ISSN No:-2456-2165

# Design and Construction of a Centrifugal Pump Test Bed

Olisedeme Uchechukwu Richard, Olisedeme Oluchukwu Richmond, Uzuanwu Calistus Ifeanyi, Wilfred Chika Charles

**Abstract:- This project work details the design, manufacture, and testing of a centrifugal pump. The centrifugal pump is driven by an electric motor, which is also linked to a tachometer, a variable frequency drive and a wattmeter, which measure the speed of the motor shafts and the electrical power of the pump, respectively. The driven centrifugal pump pulls fluid (water) from a sump reservoir and transfers it to a tank through a flow control valve. We were able to conduct the experiments required to completely describe a centrifugal pump using the demonstration unit. The correlations between the different parameters, such as head (H), efficiency (η), rotational speed (ω), and input power (Pi), and the flow rate (Q), were also generated in tabular and graphical form. The experimental findings acquired at the conclusion of this study demonstrate that the tested pump can achieve a head ($H_{max}$) of 35m, a volumetric discharge ($Q_{max}$) of 35l/min, and a speed of 2850 rpm with an input power of 0.5HP. The pump's performance was reported to be very smooth, with minimal vibration and noise levels on both the pump and the motor, ensuring the pump's reliability in service.**

## I. INTRODUCTION

Fluid mechanics students have long respected the concept of centrifugal pumps and their characteristics in terms of understanding the many equations that predict their performance under various operating conditions. Centrifugal pumps have a wide range of commercial and industrial uses, including the oil and gas business, steam power plants, buildings, agriculture and irrigation, the food industry, and the paper and pulp industry (Sharma and Rai, 2013). Added to the need for fluid mechanics students to not only understand the equations that predict the performance of these pumps under various operating conditions through calculations, but also provide them with hands-on experience through specialized training in their fluid mechanics laboratory, giving them a competitive advantage in the industry. Hence, a need for the design and construction of a centrifugal pump test bed for student use at the fluid mechanics laboratory.

The stated scope of this work is to design, build, and experimentally investigate centrifugal pump performance or to test an educational demonstration or instructional unit to allow undergraduate students to evaluate the behavior of centrifugal pumps in a variety of operating conditions, as inspired by the above literature. The unit will be used to supplement a fluid mechanics engineering science course by giving mechanical engineering students hands-on experience with pump performance characterization. Pump efficiency will also be measured directly.All experimental pump performance data should be compared to manufacturer's pump performance data as well as theoretical projections. Choate and Lenoir (Choate and Lenoir, 2008).

As previously stated, these pumps are used to transport liquids from one location to another. As a result, they are an effective tool for teaching students the relationships between pressure or head, volumetric flow rate, shaft rotational speeds, and input and output powers, effectively bridging the gap between theory and practice. The test bed is designed to give students an instructional tool that they may use to conduct various experiments to demonstrate the physical and functional links between these characteristics.

The test bed is capable of measuring pressures (pressures at the pump inlet or suction and outlet or discharge sides of the pump), volume flow rates, pump shaft rotational speeds, and shaft torques or forces with moment arms, based on the background outlined. The water flow rate is controlled by manually operated valves at the pump inlets and outputs, which aid the student experimenter in intuitively arranging the flow for the suggested designed centrifugal pump configuration.

These pumps allowed fluid to be transported between two locations by harnessing power from another source (steam turbines and electric motors). Centrifugal pumps are a form of dynamic pressure pump that generates head and flow by raising the liquid's velocity with the help of a rotating vane impeller and diffuser. The performance of such pumps is influenced by factors such as specific speed, blade orientation, casing insulation, impeller diameter, number and pitch of blades, internal surface finish, liquid viscosity, and so on (Sharma and Rai, 2013).The rotating element, which consists of an impeller and a shaft, and the stationary element, which consists of a casing, casing cover, and bearings, are the major components of this type of pump (Karrassik, 2011). Other components, however, are required to complete a centrifugal pump assembly.

