DESIGN AND DEVELOPMENT OF A WATER PUMPING SYSTEM

BY

IMARHIAGBE BELIEVE IFEANYI

MAT.NO: ENG1704467

DEPARTMENT OF PRODUCTION ENGINEERING

UNIVERSITY OF BENIN

BENIN CITY

NOVEMBER, 2022

DESIGN AND DEVELOPMENT OF A WATER PUMPING SYSTEM

BY

IMARHIAGBE BELIEVE IFEANYI

MAT.NO: ENG1704467

A PROJECT SUBMITTED TO THE DEPARTMENT OF PRODUCTION ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING IN PRODUCTION ENGINEERING

NOVEMBER, 2022

CERTIFICATION

The under-listed hereby certify that this project was carried out by Imarhiagbe Believe Ifeanyi with matriculation number ENG1704467. This project is adequate in scope and quality for the award of Bachelor of Engineering in Production Engineering, University of Benin, Benin City.

_____ _____

Prof. P.E Amiolemhen DATE

(Project Supervisor)

_____ _____

Engr. Dr. C.E. Etin-osa DATE

(Dept. Project coordinator)

_____ _____

Engr.Dr.I.D. Erhunmwun DATE

(Head of Department)

DEDICATION

This project is dedicated to God Almighty and to my wonderful parents, Mr. and Mrs. Imarhiagbe who nurtured me up to this stage and also inculcated in me the necessary values to be where I am today. A special feeling of gratitude to them for their unending prayers and words of encouragement.

ACKNOWLEDGMENT

My profound gratitude goes to God almighty for his guidance and protection, I would love to express my gratitude to my parents, Mr, and Mrs. Imarhiagbe. Also, I would love to express my thanks to my awesome siblings for all their support during my stay at this great university.

More also my gratitude goes to my supervisor, Prof. P.E Amiolemhen who has given me his full support and guidance throughout my project work. My appreciation goes to my friends and well-wishers who stood by me throughout my course at the University of Benin God bless you all.

TABLE OF CONTENT

CERTIFICATION I

DEDICATION II

ACKNOWLEDGMENT III

LIST OF FIGURES VII

LIST OF TABLES VIII

NOMENCLATURE IX

ABSTRACT XI

1.1 Background of Study 1

1.2 Statement of the Problem 1

1.3 Aim of Study 3

1.4 Objectives of study 3

1.5 Scope of Study 3

CHAPTER 2 4

LITERATURE REVIEW 4

2.1 Historical Background 4

2.2. Pumps, Pumping Systems, and Classification of Pumps 6

Pump 6

Pumping Systems 6

2.2.1. Classification of Pumps 7

2.2.2. Positive Displacement Pumps 8

2.2.3. Kinetic Energy Pumps 8

2.3. Centrifugal Pumps 9

2.3.1. Types of Centrifugal Pumps 9

2.4. Centrifugal Pump Components: 9

2.5. Principle of Operation for Centrifugal Pump 10

2.6. Problems of Centrifugal Pumps 11

2.7. Pump Materials 12

CHAPTER THREE 15

METHODOLOGY 15

3.1. Design Consideration 15

3.1.1. Impeller 16

3.1.2. Casing 16

3.1.3. Shaft 17

3.1.4. Mechanical Seal 17

3.2. Design Equations and Calculations 17

3.2.1. Detailed Design 17

3.2.2. Calculated Data 17

3.2.3. Impeller Design 18

3.2.4. Impeller Blade Angles 19

3.2.4.1 Hydraulic Efficiency Ƞh, ... 20

3.2.4.2 True Whirl Component, Vn 20

3.2.4.3 Ideal Whirl Component, V∞ 21

3.2.4.4. Velocity of Flow, Y_2 21

3.2.4.5 Outlet Blade Angle 21

3.2.5 Inlet flow velocity 21

3.2.6. Casing Design 22

Detailed Diagrams 24

CHAPTER FOUR 31

DISCUSSION AND RESULT ANALYSIS 31

BILLS FOR ENGINEERING MEASUREMENT 31

4.1 Materials Bills 31

4.2 Labor Cost 32

4.3 Manufacturing Cost 32

4.4 Testing 32

4 .5. Pump Operating Procedures 33

4.6. Maintenance 33

CHAPTER FIVE 35

CONCLUSION 35

Recommendation 35

REFERENCES 36

LIST OF FIGURES

Page number

Figure 2.1: Classification of pumps 8

Figure 3.1: 3D Model of an assembled centrifugal pumping system (circular casing) 23

Figure 3.1.1: 3D Model of an assembled centrifugal pumping system with labeled paths (circular casing) 24

Figure 3.2: front and side view of the assembled centrifugal pumping system 25

Figure 3.3: a plan of the assembled centrifugal pumping system 25

Figure 3.4: 3D model of the impeller in its casing which has the discharge outlet 26

Figure 3.5: front and side view of the impeller in its casing 26

Figure 3.6: the plan of the impeller in its casing 26

Figure 3.7: 3D model of the impeller casing which has the discharge outlet 26

Figure 3.8: Side and plan view of the impeller casing which has the discharge outlet 27

Figure 3.9: 3D model of the impeller casing cover with Bolts 28

Figure 3.10: Plan and side view of impeller casing cover 28

Figure 3.10.1: the plan of the impeller casing cover 29

Figure 3.11: 3D model of the impeller 29

Figure 3.12: Plan and side view of the impeller 29

LIST OF TABLES

	Page Number
Table 4.1: Materials Cost	30
Table 4.2: Cost of Labour and Services	31

NOMENCLATURE

Q = Capacity (m^3/s)

H = Head (m)

N = Rotational Speed (rpm)

Ns = Shape Number (m/s)

Nusf = Useful power (kW)

ρ = Density (Kg/m^3)

Nmp = Motor power (kW)

η= Efficiency

D_1 = Impeller eye diameter (mm)

D_2 = Impeller outer diameter (mm)

b_1 = Impeller eye width (mm)

b_2 = Impeller outer width (mm)

ϕ= Speed ratio

U_2= Impeller rim velocity (m/s)

U_1 =Impeller inner velocity (m/s)

η_h= Hydraulic Efficiency

V_n= True whirl velocity component (m/s)

V_∞ = Ideal whirl velocity component (m/s)

Z =Number of blades

K_S = 3.65

Kn = Factor ranging from 3-5

Y_2 = Velocity of flow (m/s)

Ψ = Flow ratio

γ = Outlet blade angle (deg)

Y_1 = Inlet flow velocity (m/s)

β = Intlet blade angle (deg).

D_3 = Casing inside diameter (mm)

b_3 = Casing width (mm)

T_C = Casing thickness (mm)

D_4 = Casing outer diameter (mm)

NPSH = Net Positive Suction Head

ABSTRACT

The design, construction, and experimental testing of a water pumping system using a centrifugal pump are reported in this project. This can be used in homes, agriculture, and industries. A centrifugal pump consists of an impeller, impeller casing, impeller shaft, suction, and delivery pipes, and an electric motor. The pump should be installed close to the source of water to be pumped and proper maintenance should be carried out periodically for good operation.

The evaluation of the pump performance was carried out by testing the centrifugal pump. This process involves measuring the height to which the water can be pumped and the volume of water that can be pumped per second. Results show that a height of 34.7m, and volume of 16,200 litres/h i.e 4.5 liters/sec. can be obtained with the pump. The pump efficiency was 90%. The pump was powered by a 2.2kW / 1450rpm single-phase electric motor.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Pumping systems works with tremendous energies that are very useful and needed in the world today. There is always a need to move liquids from one point to another, for example, water movement from underground tanks to overhead water tanks, water from dams and rivers to homes, industries, and farm settlements, or water for general purposes (Okokowa (2003)). Furthermore, pumping systems range between 25-50% usage in various industrial plant operations.

