can harvest greater amounts of energy because of the higher energy content in deep water waves. However, offshore devices are more difficult to construct and maintain, and because of the greater wave height and energy content in the waves, need to be designed to survive the more extreme conditions adding cost to construction. Despite this, it is argued that with more powerful waves, floating devices in deep water offer greater structural economy.

It is useful to note that wave energy occurs in the movements of water near the surface of the sea Up to 95 per cent of the energy in a wave is located between the water surface and one-quarter of a wavelength below it.

2.7 POWER TAKE-OFF SYSTEMS:

The method of energy capture varies from device to device, but with the exception of linear electrical generation, discussed later, the general method of producing electrical power is through conventional high-speed rotary electrical generators. One of the major challenges of WECs is concerned with how to drive these generators. Heaving and nodding type devices are not directly compatible with conventional rotary electrical machines, and a transmission system is required to interface the WEC with the electrical generator.

In this section, different types of rotary generators are briefly presented, followed by an overview of different energy transfer methods. This starts with turbine transfer, moving on to hydraulic conversion methods, and then discussing direct electrical linear generators,

2.7.1 ROTARY GENERATOR TYPES:

Traditional power stations use online synchronous generators (SGs), and are operated at a virtually constant speed, matching the frequency of the grid connection. Depending on the conversion system, generators used for wave energy may have to cope with variable speed. Four generator types are identified: doubly fed induction generators (DFIG), squirrel cage induction generators, permanent magnet SGs, and field would SGs. O'Sullivan and Lewis discuss these generator options in terms of suitability for an OWC application, by examining the advantages and disadvantages in terms of environmental, electrical, and cost factors, and by using a time-domain MATLAB model. The generators in OWC devices typically operate at variable speed. There are similarities in this application with the mature technologies currently used in wind turbines. The favoured generators used in wind turbines (DFIG driven via a gear box, and direct drive low-speed SG with dedicated power electronics) are possible candidates for use in OWC WECs. O'Sullivan and Lewis's study concludes that the latter, the SG, are the preferred option due to its better energy yield, weight, and controllability, despite the requirement for a full frequency converter between the generator and the grid. The significant disadvantage of the DFIG is its maintenance requirement; DFIGs are not brushless machines a significant issue in offshore WECs.

2.7.2 TURBINE TRANSFER:

'Turbine transfer' is the term used here to represent the method employed in devices where the flow of fluid (either sea water or air) drives a turbine, which is directly coupled to a generator. The types of devices using direct transfer include OWCs and overtopping devices.

As discussed above, the requirements for generators in OWCs, such as variable speed input, are similar to those of a wind turbine, and thus have been well researched. The significant advantage of using sea water turbines is that leakage of fluid causes no environmental problems. The disadvantage is that sea water is a complex fluid with various unpredictable constituents. In addition, in near shore devices, abrasive particles could Cavitation could also be a problem, unless the turbine is in deep water to maintain positive pressure. In low-pressure situations, experienced in overtopping devices, propeller-type turbines are often used, such as the Kaplan design.

Using air as the working fluid has the advantage of increasing the slow velocities of waves to high air flow rate. The most popular air turbine design is the Wells turbine, because of its ability to rotate in the same direction, irrespective of airflow direction. Inherent disadvantages include low efficiency (around 60–65), poor starting, high noise, and high axial thrust when compared to traditional turbines. Pitch control of the turbine blades can increase efficiency.

2.7.3 HYDRAULICS:

Another method of converting the low speed oscillating motion of the primary WEC interface is to employ a hydraulic system. Waves apply large forces at slow speeds and hydraulic systems are well suited to absorbing energy in these situations. The use of hydraulics operating at a pressure of 400 bar is a distinct advantage of some types of WEC where size and weight are an issue, and the force created by these pressures are considerably greater than those from the best electrical machines.

The rod of the hydraulic cylinder is forced up and down by a floating buoy, which forces fluid through check valves, rectifying the flow, to a hydraulic motor. In this case, the generator could be a constant speed device, and the hydraulic motor has variable capacity, to drive the generator at close to constant speed despite a variable flow rate. The control of the motor capacity could be based on measured or predicted sea states around the WEC or fluid flow measurements within the system. Additionally, a throttling valve could also be used to control the flow to the motor. Accumulators are included in the circuit to provide energy storage and to maintain constant flow to the hydraulic motor. In addition, the low pressure accumulator provides a small boost pressure to reduce the risk of cavitation on the low-pressure side.

2.7.4 ELECTRICAL LINEAR GENERATION:

During early wave power research, the possibility of using electrical linear would be too heavy, inefficient, and expensive. New magnetic materials and the reduced costs of frequency converting electronics mean that this technology may now be possible. It is argued that the increased complexity of hydraulic or turbine systems introduce reliability and maintenance issues, which are important to minimize in offshore environments.

A linear SG offers the possibility of directly converting mechanical energy into electrical energy. The electrical direct drive PTO alternative is much simpler than hydraulic systems, with no intermediate steps between the primary interface and the electrical machine.

Conventional electrical machines are designed to be driven with high-speed rotary motion. The air gap speed between the rotor and stator in these machines can be high (upwards of 60 m/s) allowing for easy conversion into a rapid change in flux. Linear oscillatory motion from a WEC, however, is expected to have a peak of around 2 m/s. Developments for the wind power industry have focused on direct drive generators (to replace unreliable and heavy gearboxes). These direct drive generators have an air gap speed of 5–6 m/s. The development of linear electrical generators requires continuing research into slow-speed electrical machines.

The basic concept of a linear generator is to have a translator (what would be the rotor in a rotary machine) on which magnets are mounted with alternating polarity directly coupled to a heaving buoy, with the stator containing windings, mounted in a relatively stationary structure (connected to a drag plate, a large inertia, or fixed to the sea bed). As the heaving buoy oscillates, an electric current will be induced in the stator.

2.8 WAVE FARM CONFIGURATIONS:

There is presently a limited amount of information available with regards to the strategic placement of WECs. However, the primary wave farm configurations utilized by leading wave energy companies arrange arrays of WECs in either parallel or staggered grids. The company CETO's wave energy converters are placed in parallel rows underwater, whereas Ocean Power Technologies' power buoys are placed in designs which are “spaced to maximize energy capture”

(OPT, 2008). The layout of the WEC prototypes is in part based on the mechanism behind each design and how each WEC affects wave characteristics as a wave propagates past. A unique layout presented by Finavera Renewables consists of rows of WECs radiating from an open centre creating a sunburst-like configuration.