The centrifugal force of the impeller blade converts mechanical energy into hydraulic energy of the handling fluid, allowing it to be transported to a desired location or height. Newton's second law governs their operation. Due to the mechanical energy on the driven impeller, the fluid at the internal radius flows to the outer radius, gaining the centrifugal head and causing suction at the pump inlet known as the eye. The fluid that is pumped by this sort of pump receives useful energy through velocity variations when the fluid goes through the impeller of the pumps Mechanical energy, such as an electrical motor on the drive shaft driven by a prime mover or a small engine, is used to operate this pump. The hydraulic energy of the fluid being elevated or conveyed is the output energy. The liquid is driven into a series of revolving vanes by atmospheric or other pressure in a centrifugal pump. These rotating vanes are contained within a housing or casing and are used to transmit energy to a fluid via centrifugal force (Khin, Mya, and Khin, 2008).

Long service life, non-toxic effects, local availability, cheap cost, easy handling during building and fabrication, lightness of weight for easy handling during usage, and supplying caster wheels for easy movability were all essential considerations in the design of this centrifugal pump test bed. The frame is built of mild steel that is welded in a rectangular shape in both vertical and horizontal directions to increase rigidity. The system's components are held in place by the supports. With a vertical elevation of 1117.6mm, the frame is approximately 1270mm long and 457.2mm wide. The centrifugal pump was not designed because it was beyond the scope of this project. However, an arbitrary centrifugal pump was obtained from the market, with suction and exit pipe diameters matching the size of the pipe ran on the bed, in order to characterize it (the pump) using the test bed. The chosen 0.5H pump has a 35m total head inscription on its nameplate and runs at a maximum speed of 2850rpm. Two fluid (water) reservoirs make up the test rig.The larger reservoir (469.9mm in length, 457.2mm in width, and 558.8mm in height) is supported by a steel support base (495.3mm by 457.2mm with a thickness of 1.5mm). The smaller reservoir is supported by a 495.3mm by 457.2mm steel support base with 1.5mm thickness that is 635mm high from the big reservoir and is perforated at the bottom side of the reservoir to allow pipe to go through to the bigger reservoir from the smaller one.

Two pressure gauges were chosen, one for the suction side and the other for the discharge side of the pump. The discharge side readings had a range of 0-100 psi, whereas the suction side gauges had a range of -30 in-Hg to 15 psi. The electrical power of the pump was measured using a Wattmeter, and the rotational speed of the electric motor, which corresponds to the pump speed, was measured with a tachometer.The outboard end of an electric motor is usually left exposed to allow the tachometer spindle to rest against a recess in the motor shaft. The mass flow rate of the fluid (water) was measured using a flow meter with an inner diameter of 25.4mm, and the water flow rate before and after the pump was controlled using manually operated valves at the pump inlets and outputs.

## II. THEORETICAL FRAMEWORK

Consider the energy transfer of a pump by applying the steady state form of the energy equation as follows in order to completely comprehend the function of the centrifugal pump.

$$Q + W = m_{outlet}\left[h + \frac{V^2}{2} + gz\right]_{outlet} - m_{inlet}\left[h + \frac{V^2}{2} + gz\right]_{inlet} \quad (1)$$

Defining the enthalpy, h, in Equation (1), therefore, h;

$$h = u + Pv = u + \frac{P}{\rho} \quad (2)$$

And by conservation of mass of the centrifugal pump's axial input and tangential output:

$$m_{outlet} = m_{inlet} \quad (3)$$

This implies that on a per unit mass basis, $m = m_{outlet} = m_{inlet}$ :

$$q + w_s = \left[u + \frac{P}{\rho} + \frac{V^2}{2} + gz\right]_{outlet} - \left[u + \frac{P}{\rho} + \frac{V^2}{2} + gz\right]_{inlet} \quad (4)$$

because the flow is incompressible, equation (3) shows that the inlet and outlet velocities are equal if the inlet and outlet areas are roughly similar. Furthermore, there is a minor change in potential energy across the pump, resulting in;

$$\left(\frac{P}{\rho g}\right)_{outlet} - \left(\frac{P}{\rho g}\right)_{inlet} = \frac{w}{g} - \frac{U_2 - U_1 - q}{g} \quad (5)$$

The last group of terms represents frictional losses and is grouped into a frictional head loss term, $h_f$. similarly, expressing the shaft work input into the pump as a shaft work head term, $h_s$, yields:

$$H = \frac{1}{\rho g}(P_{outlet} - P_{inlet}) = h_s - h_f \quad (6)$$

HERE, H is the "net" or "pump" head and is the primary output parameter for a pump. Note also that this is the difference between the shaft work and the frictional head ($h_s$- $h_f$).