The use of pumping systems is broad because they perform different operations in diverse ways. These systems provide domestic, commercial, and agricultural services in crop cultivation and production systems in exchange for money to meet various needs. Additionally, they provide municipal water, wastewater, and industrial services for food processing, chemical, petrochemical, and mechanical industries today. (Anup kumar dey, 2019). The main function of the pumping system is a liquid transfer from one place to another (e.g transferring water from an underground aquifer to a water tank) (Anup kumar dey, 2019).

Centrifugal pumps are popular in general service (domestic, agricultural, industrial, etc.) and are a type of pump with the relative simplicity of the technique, flow rate capabilities, quiet operation, electric motor/turbine drive adaptability of use, low maintenance expense, abrasive solution compatibility, etc. The reverse function of the centrifugal pump is a water turbine that converts the potential energy of water pressure into mechanical rotational energy.

1.2 Statement of the Problem

From recent studies, research, and observations, it has been discovered that one of the biggest problems of pumping systems today is the ever-growing skill gap. Every year, there are fewer people with the required expertise to diagnose, create, fix, and solve major problems associated with pumps which can be catastrophic. The effects can be seen in industries such as paper mills

and water treatment plants because one failed pump can shut down a whole production process. It is crucial and very important to keep pumps in good working conditions for continued functionality. (Samotics, 2020)

Centrifugal pumps and pumps, in general, have some problems which are outlined as follows:

i. Mechanical seal leakage
ii. Foreign objects entering the pump cause malfunctions in the system, which leads to subpar performance.
iii. Low flow operation and fatigue stress lead to excessive shaft deflection and breaking of the shaft respectively.
iv. A pump with metal parts wears easily and runs the risk of seizure and excessive damage.
v. Delivery failure: This happens when the pump is unable to deliver the pressure required.
vi. Priming failure: Pump priming is necessary to begin pumping and improper priming leads to failure.
vii. Leakage in the pump
viii. Air leakage
ix. Leakage in gland point
x. Faulty priming gland.
xi. **Inability to build pressure:** This occurs when the pump is unable to build the required pressure to ensure a smooth flow of liquid. Furthermore, the presence of unopened air cocks and proper priming, the absence of worn-out or damaged wear rings, and other mechanical pump defects indicate c**avitation in the casing of the pump**.
xii. **Reduced capacity:** Due to the consistent and continuous running of the pumping system, the capacity of the pump tends to drop drastically which leads to insufficiency in capacity.
xiii. **Process issues:** This type of failure occurs as a result of an improperly selected pump peculiar to the process, industrial application, or operating conditions. So it is very important and crucial to install the right pump for the required process.
xiv. **Bearing issues:** According to research and experiences from professionals, this occurs due to poor lubrication of the system causing it to overheat. Bearings are to supposed be covered in lubricants to about 80% for proper functionality and free flow. Other related causes of bearing issues could be overload and fatigue.

xv. **Impeller wear and tear**: This failure occurs due to erosion and imbalance of the pump leading to unstable pressure. It could also result from an improperly sized pump (samotics 2020).

1.3 Aim of the Study

This project aims to design and construct a stable, fast, reliable, and affordable centrifugal water pumping system that can deliver a vertical head of 13m using locally made materials.

1.4 Objectives of the study

To achieve the aim of this project, the following objectives were taken during the execution of the project:

i. Detailed design of the centrifugal pump components.
ii. Appropriate selection of materials sourced locally
iii. Fabrication and assembly of the centrifugal pumping system.
iv. Testing and performance evaluation of the designed pump.

1.5 Scope of the Study

A simple design with a simple circular casing and an enclosed impeller was made. The impeller and casing material was made from Aluminum. The entire unit is a monoblock pump i.e. direct coupling of the motor to the impeller.

CHAPTER 2

LITERATURE REVIEW

2.1 Historical Background

The first traditional pumping method applied in ancient Persia was gravity based. If a water source was available at a higher elevation than its point of use, gravity can supply water via pipes or aqueducts. The Qanat is an example of this method and it was applied for the first time in Iran ca. 1200 BC (Jomehpour, 2009 and Kristoferson et al., 1986). The collection of rainwater from roofs or catchment areas and its storage in cisterns or as groundwater was another possibility. Horizontal drilling was another reasonably easy and low-cost method for tapping water resources in a way that would provide water without pumping, just by gravity flow. This is also an old method dating back to ca. 800 BC when the Persians began to dig the famous Qanats (Kristoferson et al., 1986). Like the Egyptians, the ancient Persians also used the shaduf, an old and simple device that evolved from the hand-carried bucket (see Figure 5a and (Koth et al., 2000).

The original method of using animals to lift water was a device called mohte. Here, animals walk in a straight line, down a slope, away from the well or water source, while hauling water up in a bag or container. Traditional mohtes used a leather bag to collect the water, but in recent years more durable materials such as rubber truck inner tubes (or more rarely steel oil barrels) have been used. The Persian waterwheel (Raha) is a great improvement over the mohte, as its chain of buckets imposes an almost constant load on the drive shaft to the waterwheel. Persian waterwheels are usually driven by some form of right-angle drive. The first is the most common; the drive shaft from the second gear is buried and the animals walk over it; this has the advantage of keeping the Persian waterwheel as low as possible, to minimize the head through which water is lifted. The second example is a traditional wooden Persian waterwheel mechanism, which is based on the animal passing under the horizontal shaft. The sweep of a Persian wheel carries an

almost constant load and therefore the animal can establish a steady comfortable pace and needs little supervision. The advantages of the Raha were: It was based on a relatively inexpensive traditional technology. It could be locally constructed and maintained and lifted water to 20 m (although it was most efficient at depths under 7.5 m and yielded approximately 160–170 L/min of water for lifts of 9 m), it was easy to operate and it had medium efficiency (40%–70%). Howes, (1984) indicated the advantages of the Raha when compared to solar-powered pumps. The disadvantages of these devices were that water had to be raised above the point of discharge before falling into the collection channel and that animals had to be maintained year-round, even when irrigation was not necessary (rainy season) (Fraenkel, 1986 and Olley, 2008).

Furthermore, in 1687 a French-born inventor **Denis Papin** developed the **first true centrifugal pump**, one with straight vanes used for local drainage. A hundred and sixty-four years later, the curved vane centrifugal pump was introduced by British inventor John Appold. During that same year, John Gwynne filed his first centrifugal pump patent. These pumps were used primarily for land drainage, and many can still be seen today in pump house museums. They were usually powered by Gwynnes' steam engines. By the end of the 19th century, Gwynne was producing pumps of all sizes to cover all industrial applications, from small electric pumps to those rated at 1,000 tons per minute. His company had also begun to produce scientific pumps, e.g., porcelain pumps for chemical works. In the 1930s they were producing almost 1,000 different models (Champlin 2018).

The great exhibition of 1851 became a turning point for the development of the centrifugal pump. Several designs were shown, of which a few appeared to be very successful. Since then the centrifugal pump has been developed into a high-efficiency machine, which can be adapted to suit almost any working condition. In 1870 UK Professor Osborne Reynolds developed an original design of a centrifugal pump and sixteen years later the United Centrifugal Pumps was incorporated. It became the world's foremost supplier of high-pressure crude oil and refined product pipeline pumps.

Centrifugal pumps can be used for an oil pipeline, which was demonstrated in 1923 by Byron Jacksondem. He also demonstrated the use of this pump in the first automatic booster station. Aldrich also produced the first variable-stroke multi-cylinder reciprocating pump in 1927.

Also, in 2006 Sims manufactured the largest structural composite centrifugal impeller in the world. This huge impeller was installed in a cooling tower pump for Puerto Rican Electrical Power Company. It was 50 inches in diameter and consumed 2,000 horsepower. In the same year, Allweiler designed and produced a high-tech EMTEC-A pump designed specifically for moving emulsions and cooling lubricants. More discoveries and innovations concerning pumps continue to be made such as Sims designing and engineering the first structural composite anti-heeling pump manufactured for NCL Cruise lines.

2.2. Pumps, Pumping Systems, and Classification of Pumps

Pump

A pump is a device that moves fluids (liquids or gases), or sometimes slurries by mechanical action, typically converted from electrical energy into hydraulic energy. Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps (Naidoo, 2006).