Wind farms follow similar layouts and components as wave farms and have been evaluated not only for their physical parameters but also with respect to optimal electrical configurations using either alternate or direct currents (AC/DC). Wind turbines generating DC power connected in series have the greatest potential in providing the lowest energy production costs when the transmission distance is greater than 10 to 20km (Lundberg, 2004). The energy production and investment costs in the study were determined using cost analysis for models of the wind farm components.

2.9 ENVIRONMENTAL IMPACT OF WAVE ENERGY:

In 2005, the Spanish Ministry of Science and Innovation launched a project to determine the minimum content that any environmental impact assessment should cover for wave energy systems. The project analysed a variety of wave energy converters including near shore and offshore devices using an exhaustive compilation of secondary data.

It was determined that surveillance programs for wave energy systems should focus on monitoring the following components (Bald, 2010):

- Submarine cable and moorings
- Benthic communities or life found in the lowest ocean level
- Ichthyofauna or fish populations within a region
- Underwater noise
- Marine mammals
- Fishing activities
- Underwater archaeological resources

In the physical environment, the study concluded that wave energy systems significantly impact swells and sediment quality, where as in the biotic environment, benthic communities, ichthyofauna, marine mammals, and marine birds are appreciably affected the primary actions resulting in the aforementioned dismantling of wave energy systems (Bald, 2010).

Installation	• Transport of material and equipment to and from the selected site • Installation of equipment/structures: WECs, moorings and submarine cables (associated noise, marine bottom and landscape alteration) and structures along the coastline • Residues storage (if required) • Small hydrocarbon leaks
Operation and maintenance	• Presence of structures • Operation of underwater cables (electromagnetic field) • Reduction of marine energy • Noise • Use of anti-fouling paints • Hydraulic/other liquid pollutants leaking • Presence of maintenance equipment/structures (associated noise, marine
Dismantling	• Transport of material and equipment to and from the selected site • Presence of dismantled equipment (associated noise, marine bottom and landscape alterations) • Final destination of dismantled structures • Small hydrocarbon leak.

Table 2.2 Primary actions causing environmental impacts

Installing WECs in areas that minimize the environmental impact is an important issue to consider when selecting a site for implementation. There are concerns about the potential environmental effects on marine animals including fish, birds, and mammals as well as on hydrography, coastal processes, and water quality. This disturbance for marine life would be particularly prevalent during the construction phase where the impacts are expected to be only temporary (Sorenson, 2002). The key would be to reduce the effects present during operation and maintenance to ensure an environmentally safe WEC project.

For fish, WEC installations are likely to act as artificial reefs and provide hard components of wave energy converters could become the centre for fish aggregations depending on the specific location of the device and on fish response. For marine birds, concerns include seabird collision for nocturnal species due to navigation lights, disturbance to local breeding colonies, and changes in distribution or availability of forage fishes (Sorenson, 2002). For marine mammals, issues such as collision, interference with migratory behaviour, and the disruption of sensory mechanisms are potential impacts (Sorenson, 2002). The effect of electromagnetic fields on marine life particularly fish have been found to be negligible assuming that electrical transmission cables have been sufficiently shielded (Nelson, 2008). An assessment of the local mammal population and whether the specific site is located in the vicinity of colonies would be important factors in order for a project to receive approval.

CHAPTER – 3

OSCILLATING WAVE SURGE CONVERTER

Of the entire available models, a bottom hinged model is selected for the following reasons

- Simple wave power configuration
- Reasonable point absorber efficiency
- Excellent potential for survivability
- Direct load transfer into sea bed
- Structural element is minimum
- Can skip high waves and hence is safe

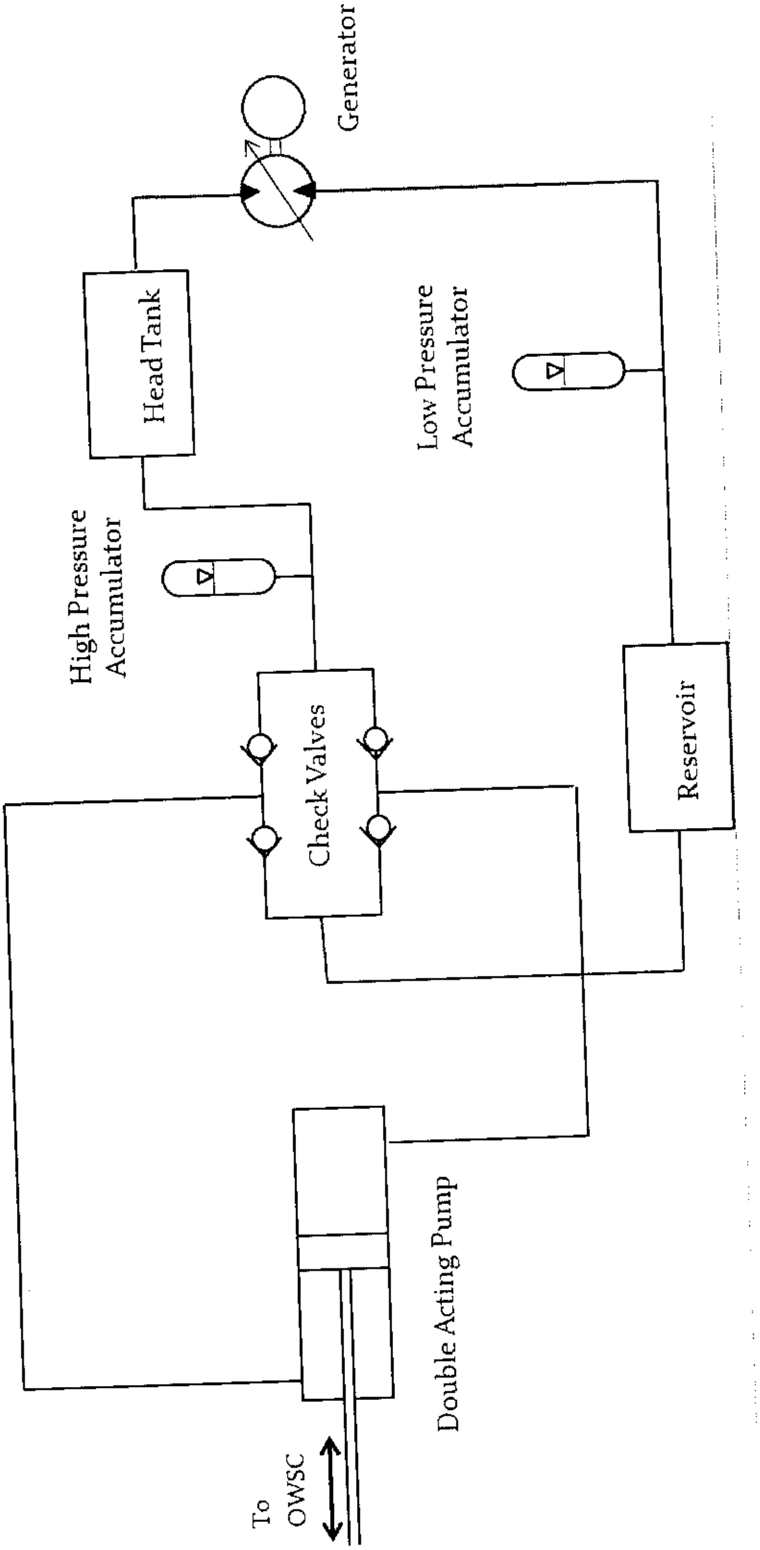
The Power take-off system used here is a Fresh water closed loop hydraulic system for the following reasons