Pumps operate by some mechanism (typically reciprocating or rotary) and consume energy to perform mechanical work moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power, and come in many sizes, from microscopic for use in medical applications, to large industrial pumps. Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps (Fraenkel 1986).

Pumping Systems

Pumping systems are usually composed of one or more than one centrifugal pump arranged in parallel. Early pumping systems used fixed-speed pumps driven by electric motors, and their design and management were considerably simpler. Today, to pump variable flow rates to different total heads efficiently, variable speed pumps are commonly used in these systems. Variable speed pumps are powered by an asynchronous motor and an electronic frequency converter that allows the pump to work under different angular velocities. The frequency converter can be considered an inverter that can modulate the output signal to the desired frequency and amplitude (Reca-Cardeña et al., 2018).

Pumping systems account for nearly 20% of the world's electrical energy demand, with widespread use in domestic, commercial, and agricultural services. Furthermore, they range between 25-50% of the energy usage in certain industrial plant operations and provide wastewater, industrial, and municipal water services for food processing, chemical, petrochemical, pharmaceutical, and mechanical industries.

2.2.1. Classification of Pumps

Pumps are classified into two types:

i. Kinetic Energy pumps.
ii. Positive Displacement pumps.

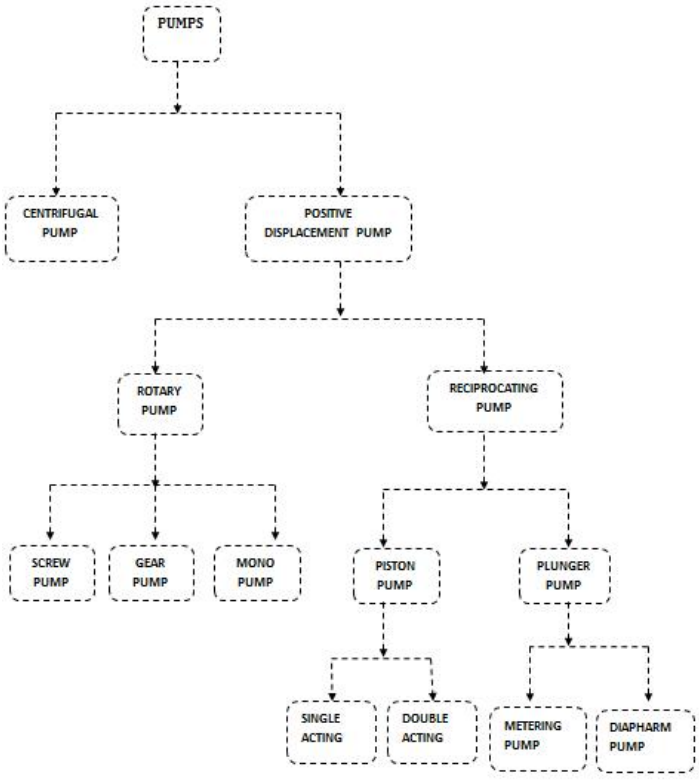

Figure 2: Classification of pumps.

2.2.2. Positive Displacement Pumps

Positive displacement (PD) pumps are designed to ensure that any pumping action is forward (positive). Its internal design ensures and prevents fluid from recirculating back towards the pump inlet, or within its casing. PD pumps can be of rotary or reciprocating positive displacement design. With differing internal parts, and designs to accommodate a variety of fluid characteristics. These designs have the following characteristics: A fixed volume of fluid transferred per revolution, pressure remains constant, and the flow is proportional to speed (Hooton, 2019).

In a positive-displacement pump, the liquid flow is intermittent and therefore characterized by pressure fluctuations. The flow rate is a function of the size of the space and the frequency/speed with which it is filled and emptied (Okokowa 2003).

Positive displacement pumps can be further classified as

i. Rotary PD pump
ii. Reciprocation PD pump.

2.2.3. Kinetic Energy Pumps

These pumps add energy directly through a rotating part in the form of velocity and convert the velocity to pressure (Prosoli 2009). The kinetic energy pump is also known as **the rotor dynamic pump**, which is based on bladed impellors, which rotate within the fluid to impart a tangential acceleration to the fluid and a consequent increase in the energy. The purpose of the pump is to convert this energy into the pressure energy of the fluid to be used in the associated pumping system. In rotodynamic pumps liquid moves under the force created in the chamber, which is in constant communication with the inlet and outlet pipes. This pump group includes a variety of impeller pumps, which have found wide applications as well as peripheral, jet pumps, etc. (Kinrchenko 1986).

2.3. Centrifugal Pumps

Centrifugal pumps are the most economical and most common pumps used for pumping water in industrial applications. Their components are rotating components, an impeller coupled to a shaft, stationary components, casing, casing cover, and bearings. The operation of a centrifugal pump is based on a rotating impeller, which converts kinetic energy into pressure or velocity that is needed to pump the fluid. The product enters the pump at the center of the impeller rotation and, owing to centrifugal force moves to the impeller periphery. At this point, the liquid experiences maximum pressure and moves through the exit to the pipeline. The simple design of the centrifugal pump makes it easily adaptable to cleaning-in-place functions. Most sanitary centrifugal pumps used in the food industry use two vane impellers. Centrifugal pumps are most efficient with low-viscosity liquids such as fruit juices and must, for which flow rates are high and pressure requirements are moderate. The discharge flow from a centrifugal pump is steady. These pumps are suitable for either clean/clear or dirty liquids. Flow rates through a centrifugal pump are controlled by a valve installed in the pipe and connected to the discharge end of the pump (Kosseva 2017)

2.3.1. Types of Centrifugal Pumps

The major centrifugal pump variations include the following:

i. Radial Centrifugal Pump
ii. Axial Centrifugal Pump

The classification of centrifugal pumps by stage is dependent on the number of impellers present within their setup

i. Single-stage Centrifugal Pump
ii. Two-stage Centrifugal Pump
iii. Multi-stage Centrifugal Pump

2.4. Centrifugal Pump Components:

The following are the components of a centrifugal pump

i. Impeller: A wheel with a series of backward curved vanes.

ii. Casing: Air-tight chamber surrounding the impeller.

iii. Suction Pipe: One end is connected to the eye and the other is dipped in a liquid.

iv. Delivery pipe: One end is connected to the eye, the other to the overhead tank.

v. Foot valve: Allow water only in an upward direction.

vi. Strainer: Prevent the entry of foreign particles/material into the pump

vii. Shaft - The rod that connects the motor to the impeller.

Other components include: motor, mechanical seal, labyrinth seal, gasket or packing, bearing, outboard bearing, etc

2.5. Principle of Operation for Centrifugal Pump

A centrifugal pump is a type of rotodynamic pump that uses bladed impellers with essentially a radial outlet to transfer rotational mechanical energy to the fluid primarily by increasing the fluid kinetic energy (angular momentum) and increasing potential energy (static pressure). Kinetic energy is then converted into usable pressure energy in the discharge collector (hydraulic institute, 2018).

A cross-section view of a centrifugal pump would show the use of a rotating impeller to add energy to the pumped liquid. The liquid enters the impeller axially at a smaller diameter, called the impeller eye, and progresses radially between the vanes until it exits at the outside diameter. As the liquid leaves the impeller, it is collected in a pressure container casing. One design, referred to as a volute, collects the flow and efficiently directs it to a discharge nozzle. Image 1 highlights the discharge nozzle, which is shaped like a cone so that the high-velocity flow from the impeller is gradually reduced. This cone-shaped discharge nozzle is also called a diffuser. During the reduction in velocity in the diffuser, energy in the flow is converted to pressure energy. An optimum angle of seven to 10 degrees is used to most efficiently convert velocity energy to pressure energy. Centrifugal pumps can have many drivers, but the most common is the electric motor. The motor provides mechanical energy to the pump shaft through a coupling.

The radial and axial loads are carried by pump and/or motor bearings. Sealing the pumped fluid can be done with compression packing or mechanical seals. Additionally, sealless designs are available with canned motors or magnetic drive couplings (hydraulic institute, 2018).