- Hydraulic system helps to overcome the fluctuation in flow using an Accumulator which acts as a shock absorber.
- The construction is simple.
- Fresh water is used as the working fluid to avoid the hazard in case of any leakages as it is safe.
- Fresh water reduces the action of rusting on the internal walls of the pump and pipe lines.
- Being a closed loop system the working fluid is free from impurities and does not clog the pipelines.
- Formation of scales on the inner walls of pipes is absent.

The power generation plant is placed on shore for the following reasons

- Conventional electrical generation system can be used.
- Electrical power lines can be easily laid.
- Maintenance of the system is easy.
- Impact of the system on ocean environment is reduced.

3.1 PROPOSED SYSTEM:



The major components of the system are

- Paddle Buoy
- Double acting reciprocating Pump
- Accumulator
- Francis turbine
- Storage tank

3.2 PADDLE BUOY:

The power absorption system comprises of a paddle buoy. It is a rectangular buoy pivoted at its bottom. The buoy is designed in such a way that the buoyant force exerted on the buoy by the sea water is greater than the self-weight of the buoy. Because of this the buoy is maintained in a vertical position and also falls back to its vertical position when deflected.

3.3 DOUBLE ACTING RECIPROCATING PUMP:

A pump is a device used to move fluids, such as liquids, gases or slurries. A pump displaces a volume by physical or mechanical action.

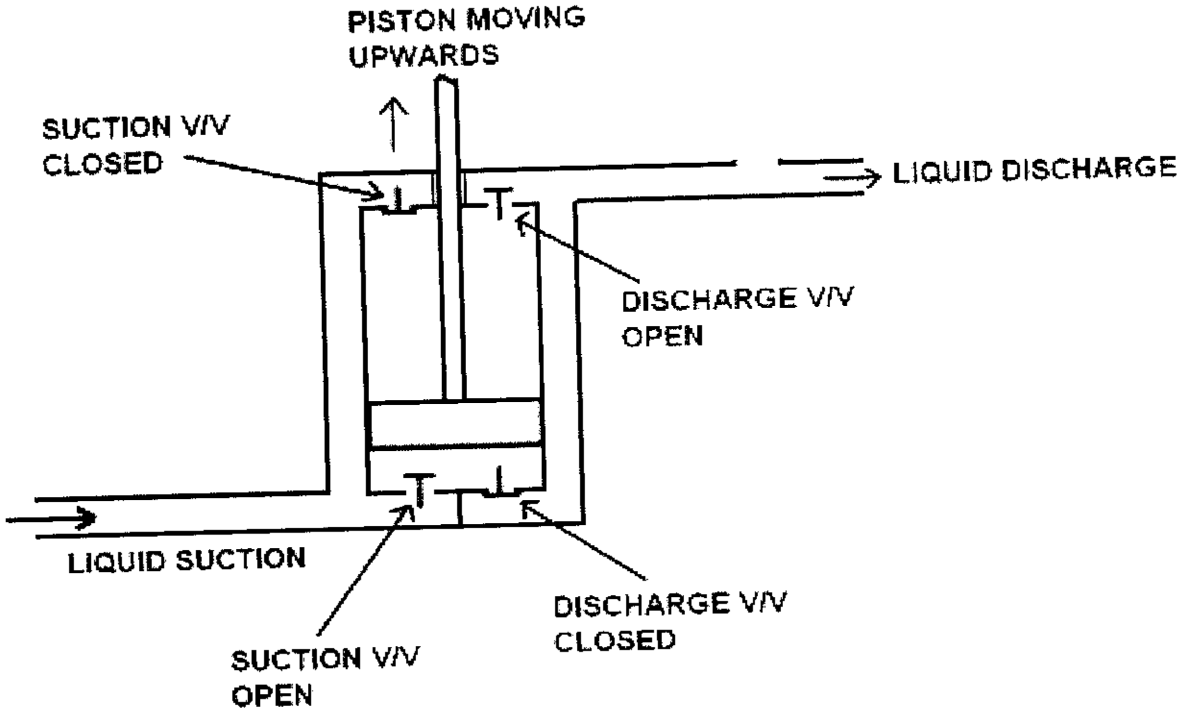


Figure 3.2 Double acting reciprocating pump

increase in internal leakage as the pressure increases, a truly constant flow rate cannot be achieved.

A positive displacement pump must not be operated against a closed valve on the discharge side of the pump, because it has no shut-off head like centrifugal pumps. A positive displacement pump operating against a closed discharge valve will continue to produce flow and the pressure in the discharge line will increase, until the line bursts or the pump is severely damaged, or both.