2.6. Problems of Centrifugal Pumps

Following are the various problems associated with centrifugal pump

The difficulty of filling the pump with water, decrease in pump capacity and pump head, overload of motor, Large leakage from mechanical seal and abnormal wear of the sealing parts, Overloading and short life of bearings, Large noises, Heavy vibration, Overheating or seizing.

The following are the causes of the above-mentioned problems

For Suction Side

Insufficient water filling at the pump or suction side, a Suction lift is too high, Insufficient NPSH* (net positive suction head)(excessively high loss of the suction piping or high water temperature), Excessively lowered suction side water level, Submerging of the suction inlet and is not sufficient, The amount of air or gas contained in the liquid is too large, Air is trapped in the middle of the suction pipe.

Operational causes

Insufficient speed of rotation by reduction of power supply frequency, Excessively high speed of rotation, Reverse rotation, Required head exceeds the head of the pump, Exceeding the designed pump capacity, The specific gravity larger than the planned value, The viscosity of the liquid is larger than planned, The operation delivery capacity is too large, The characteristics of the pump is not suitable for parallel operation (operating head is not less than shut off head of the pump), A quantity of sand is contained in water.

Mechanical Causes

These include: Foreign substances are in the casing, foreign substances are sticking to the impeller, the foundation of the pump is not satisfactory, improper alignment of the pump and motor, unbalanced rotary assembly, bent shaft, damaged impeller, the interface between the rotary assembly and the stationary part, worn bearings, worn casing wear ring or impeller wear ring, worn sealing parts of the shaft seal, aging of mechanical seal, improper positioning of mechanical seal, selection of improper packing for operating conditions, excessively tightened gland, reduction of sealing water pressure or blocked sealing water pipe, insufficient lubrication, excessive supply of lubricant (oil), improper lubricant, deteriorated lubricant, insufficient cooling water, improper assembly of bearings, etc.

2.7. Pump Materials

Centrifugal pumps can be fabricated of almost all the known common metals or metal alloys, as well as of porcelain, glass, and even synthetics. The conditions of service and the nature of the liquid to be handled finally determine which materials will be the most satisfactory.

Centrifugal pump casings are usually made of cast iron. Bronze is frequently used for pump casings if the liquid pumped is mildly corrosive. Cast steel or even forged steel is used if the discharge pressure or the pumping temperature or a combination of both factors make cast iron unsuitable. Stainless steel is used if the pumped liquid is corrosive or excessively abrasive. Porcelain or glass casings are sometimes used for very special applications (Okokowa 2003, Igor and carter 1960, Cherkassy 1990).

Bronze, impellers are usually preferred for handling normal liquids. However, bronze impellers should not be used with cast-iron casing if the liquid handled is a strong electrolyte. Such liquids require ferrous materials. The use of bronze impellers is also limited by the effect of peripheral speeds. Stainless steel (Grade 304) is very useful in casting impellers for handling liquids containing sand and pumps exposed to corrosion Impellers designed to handle high-temperature liquids make use of steel alloyed with chromium and nickel. Pumps for the chemical industry have impellers manufactured from special alloys, ceramics, or plastics (Okokowa 2003, Igor and carter 1960, Cherkassy 1990).

Generally, steel is often used for shafts but this material varies depending on the fluid to be handled. High-strength alloy steels may be preferred where high stresses are applied. Non-corrosive metal shafts such as stainless steel, phosphor bronze, or monel metal may be preferred when handling corrosive liquids.

CHAPTER THREE

METHODOLOGY

3.1. Design Consideration

The use of accumulated data, experiments, research, and experience in the hydraulic fields has been the cause of centrifugal pump development over the years. Therefore, the design and the material selection of the components of this pump are based on established codes and standards in design and fabrication.

This project considers designs and analysis for a single-stage centrifugal pump with a desired capacity (Q) of $0.0125m^3/s$ (12.5Litres/sec), at a head H. of 13m and shaft speed of about 1450rpm.

The mechanical and hydraulic suitability of a centrifugal pump is very important for the effectiveness and reliability of the system. A system's lifetime can run into problems arising from the pump over or under-sizing. The following are considerations for both the mechanical and hydraulic characteristics of the pump.

Mechanical Considerations

This includes pumping conditions, pump sealing, and impeller geometry among others. Generally, a tradeoff between practicality, efficiency, and cost has to be carried out when it comes to geometry.

Hydraulic Considerations

This includes duty point, flow rate, fluid characteristics, and system resistance. Suction conditions cannot be ignored when designing or installing a centrifugal pump. An important concept in this area is **the Net Positive Suction Head (NPSH)**, which is the head required at the suction of the pump for particular working conditions to avoid cavitation problems. The NPSH

required depends only on the manufacturer's design of the pump (casing, impeller, and nozzle). This data is produced and calculated by the manufacturer as a curve and the NPSH available depends on the suction condition of the pump: fluid pressure, temperature, fluid pressure vapor, suction head, or suction lift.

Specification of a centrifugal pump is based on the characteristics of the machine. These characteristics affect the general performance of the various components. The overall performance of the pump is dependent on the efficiency of the parts. Furthermore, basis and justification are given to back up the characteristics of the various components listed below.

3.1 Design Consideration for Major Components of a Centrifugal Pump

3.1.1. Impeller

The pump under consideration is an end-suction pump and so an overhang single suction backward curved vane, the semi-open impeller was adopted. This impeller incorporates six vanes and is to be placed between the impeller casing, which connects to the motor and its cover. The impeller was cast in a sand mold and machined afterward. The material used for its construction was aluminum because of its availability, low cost, resistance to corrosion, ease of casting, and machinability. The impeller is housed by its casing connected to the motor and rotates when the motor is powered on.

3.1.2. Casing

The impeller casing has a cover that carries the inlet for suction while the discharge outlet is on the casing itself. Aluminum was the material used for construction. It was obtained from scrap metal, melted down in the foundry shop, and cast using a sand mold. After which the material was taken for dressing in the machine shop and fit specification. Holes were inserted at various points on the casing and its cover using drilling operations. These holes were made at the required locations where bolts and nuts will be used to keep the casing and its cover together. The impeller casing carries the discharge valve linked to the shaft of the motor and the cover

carries the suction pipe which moves water from a source into the pump. Furthermore, the casing and its cover are to be made stationary and this was ensured using a bolt connected to the base of the entire mechanism.

3.1.3. Shaft

The shaft speed of this pump is 1450rpm and this differs from the critical speed by about 20% (Igor and Carter 1960). The construction material is mild steel.

3.1.4. Mechanical Seal

The internal assembly mechanical seal (hole ring) was adopted for this project. The seal is made of synthetic rubber and spring, since rubber is flexible it is more effective.

3.2. Design Equations and Calculations

3.2.1. Detailed Design

Certain essential items of information must be available before a suitable pump can be designed these include:

i. Liquid: The liquid to be pumped is clean water. With a temperature between 15°C to 40°C.

ii. Rate of discharge (capacity) Q = 0.0125m^3/s

iii. Head or pressure, H = 13m.

iv. Rotational speed, N = 1450rpm.

3.2.2. Calculated Data

$$N_S = K_S.N.\left(\frac{\sqrt{Q}}{\sqrt[3]{H^4}}\right) \quad (3.1)$$

$K_S = 3.65$ (Inegbedion et al., 2021) (3.2)

∴ The shape number $N_S = 3.65 \times 1450 \times \left(\frac{\sqrt{0.0125}}{13^{\frac{3}{4}}}\right) = 86.43 m/s$

$$N_{usf} = \frac{\rho Q g H}{1000} \quad (3.3)$$

Where $\rho = 1000 kg/m^3$ and $g = 9.81 m/s^2$

∴ The useful power $N_{usf} = \frac{1000 \times 0.0125 \times 9.81 \times 13}{1000} = 1.59KW$

N_{mp} which is the motor power = 2.2KW

$$\eta = \frac{Nusf}{Nmp} \quad (3.4)$$

$\eta = \frac{1.59}{2.2} = 0.722$

∴ $\eta = 72.2\%$

3.2.3. Impeller Design

$$\phi = \frac{U_2}{\sqrt{2gH}} \quad (3.5)$$

A Speed constant of 0.97 is used

∴ The Impeller rim velocity $U_2 = \phi\sqrt{2gH} = 0.97\sqrt{(2 \times 9.81 \times 13)} = 15.49$ m/s

Also, the Impeller rim velocity

$$U_2 = \frac{\pi D_2 N}{60} \quad (3.6)$$

Making D_2 subject formula

$$D_2 = \frac{60\, U_2}{\pi N} \quad (3.7)$$

$D_2 = \frac{60 \text{ x } 15.49}{\pi \text{ x } 1450} = 0.204\text{m} = 204.0\text{mm}$

Furthermore,

$$\frac{D_1}{D_2} = 0.3 \quad (3.8)$$

$\therefore D_1 = 0.3D_2 = 0.3 \text{ x } 204.0 = 61.2\text{mm} = .0612\text{m}$

With the impeller eye diameter, the impeller eye velocity can be obtained using

$$U_1 = \frac{\pi D_1 N}{60} \quad (3.9)$$

$U_1 = \frac{\pi \text{ x } 0.0612\text{x } 1450}{60} = 4.65\text{m/s}$

The Impeller eye width and Impeller outer width b_1 and b_2 can be obtained as such:

$$b_1 = \frac{1.5D_1}{4} \quad (3.10)$$

$b_1 = \frac{1.5\ x\ 0.0612}{4} = 0.02295\text{m} = 22.95\text{mm}$

$$b_2 = \frac{b_1 D_1}{D_2} \quad (3.11)$$

Recall, from equation (3.8)

$\frac{D_1}{D_2} = 0.3$

$\therefore\ b_2 = 0.3b_1 = 0.3 \text{ x } .02295 = 0.006885\text{m} = 6.885\text{mm}$

3.2.4. Impeller Blade Angles

This paragraph deals only with blades suited for two-dimensional flow, they are described as cylindrical because they form part of surfaces. The routine of calculation proceeds thus;

3.2.4.1 Hydraulic Efficiency ηh,

This value is always greater than that of the gross efficiency, and it's estimated from the relationship:

$\frac{(1-\eta h)}{(1-\eta)} = K_h,$ (3.12)

Where K_h, ranges from about 0.5 for low specific speeds to about 0.8 for high specific speeds.

K_h=0.5

Thus $\frac{(1-\eta h)}{(1-\eta)} = 0.5,$

$(1-\eta_h) = 0.5(1-\eta)$

$\eta = 0.722$

$(1-\eta_h) = 0.5(1-0.722) = 0.139$

$(1-\eta_h) = 0.139$

$\therefore\ \eta_h = 1 - 0.139 = 0.861 = 86.1\%$

3.2.4.2 True Whirl Component, Vn

For the stipulated head H to be attained, the liquid must leave the impeller with a tangential velocity component V, which can be obtained from the relationship shown below

$H = \eta_h (VnU_2) / g$ (3.13)

Making Vn subject formula

$Vn = \frac{Hg}{\eta_h U_2} = \frac{13\ x\ 9.81}{86.1 \text{ x } 15.49} = 0.0956 m/s$

3.2.4.3 Ideal Whirl Component, V∞

Due to the imperfection of the liquid's response to the tangential impulsion of the blades, the outlet impeller blade angle must be suited to an ideal tangential component V∞ that is greater than the true value. The relation between the two (ideal and true value) is highly complex, which means, only a rough approximation can be obtained using the relationship below the relationship;

$$V\infty = Vn\,[1 + (Kn/Z)] \qquad (3.14)$$

Where Z is the estimated number of blades, and K_n, is a factor taken as about 3 for low specific speeds, and 5 for high specific speeds. (Inegbedion et al., 2021)

$V\infty = 0.0956[1 + (3/6)] = 0.1434 m/s$

3.2.4.4. Velocity of Flow, Y_2

This is obtained from the expression;

$$Y_2 = \Psi \sqrt{2gH} \qquad (3.15)$$

Where Ψ is the flow ratio of 0.28.

$\therefore\ Y_2 = 0.28\sqrt{(2 \times 9.81 \times 13)} = 4.472 m/s$

3.2.4.5 Outlet Blade Angle γ

This is found in the expression.

$$\text{Cot}\,\gamma = (U_2 - V\infty)/Y_2 \qquad (3.16)$$

$$\text{Cot}\,\gamma = \frac{15.49 - 0.1434}{4.472} = 3.4317$$

$$\gamma = \tan^{-1}\frac{1}{\text{Cot}\,\gamma} = \tan^{-1}\left(\frac{1}{3.4317}\right) = 16.246°$$

3.2.5 Inlet flow velocity

$Y_1 = (Y_2 \text{ x } (D_2\ b_2))/(D_1\ b_1)$ (3.17)

Therefore, $Y_1 = 4.472 \text{ x } (0.204 \text{ x } 0.006885)/(0.0612 \text{ x } 0.02295) = 3.9220 \text{ x } 1 = 4.472 \text{m/s}$

Inlet blade angle, ß.

$\tan ß = Y_1/ U_1$ (3.18)

$ß = \tan^1 (Y_1 / U_1) = \tan^1 (\frac{4.472}{4.65}) = 43.882°$

Check for the exact number of blades, Z.

$Z = 6.5 [\frac{M+1}{M-1}] \text{ x } \sin [\frac{ß+\gamma}{2}]$ (3.19)

Where $M = \frac{D_1}{D_2} = \frac{1}{0.3} = 3.33$

$Z = 6.5 [\frac{3.33+1}{3.33-1}] \text{ x } \sin [\frac{43.882+16.246}{2}] = 6.05$

$\therefore Z = 6$ blades

3.2.6. Casing Design

For casing inside diameter, D_3.

$D_3 = D_2 (\delta + 1)$ (3.20)

where, $\delta = 0.07$

$D_3 = 204\text{x } (0.07+1) = 218.28\text{mm} = 0.21828\text{m}$

For casing width, b_3

$b_3 = 1.25 b_1$ (3.21)

$b_3 = 1.25 \text{ x } 22.95 = 28.6875\text{mm} = .0286875\text{m}$

For casing thickness, T_C

$T_C = [(XYDP) / 200\ dt] + Z$ (Inegbedion et al., 2021) (3.22)

where, D= 35.5

P= 50m of water

X = 4.5

Y = 1.6

Z = 2mm

dt = 2.5

From tables

10m of water = 1kg/mm²

50m of water = 50 x 0.1= 5kg/mm²

$T_C = [(4.5 \times 1.6 \times 5 \times 35.5) / (200 \times 2.5)] + 2 = 4.556$ mm ≡ 5mm

For Casing outer diameter

$D_4 = 2T_C, + D_3$ (3.23)