A relief or safety valve on the discharge side of the positive displacement pump is therefore necessary. The relief valve can be internal or external. The pump manufacturer normally has the option to supply internal relief or safety valves. The internal valve should in general only be used as a safety precaution, an external relief valve installed in the discharge line with a return line back to the suction line or supply tank is recommended.

3.3.1 POSITIVE DISPLACEMENT TYPES:

A positive displacement pump can be further classified according to the mechanism used to move the fluid:

Rotary-Type Positive Displacement: internal gear, screw, shuttle block, flexible vane or sliding vane, circumferential piston, helical twisted roots (e.g. the Wendelkolben pump) or liquid ring vacuum pumps.

Reciprocating-Type Positive Displacement: piston or diaphragm pumps.

Linear-Type Positive Displacement: rope pumps and chain pumps.

3.3.2 RECIPROCATING POSITIVE DISPLACEMENT PUMPS:

Reciprocating pumps are those which cause the fluid to move using one or more oscillating pistons, plungers or membranes.

Reciprocating-type pumps require a system of suction and discharge valves to ensure that the fluid moves in a positive direction. Pumps in this category range from having "simplex" one cylinder, to in some cases "quad" (four) cylinders or more. Most reciprocating-type pumps are "duplex" (two) or "triplex" (three) cylinder. Furthermore, they suction and discharge in both directions. The pumps can be powered by air, steam or through a belt drive from an engine or motor. Reciprocating pumps are now typically used for pumping highly viscous fluids including concrete and heavy oils, and special applications demanding low flow rates against high resistance.

3.4 ACCUMULATOR

A hydraulic accumulator is a pressure storage reservoir in which a non-compressible hydraulic fluid is held under pressure by an external source. The external source can be a spring, a raised weight, or a compressed gas. An accumulator enables a hydraulic system to cope with extremes of demand using a less powerful pump, to respond more quickly to a temporary demand, and to smooth out pulsations. It is a type of energy storage device.

3.4.1 FUNCTIONING OF AN ACCUMULATOR:

In modern, often mobile, hydraulic systems the preferred item is a gas charged accumulator, but simple systems may be spring-loaded. There may be more than one accumulator in a system. The exact type and placement of each may be a compromise due to its effects and the costs of manufacture.

An accumulator is placed close to the pump with a non-return valve preventing flow back to it. In the case of piston-type pumps this accumulator is placed in the best place to absorb pulsations of energy from the multi-piston pump. It also helps protect the system from fluid hammer. This protects system components, particularly pipework, from both potentially destructive forces.

An additional benefit is the additional energy that can be stored while the pump is subject to low demand. The designer can use a smaller-capacity pump. The large excursions of system components, such as landing gear on a large aircraft, that require a considerable volume of fluid can also benefit from one or more accumulators. These are often placed close to the demand to help overcome restrictions and drag from long pipework runs. The outflow of energy from a discharging accumulator is much greater, for a short time, than even large pumps could generate.

An accumulator can maintain the pressure in a system for periods when there are slight leaks without the pump being cycled on and off constantly. When temperature fluid that might otherwise be locked in a small fixed system with no room for expansion due to valve arrangement.

The gas precharge in an accumulator is set so that the separating bladder, diaphragm or piston does not reach or strike either end of the operating cylinder. The design precharge normally ensures that the moving parts do not foul the ends or block fluid passages. Poor maintenance of precharge can destroy an operating accumulator. A properly designed and maintained accumulator should operate trouble-free for years.

3.4.2 COMPRESSED GAS (OR GAS-CHARGED) CLOSED ACCUMULATOR:

A compressed gas accumulator consists of a cylinder with two chambers that are separated by an elastic diaphragm, a totally enclosed bladder, or a floating piston. One chamber contains hydraulic fluid and is connected to the hydraulic line. The other chamber contains an inert gas under pressure (typically nitrogen) that provides the compressive force on the hydraulic fluid. Inert gas is used because oxygen and oil can form an explosive mixture when combined under high pressure. As the volume of the compressed gas changes, the pressure of the gas (and the pressure on the fluid) changes inversely. Existing hydraulic accumulator designs are large and heavy due to the need for two storage tanks and do not have the high energy density needed for many applications.

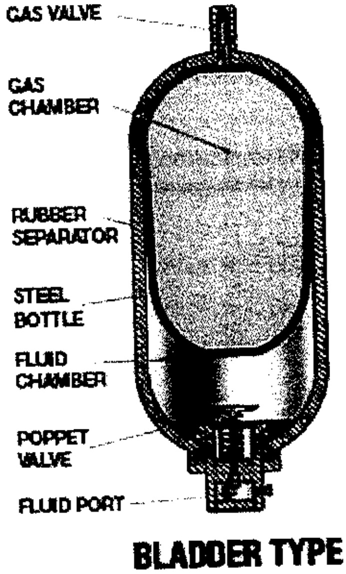


Figure 3.3 Bladder type accumulators

It is possible to increase the gas volume of the accumulator by coupling a gas bottle to the gas side of the accumulator. This is mainly done since a gas bottle normally is cheaper

3.5 FRANCIS TURBINE

The Francis turbine is a type of water turbine that was developed by James B. Francis in Lowell, Massachusetts. It is an inward-flow reaction turbine that combines radial and axial flow concepts.

Francis turbines are the most common water turbine in use today. They operate in a head range of 10 to 650 meters (33 to 2,133 feet) and are primarily used for electrical power production. The power output generally ranges from 10 to 750 megawatts, though mini-hydro installations may be lower. Runner diameters are between 1 and 10 meters (3 and 33 feet). The speed range of the turbine is from 83 to 1000 rpm. Medium size and larger Francis turbines are most often arranged with a vertical shaft. Vertical shaft may also be used for small size turbines, but normally they have horizontal shaft.

3.5.1 THEORY OF OPERATION:

The Francis turbine is a reaction turbine, which means that the working fluid changes pressure as it moves through the turbine, giving up its energy. A casement is needed to contain the water flow. The turbine is located between the high-pressure water source and the low-pressure water exit, usually at the base of a dam.