$D_4 = 2 \times 5 + 95.765 = 105.765$ mm

Detailed Diagrams

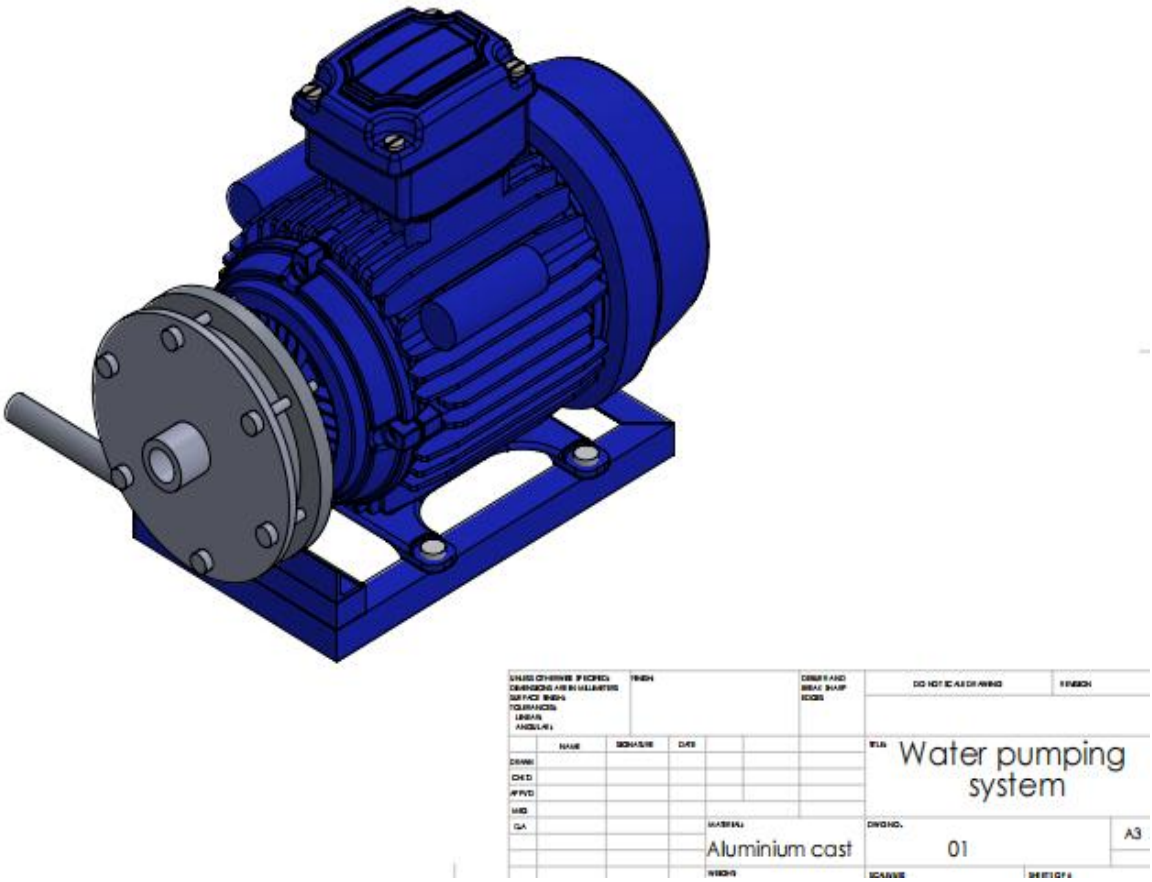

Figure 3.1: 3D Model of an assembled centrifugal pumping system (circular casing)

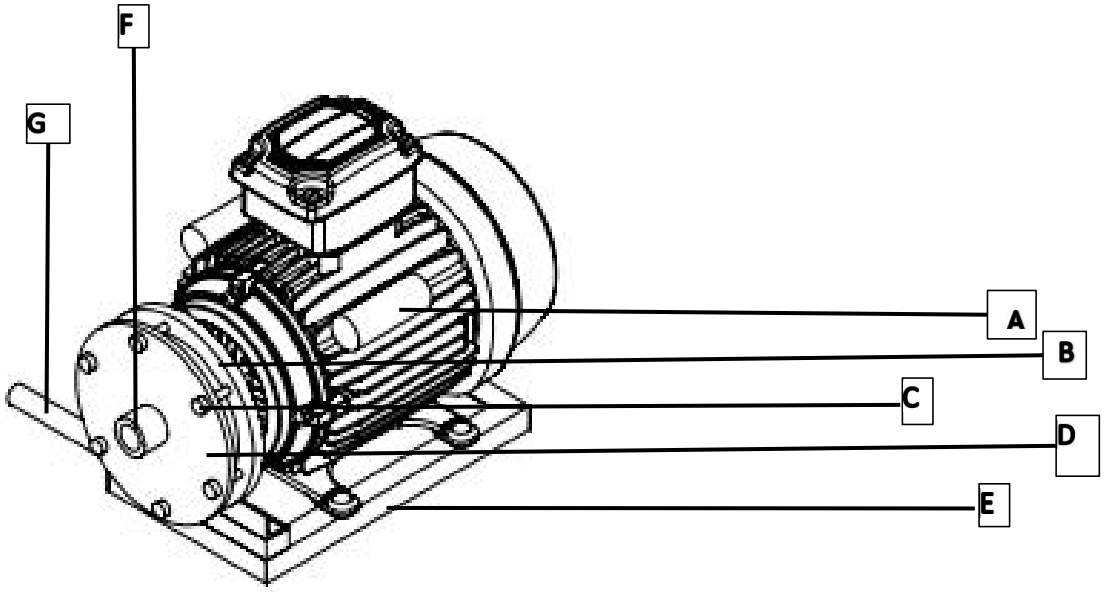

Figure 3.1.1: 3D Model of an assembled centrifugal pumping system with labeled paths (circular casing)

PARTS

A - Motor Capacitor

B - Impeller casing

C - Nut and bolt (Fastening mechanism)

D - Impeller casing cover

E - Base

F - Suction outlet

G - Discharge outlet

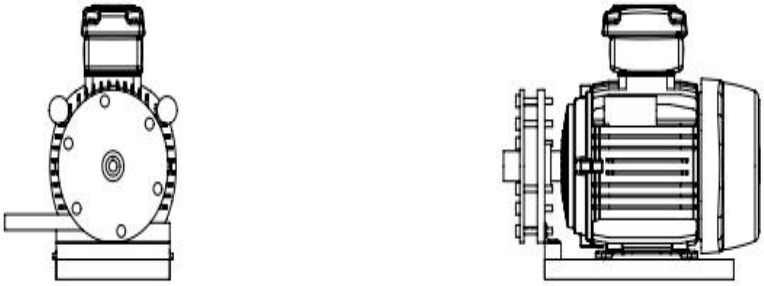

Figure 3.2: front and side view of the assembled centrifugal pumping system

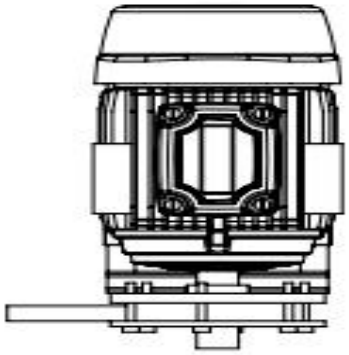

Figure 3.3: a plan of the assembled centrifugal pumping system

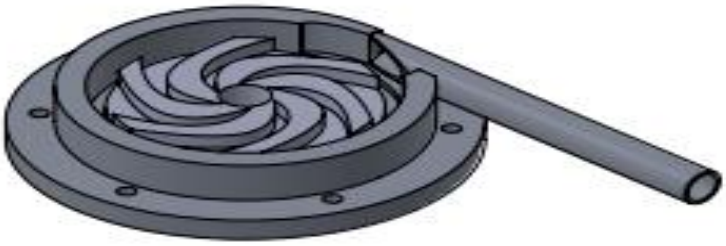

Figure 3.4: 3D model of the impeller in its casing which has the discharge outlet