The inlet is spiral shaped. Guide vanes direct the water tangentially to the turbine wheel, known as a runner. This radial flow acts on the runner's vanes, causing the runner to spin. The guide vanes (or wicket gate) may be adjustable to allow efficient turbine operation for a range of water flow conditions.

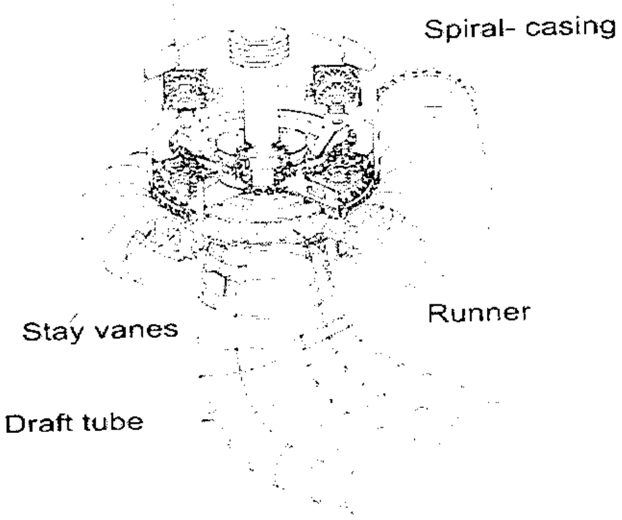


Figure 3.4 Francis turbine

As the water moves through the runner, it's spinning radius decreases, further acting on the runner. For an analogy, imagine swinging a ball on a string around in a circle; if the string is pulled short, the ball spins faster due to the conservation of angular momentum. This property, in addition to the water's pressure, helps Francis and other inward-flow turbines harness water energy efficiently.

3.6 CHECK VALVES:

A check valve, clack valve, non-return valve or one-way valve is a mechanical device, a valve, which normally allows fluid (liquid or gas) to flow through it in only one direction.

Check valves are two-port valves, meaning they have two openings in the body, one for fluid to enter and the other for fluid to leave. There are various types of check valves used in a wide variety of applications. Check valves work automatically and most are not controlled by a person or any external control; accordingly, most do not have any valve handle or stem. The bodies (external shells) of most check valves are made of plastic or metal.

An important concept in check valves is the cracking pressure which is the minimum upstream pressure at which the valve will operate. Typically the check valve is designed for and can therefore be specified for a specific cracking pressure.

Check valves are often used with some types of pumps. Piston-driven and diaphragm pumps such as metering pumps and pumps for chromatography commonly use inlet and outlet ball check valves. These valves often look like small cylinders attached to the pump head on the inlet and outlet lines. Many similar pump-like mechanisms for moving volumes of fluids around use check valves such as ball check valves. The feed pumps or injectors which supply water to steam boilers are fitted with check valves to prevent back-flow.

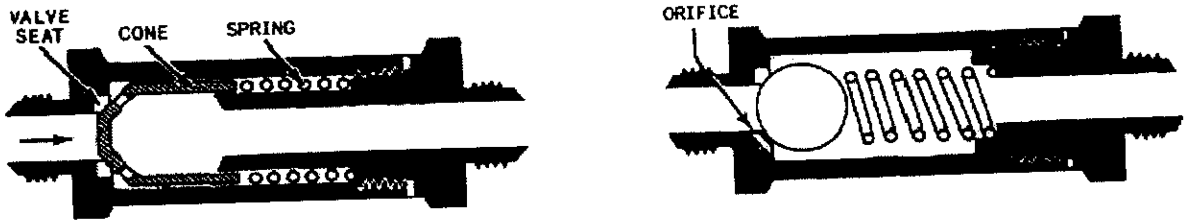


Figure 3.5 Check valve

TYPES OF CHECK VALVES:

A ball check valve in the open position to allow forward flow and closed position to block reverse flow

BACKWATER VALVE:

Backwater valve (for sanitary drainage system) protects lower located rooms against flooding caused by return flow of sewage waters. Such risk occurs most often in sanitary drainage systems connected to combined sewerage systems and in rainwater drainage systems. It may be caused by intense rainfall, thaw or flood. Backwater valve prevents rats and other rodents entering the sanitary and rainwater drainage systems and, consequently, the building interiors. It protects also against unpleasant smells in case of longer breaks in system use.

BALL CHECK VALVE:

A ball check valve is a check valve in which the closing member, the movable part to block the flow, is a spherical ball. In some ball check valves, the ball is spring-loaded to help keep it shut. For those designs without a spring, reverse flow is required to move the ball toward the seat and create a seal. The interior surface of the main seats of ball check valves are more or less conically-tapered to guide the ball into the seat and form a positive seal when stopping reverse flow.

Ball check valves are often very small, simple, and cheap. They are commonly used in liquid or gel minipump dispenser spigots, spray devices, some rubber bulbs for pumping air, etc., manual air pumps and some other pumps, and refillable dispensing syringes. Although the balls are most often made of metal, they can be made of other materials, or in some specialized cases out of artificial ruby. High pressure HPLC pumps and similar applications commonly use small inlet and outlet ball check valves with both balls and seats made of artificial ruby, for both hardness and chemical resistance. After prolonged use, such check valves can eventually wear out or the seat can develop a crack, requiring replacement. Therefore, such valves are made to be replaceable, sometimes placed in a small plastic body tightly-fitted inside a metal fitting which can withstand high pressure and which is screwed into the pump head.

There are similar check valves where the disc is not a ball, but some other shape, valves, which is a different type of valve in which a ball acts as a controllable rotor to stop or direct flow.

DIAPHRAGM CHECK VALVE:

A diaphragm check valve uses a flexing rubber diaphragm positioned to create a normally-closed valve. Pressure on the upstream side must be greater than the pressure on the downstream side by a certain amount, known as the pressure differential, for the check valve to open allowing flow. Once positive pressure stops, the diaphragm automatically flexes back to its original closed position.

SWING CHECK VALVE:

A swing check valve or tilting disc check valve is check valve in which the disc, the movable part to block the flow, swings on a hinge or trunnion, either onto the seat to block reverse flow or off the seat to allow forward flow. The seat opening cross-section may be perpendicular to the centreline between the two ports or at an angle. Although swing check valves can come in various sizes, large check valves are often swing check valves. The flapper valve in a flush-toilet mechanism is an example of this type of valve. Tank pressure holding it closed is overcome by manual lift of the flapper. It then remains open until the tank drains and the flapper falls due to gravity. Another variation of this mechanism is the clapper valve, used in applications such fire fighting and fire life safety systems. A hinged gate only remains open in the inflowing direction. The clapper valve often also has a spring that keeps the gate shut when there is no forward pressure.

STOP CHECK VALVE:

A stop-check valve is a check valve with override control to stop flow regardless of flow direction or pressure. In addition to closing in response to backflow or insufficient forward pressure (normal check-valve behaviour), it can also be deliberately shut by an external mechanism, thereby preventing any flow regardless of forward pressure.

LIFT CHECK VALVE:

A lift-check valve is a check valve in which the disc, sometimes called a lift, can be lifted up off its seat by higher pressure of inlet or upstream fluid to allow flow to the outlet or downstream side. A guide keeps motion of the disc on a vertical line, so the valve can later reseat properly. When the pressure is no longer higher, gravity or higher downstream pressure will cause the disc to lower onto its seat, shutting the valve to stop reverse flow.

DUCKBILL VALVE:

A duckbill valve is a check valve in which flow proceeds through a soft tube that protrudes into the downstream side. Back-pressure collapses this tube, cutting off flow.

CHAPTER - 4

CALCULATIONS

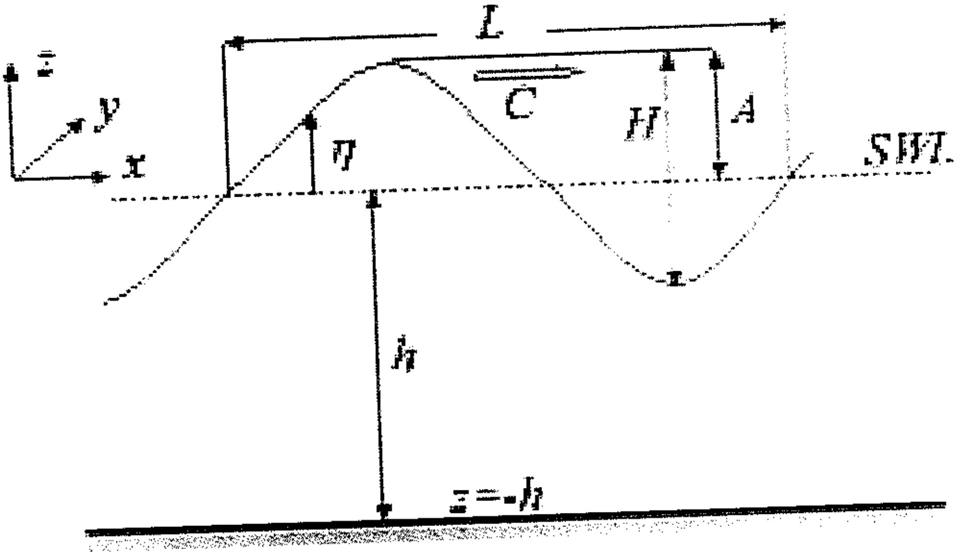


Figure 4.1 Attribute of Wave

4.1 ENERGY FROM WAVE FRONT:

The Energy from a wave front is given as

$$E = \frac{\rho_w g^2}{64\pi} H_{1/3}{}^2 \, T_{1/3} \qquad [1]$$

Substituting, $\rho_w = 1030 \; kg/m^3$, $g = 9.81 \; m/s^2$ in equation [1], we get

$$E = 0.5 \, H_{1/3}{}^2 \, T_{1/3} \;\; kW/m$$

Energy absorbed by the Buoy = Energy from Wave Front x Width of the OWSC

[2]

4.2 DESIGN OF BUOY:

To determine the volume of the Buoy, consider it as a structure made up of a Hollow cuboid opened at both ends and a hollow cylinder

Arc Length, x = $2l_s \sin\theta_0$ m

Volume of the Hollow cuboid = $\left((w \times B) - \left((w-2t)\times(B-2t)\right)\right) \times (l_b - w)$

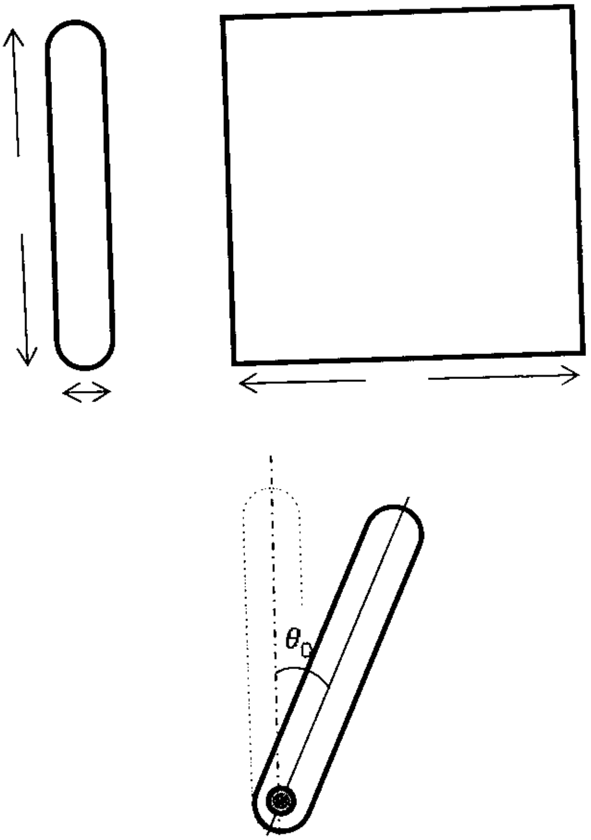


Figure 4.2 Dimensions of Buoy

Volume of the Hollow cylinder = $\frac{\pi w^2 B}{4} - \frac{\pi (w-t)^2 (B-2t)}{4}$