Figure 3.5: front and side view of the impeller in its casing

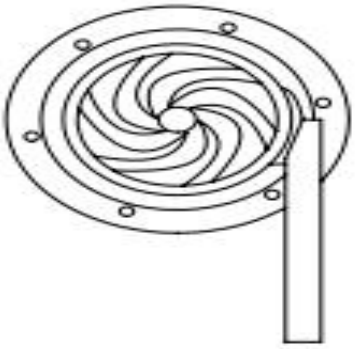

Figure 3.6: a plan of the impeller in its casing

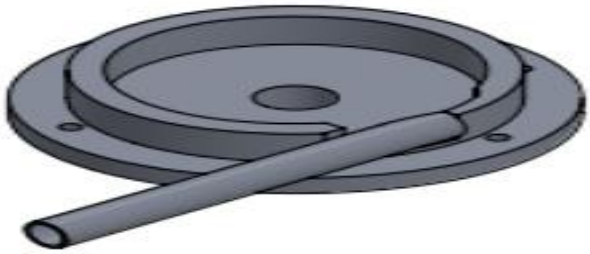

Figure 3.7: 3D model of the impeller casing which has the discharge outlet

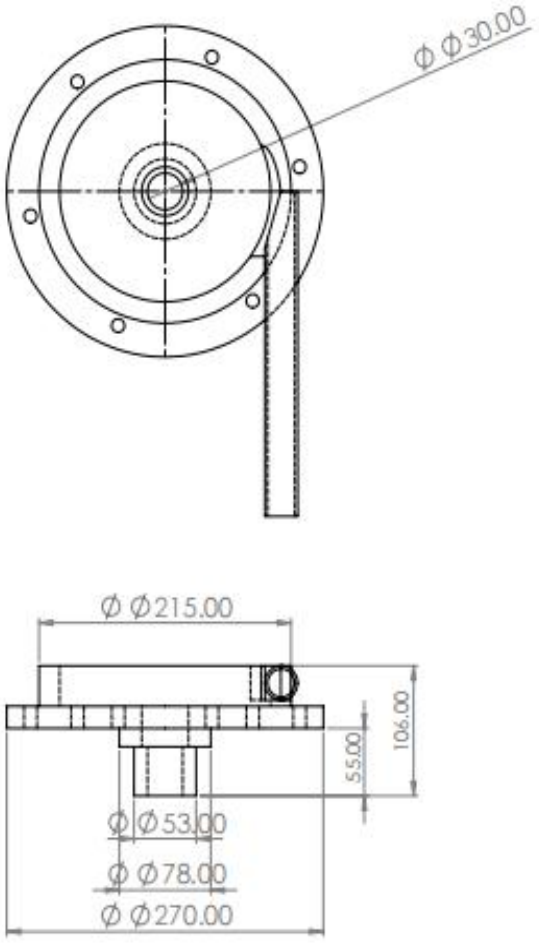

Figure 3.8: Side and plan view of the impeller casing which has the discharge outlet

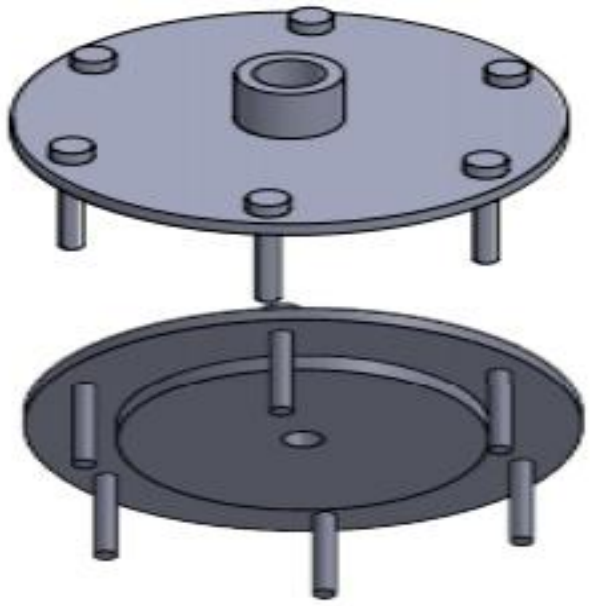

Figure 3.9: 3D model of the impeller casing cover with Bolts

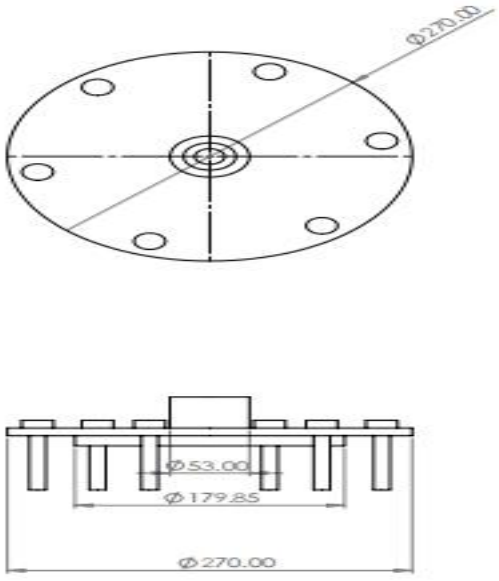

Figure 3.10: Plan and side view of the impeller casing cover

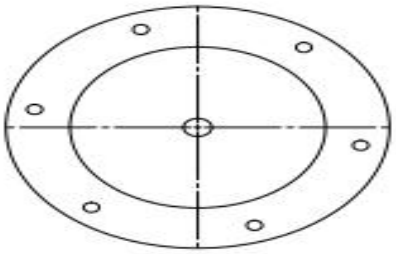

Figure 3.10.1: a plan of the impeller casing cover

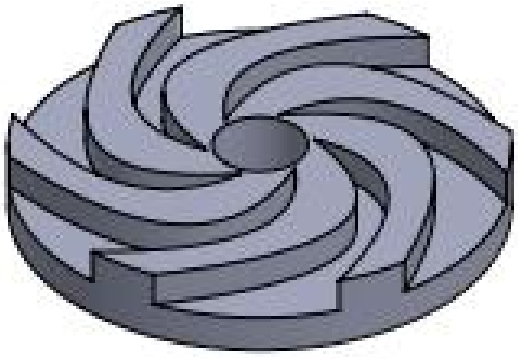

Figure 3.11: 3D model of the impeller

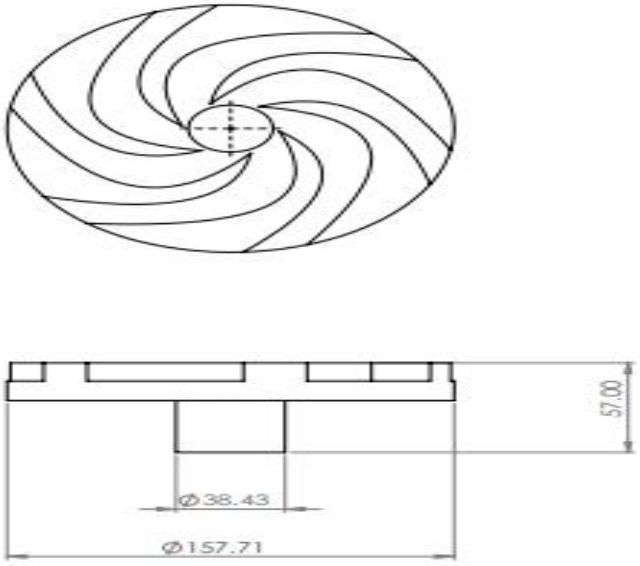

Figure 3.12: Plan and side view of the impeller

CHAPTER FOUR

DISCUSSION AND RESULT ANALYSIS

BILLS FOR ENGINEERING MEASUREMENT

4.1 Materials Bills

The table below shows the average cost of all materials used for the construction or fabrication of the centrifugal pumping system incorporating an electric motor. The method of manufacture for each component used was also shown below.

Table 4.1: Materials Cost

Item number	Description of Material	Source material used	Quantity	Methods of Manufacture	Estimated cost (N)
1	Shaft	Mild Steel	1	Purchased	5000
2	Impeller Cover	Aluminum		Casting	25000
3	Impeller	Aluminum	1	Casting	15000
4	Impeller casing	Aluminum	1	Casting	40000
5	Shaft-Impeller key	Steel	1	Purchased	2000
6	Gasket (pump casing)	Rubber	2	Purchased	1000
7	Bolts and Nuts	Steel	6	Purchased	2600
8	Packing	rubber	2	Purchased	1500
9	Electric motor (Single-Phase)	Nil	1	Purchased	70000
10	Suction hose	Rubber	2yards	Purchased	40000

11	Discharge outlet	Iron and rubber	2m	Purchased	3200
12	Electric Wire	Copper	8yards	Purchased	7000
13	Mechanical seal (hole ring)	Rubber/ stainless steel	1	Purchased	2500
14	Base	Mild steel	2 yards	Purchased	1500
	Total				216300

4.2 Labor Cost

The table below shows a summary of the cost of labor incurred

Table 4.2: Cost of Labour And Services

S/N	Description of Services	Estimated Cost (N)
1	Transportation	12500
2	Fabrication / Welding	30000
3	Machining	33000
	Total cost	75500

4.3 Manufacturing Cost

The total cost of manufacturing the centrifugal pump is obtained by adding the cost of materials and the cost of labor/ services as listed in tables 4.1 and 4.2 respectively:

Total cost of pump = N216300 + N75500 = N291800

4.4 Testing

The performance of the centrifugal pump and its parameters such as head, capacity, and efficiency was measured and investigated during the operation of the pump. This investigation was carried out at the University of Benin Workshop using measured filtered water in containers.