Volume of the Buoy, V_b = Volume of the Hollow cuboid + Volume of the Hollow cylinder

$$= \left(\left((w \times B) - \left((w-2t)\times(B-2t)\right)\right) \times (l_b - w)\right) +$$

$$\left(\frac{\pi w^2 B}{4} - \frac{\pi (w-t)^2 (B-2t)}{4}\right) \qquad [3]$$

Weight of the Buoy, W = $\rho_b \times g \times V_b$

According to Archimedes Principle,

Buoyancy = Weight of Displaced Fluid

Volume of Displaced Water, $V_w = \frac{\pi w^2 B}{8} + wB(l_i - w/2)$

Weight of Displaced Water = $\rho_w \times g \times V_w$ [4]

Buoyant Force exerted on the Buoy = Weight of Displaced Water

To maintain the buoy in the vertical position,

Buoyant Force exerted on the Buoy > Weight of the Buoy

$$\rho_w V_w > \rho_b V_b \qquad [5]$$

4.3 DESIGN OF RECIPROCATING PUMP:

Weight of water delivered per second, W = $\rho_f \times g \times Q$ N/s

Discharge of Pump per second, Q = Discharge in one cycle × No. of cycle per second

Time taken for 1 cycle = Time period of Wave, s

Time taken for 1 cycle = T s

Stroke length, L_p > Arc length, x

Therefore, No of cycle per second = $\frac{1}{T}$ s^{-1}

Discharge in 1 cycle = $\left(\frac{\pi}{4} \times D^2 + \frac{\pi}{4} \times (D-d)^2\right) \times L_p$ m^3

Discharge of Pump per second, $Q = \dfrac{\left(\frac{\pi}{4}\times D^2 + \frac{\pi}{4}\times(D-d)^2\right)\times L_p}{T}$ m^3/s [6]

Power required to drive the Pump, P_p = Weight of water delivered per second × Total height through which water is lifted

$$P_p = \frac{W \times (h_s + h_d)}{1000} \text{ kW}$$

Since Suction Head is at the same level as the Inlet of the pump, $h_s = 0$

Hence, $P_p = \dfrac{W \times h_d}{1000}$ kW

$$P_p = \frac{\rho_f \times g \times \left(\frac{\pi}{4}\times D^2 + \frac{\pi}{4}\times(D-d)^2\right)\times L_p \times h_d}{T\times 1000} \text{ kW} \quad [7]$$

Also, Power required to drive the Pump = Energy absorbed by the Buoy

$$\frac{\rho_f \times g \times \left(\frac{\pi}{4}\times D^2 + \frac{\pi}{4}\times(D-d)^2\right)\times L_p \times h_d}{T\times 1000} = 0.5 H_{1/3}{}^2\, T_{1/3} B \quad [8]$$

From equation [8], the Discharge head of the pump can be determined.

The value of μ for water at different temperatures is

Temperature °C	**Viscosity** ×10^{-3} Ns/m^2
10	1.308
20	1.002
30	0.7978
40	0.6531
50	0.5471
60	0.4668
70	0.4044
80	0.3550
90	0.3150

Table 4.1 Variation of Viscosity of water with respect to Temperature

Considering the major loss in Transmission Pipes, i.e. the Loss due to friction

Loss of head given by Darcy Formula, $h_f = \frac{4 \times f \times l_d \times V^2}{d_d \times 2 \times g}$ m [9]

$$f = \frac{16}{R_e} \text{ for } R_e < 2000 \text{ (Viscous flow)}$$

$$f = \frac{0.079}{R_e^{1/4}} \text{ for } R_e \text{ varying from } 4000 - 10^6$$

Reynold's Number, $R_e = \frac{\rho_f \times V \times d_d}{\mu}$

Net Head of water = Discharge head - Loss of head

$$H_N = h_d - h_f \text{ m} \quad [10]$$

Conversion from Head of water to Pressure is given by

$$\text{Pressure} = 0.0981 \times H_N \times S.G \text{ bar} \quad [11]$$

4.4 DESIGN OF PROTOTYPE MODEL:

The wave data taken for calculation is as follows

$H_{1/3} = 0.05$ m, $T_{1/3} = 1$ s

dimension of the buoy as,

$B = 0.36$ m, $w = 0.09$m, $t = 2 \times 10^{-3}$ m, $l_b = 0.36$ m, $l_s = 0.025$ m ,

Energy absorbed by the buoy, $P = 0.5 \times 0.05^2 \times 1 \times 0.36$

$= 0.45$ W

For buoy,

Volume of the buoy $= \left((\pi \times 0.045^2 \times 0.36) - (\pi \times 0.043^2 \times 0.356)\right) \times 4$

$V_b = 8.891 \times 10^{-4}$ m^3

$V_w = (\pi \times 0.045^2 \times 0.36) \times 3$

$V_w = 6.87 \times 10^{-3}\ m^3$

From equation [5]

$$\rho_w V_w > \rho_b V_b$$

$$1000 \times 6.87 \times 10^{-3} > 1300 \times 8.891 \times 10^{-4}$$

$$6.87 > 1.15$$

Hence, the dimension of the buoy satisfies the design condition.

For the pump,

Assume D = 0.015 m, L_p = 0.025 m, d = 0.01m, d_d = 0.06 m, l_d = 0.5 m

Calculating Discharge head,

$$Q = \frac{\left(\frac{\pi}{4} \times 0.015^2 + \frac{\pi}{4} \times (0.015 - 0.01)^2\right) \times 0.025}{1}$$

$$Q = 4.9 \times 10^{-6}\ m^3/s$$

$$Q = 2.94 \times 10^{-4}\ m^3/min$$

$$P_p = 1000 \times 9.81 \times 4.9 \times 10^{-6} \times h_d$$

$$0.45 = 0.024\ h_d$$

$$h_d = 9.4\ m$$

Calculating Loss of head,

$$Q = A \times V$$

$$4.9 \times 10^{-6} = \pi \times 0.006^2/4 \times V$$

$$V = 0.173\ m/s$$

$$R_e = \frac{1000 \times 0.173 \times 0.006}{1.002}$$

[Since $\mu = 1.002$ at $20^{\circ}C$]

[Therefore, the flow is Laminar]

$$f = \frac{16}{1.035}$$

$$f = 15.46$$

$$h_f = \frac{4 \times 15.46 \times 0.5 \times 0.173^2}{2 \times 9.81 \times 0.006}$$

$$h_f = 7.8 \text{ m}$$

Therefore, Net head of Water, $H_N = 9.4 - 7.8$

$$H_N = 1.6 \text{ m}$$

CHAPTER-5

CONCLUSION

The existing source of fuels driving the world is fast depleting and is producing a huge impact on the environment. Hence, the development of Renewable energy sources has become the need of the day.

Two-third of the world is covered by ocean. The ocean are constantly generating huge amount of energy and tapping of such enormous energy could support our growing energy needs. But harnessing energy from ocean involves a huge investment and great engineering technologies.

The model proposed in this report can be used to tap the energy from the swells at shallow water where the wave length and the wave height are high. The model has the advantage that it can absorb the energy from the wave to the full depth this provides a better energy absorption. In case of harsh conditions the huge waves overflow the flap and hence it is protected. Being a closed loop system using fresh water as the working fluid it impact on the ocean environment is less even in case of any breakdowns. The entire power generating unit is placed On-Shore. Hence it is safe and Cost efficient. Sufficient care has been taken while designing the various aspects to reduce the environmental impact caused by the implementation of the project.

A prototype was also fabricated to prove the working of the concept.

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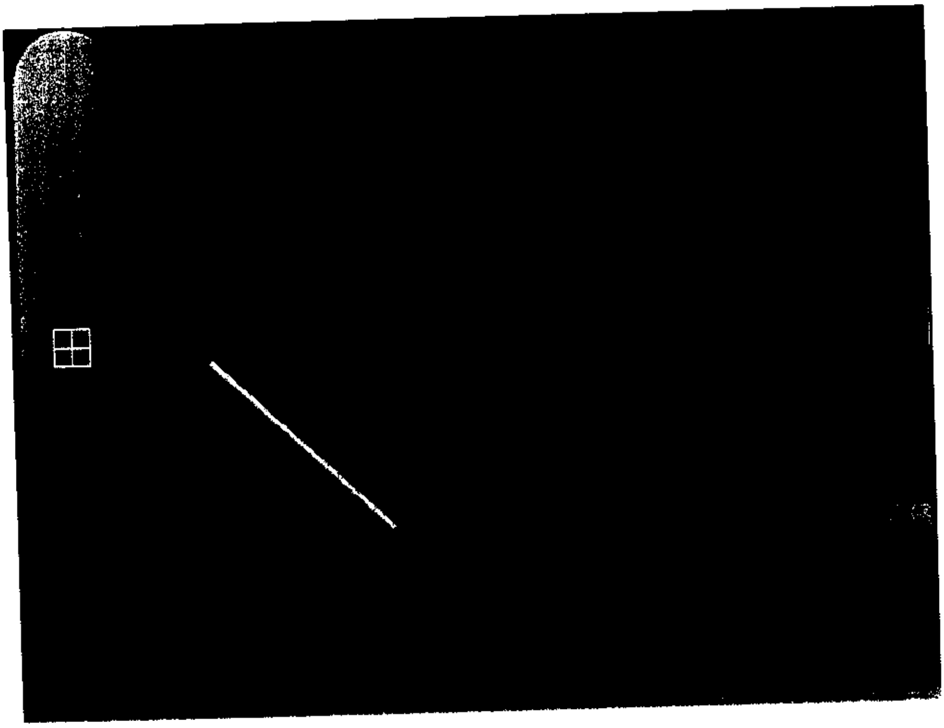
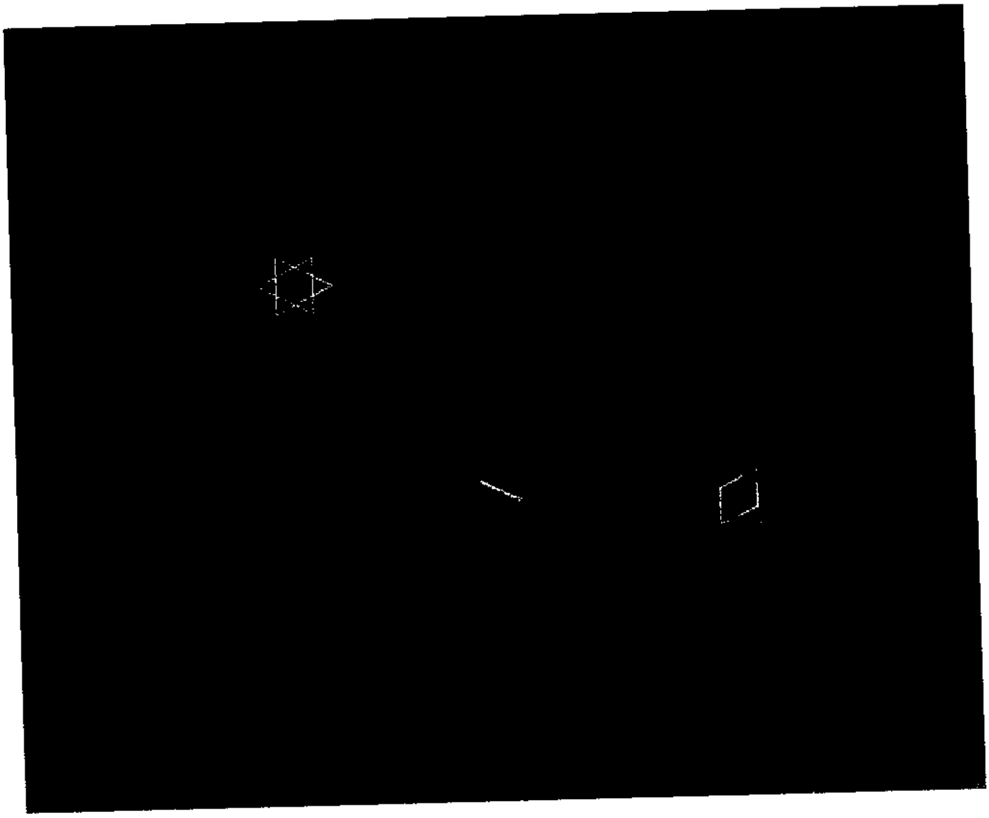
ANNEXURE - I



Side View of the Prototype



Photograph of the Model