The time is taken to empty each measured container was recorded against the head of water pumped.

The water rose to a height of 23.5m and the discharge recorded was 28800 liters/hr or 8 liters/sec.

The pump was designed to deliver 12.5 liters/sec at a height of 13m therefore the achieved performance of 64% efficiency is satisfactory and acceptable for a centrifugal pump that falls within this capacity of specific speed.

4 .5. Pump Operating Procedures

Cherkassky (1969) and Igor et al. (1960), both agree that all centrifugal pumps must be filled with the liquid to be pumped before starting. For satisfactory operations, the following industry standard practices for pump construction have been adopted, before starting the pumping unit. Therefore, the following preparatory steps should be taken;

(1) Make sure the shaft is rotating freely.

(2) Ensure the pump casing and suction line are primed.

(3) Make sure that the stuffing boxes do not leak excessively.

(4) Check the grease in the bearings.

(5) While running, the temperature of the bearings and motor casing/housing must not be above 60°C under normal conditions.

The operating procedure of this pump is very simple and does not require any special skill to operate. Therefore to operate this pump simply connect the suction and delivery hoses or piping as may be required, to the pump inlet and outlet connections, respectively, and secure them firmly. Prime pump by filling pump casing and suction hose with liquid to be pumped. If a foot or suction valve is installed, make sure it is in the open position, then connect the pump to a source of power supply (single phase power supply) and switch it on. At the end of pumping operations switch off power from the supply and unplug from the power source.

4.6. Maintenance

Agbabune (2002), defined maintenance as any activity carried out on equipment to keep it in a condition necessary for its best performance. Maintenance activities therefore can be classified into two broad categories;

(1) Breakdown maintenance; is maintenance activities carried out on a piece of equipment to bring it back to maintaining its designed/original operating form.

(2) Preventive maintenance; is maintenance activities intended to prevent equipment failure, an important form of preventive maintenance activity is regular inspection, vibration, temperature monitoring e.t.c undertaken to identify seemingly failing parts before breakdown eventually occurs. Remedial actions usually taken could be the replacement of parts, greasing, cleaning, etc. (Agbabune 2002).

The maintenance of a centrifugal, pump is hereby listed as follows;

(1) The bearings - The bearings should be inspected every month, and greased if found dry or noisy. Bearings are to be replaced after about 8000 running hours, or whenever the shaft wobbles or stiffens.

(2) Gland packing - This should be adjusted to allow a few drops per minute, and replaced whenever the seal, leaks profusely either while running or stopped.

(3) Casing gasket - To be replaced when found broken or partially cut. However, gaskets are recommended for replacement during inspections or major repair work on the pump.

(4) Pump and motor mounting bolts monthly checks on tightness or otherwise recommended.

CHAPTER FIVE

CONCLUSION

At the end of this project, it is expected that the simple principle of operation of a centrifugal pump incorporating an electric motor that rotates an impeller can raise water to an appreciable height of 13m. Calculations showed a 72.2% efficiency with a flow rate of 0.0125m^3/s, and a rotational speed of 14500rpm. The actual efficiency was 64% with a flow rate of 8liters/s at a height of 23.5m

A centrifugal pump is a fluid kinetic machine designed for increasing power within a rotating impeller. It has delivery heads that depend on the flow rate and this is called pump performance. This pump was manufactured using locally sourced materials fabricated in the Department of Production Engineering workshop. Mass production of this pump creates a market and job opportunity for Nigerians and reduced the importation of pumps.

Recommendation

The best of the pump design is still very much open to further improvements in the areas of manufacturing processes, material selections, and more importantly computer design programs so that it can be as economical as possible.

REFERENCES

Drew Champlin 2018: An introduction to pump types and their histories.

Stefanie Wallace (2012): A glimpse into the history of pumps.

Larry Bachus, Angle Custodio (2003). Know and understand centrifugal pumps. Elsevier Ltd. ISBN 1856174093.

P.L. Fraenkel (1986): Fao Irrigation And Drainage Paper 43

Centrifugal pump overview Presented by Matt Prosoli Of Pumps Plus Inc.

G.I Kinrchenko, (1986): Hydraulic Machines, Turbines, and Pumps, Mir Publishers MOSCOW

Anup Kumar Dey (2019) Pumps & Pumping Systems (With PDF)

Okokowa Jeremiah Esiyede, (2003): Thesis on the Design and Construction of a 2-Stage Centrifugal Pump.

Igor J. Karasssik and Ray Carter, (1960): Centrifugal Pumps Selection, Operation, and Maintenance. McGraw- Hill Book Company.

V. Cherkassy, (1990): Pumps, Fans and Compressors, Mir Publishers MOSCOW

Micheal Valenti, (2002): Fluid handling and Fluid Power, Monthly Mechanical Engineering journal – Pit Field USA, American Society of Engineers.

"Sprayer Pump Types, Costs, and Specifications" (https://web.archive.org/web/20181121120151 or https://www.sprayersupplies.com/sprayer-pumpguide) Sprayer Supplies. 2018-10-13. Archived from the original (https://www.sprayersupplies.com/sprayer-pump-guide) on 2018-11-21. Retrieved 2018-11-21.

Bazza, M. Overview of the History of Water Resources and Irrigation Management in the Near East Region. Water Sci. Technol Water Supply 2007, 7, 201–209.

Cohn, G.S. L'origine des Norias de Fés. Hespéris 1933, 16, 156–157.

Hazen, T.R. Pond Lily Mill Restorations. The Noria Water Wheels 2000.

Francis Inegbedion, Chidiebele Nnadike Okonkwo and Joseph Okechukwu (2021). Design and Manufacture of a Centrifugal Water Pump with a Circular Casing

Molenaar, A. Water Lifting Devices for Irrigation; FAO Paper No.60; FAO: Rome, Italy, 1956; p. 75.

Eubanks, B.M. The Story of the Pump and Its Relatives; Bernard M. Eubanks: Salem, OR, USA, 1971; p. 185

Ozora P.A., Ojoborb S.N., (2012). Design, Construction, And Measured Performance Of A Single-Stage Centrifugal Pump Demonstration Unit Nigerian Journal Of Technology Vol. 31, No. 3

Stavros I. Yannopoulos, Gerasimos Lyberatos, Nicolaos Theodossiou, Wang Li, Mohammad Valipour, Aldo Tamburrino, and Andreas N. Angelakis (2015). Evolution of Water Lifting Devices (Pumps) over the Centuries Worldwide.

Ann, C. History of Water Pumps, eHow Contributor. 2009. Available online: http://www.ehow.com/facts_5031932_history-water-pumps.html (accessed on 14 August 2013).

Oleson, J.P. Greek and Roman Mechanical Water-Lifting Devices: The History of a Technology; University of Toronto Press: Toronto, Canada, 1984.

Tassios, T. Hellenic Ancient Technology; Kathimerini: Thens, Greece, 1998.

Angelakis, A.N.; Mamassis, N.; Defteraios, P. Urban Water Supply, Wastewater, and Stormwater Considerations in Ancient Hellas: Lessons Learned. Environ. Natl. Resour. Res. 2014, 4, 95–102.

Kostas Apostolou PROCTECH 2EC3 Lab Manual 2010

Agbabune Joe B 2002; Design and construction of a submersible pump, M. Eng. Thesis. Ambrose Ali University Graduate School, Ekpoma, Nigeria.