The energy that is been delivered to the fluid is as a result of the difference between the input energy and the energy lost to friction, both mechanical and viscous, and losses due to pump leakage. The power delivered to the fluid is by tradition termed the "water horsepower" or whp, and therefore, represented as:

$$whp = \rho gVH \quad (7)$$

Where V, g, and H are the volumetric flow rate of the fluid, the density of water, acceleration due to gravity and the head of the pump respectively.

In contrast, the power required to drive the pump is termed the "brake horsepower" or bhp:

$$bhp = \omega T \quad (8)$$

Where T is the measured shaft torque and $\omega$ is the shaft rotational speed in radians per second. The overall efficiency of the pump is defined as the ratio between the power delivered to the fluid (power required to move the fluid) and the pump input power.

Recall, whp is the "water horsepower" while bhp is the "brake horsepower, therefore, the efficiency of the pump is;

$$\eta_{pump} = \frac{whp}{bhp} = \frac{\rho gVH}{\omega T} \quad (9)$$

This overall efficiency is a function of both mechanical and fluid losses.

The viscous frictional effects and mechanical frictional effects in the bearings, packing and other contact points in the pump are the contributing factors to the overall efficiency of the pump.

The most suitable mechanical engineering software that can be used to systematically analysis and easily evaluate the working efficiency of the centrifugal pump rest bed is the solid works. The testing points are at the inlet to the pump and at its exit. Also we test for the variation of head, input power and pump performance i.e. the pump efficiency with discharge.

The correlation used to calculate total head, discharge, efficiency, specific speed and power has been given by the expressions.

Input power of motor to the shaft =
(Number of revolution × 3600) ÷ (time × Z × W) (10)

Input power to the pump = (input power of motor to the shaft) × (transmission efficiency)

$$Q = \frac{(W \times L \times h)}{t} \quad (11)$$

Where h is the height of water in collecting tank and W and L are width and length of the collecting tank respectively (all in m). Discharge is denoted by Q ($m^3$/s).

The total head (H) estimated by the relation

$$H = H_s + H_d \quad (12)$$

Where $H_s$ and $H_d$ used for suction Head and discharge Head in (m) respectively.

$$P_o = \rho\ g\ Q\ H \quad (13)$$

Where $\rho$, g and $P_o$ represents the density of water, acceleration due to gravity and output power ($P_o$) respectively.

The efficiency estimated through the relation given:

Efficiency (η) = (Hydraulic power output) ÷ (Input power) (14)

$$\eta_{pump} = \frac{whp}{bhp} = \frac{\rho g V H}{\omega T} \quad (15)$$

## III. MATERIALS AND METHODS

- **Materials (Equipment):** After doing research into viable possibilities for the system's various equipment, performing technical calculations, and properly justifying all aspects of the centrifugal pump test bed. The equipment was chosen based on requirement and market availability. The major equipment that will be integrated into the final system includes: the bench frame on which the whole assembly is mounted, the reservoir on a platform, valves fitted on inlet and delivery pipes, the piping system, flow meter, stop watch, pressure gauge, the pump, electric motor, caster wheels, strainers, thermometer, fittings and flexible hose, variable frequency drives (Advanced inverter). Each piece of equipment was chosen based on its use, cost effectiveness, and market availability. Each of these elements is briefly discussed in the following sections:
- **The Bench Frame:** Stress and deflection analysis was used to choose and design the bench frame material. We were able to relate the analysis results to material properties so that we can choose the best material from the material group. The material chosen have good ductility, strength, corrosion-resistant, and was locally sorted (cheap). Mild steel have been chosen as the preferred material for this design.
- **The Reservoir:** For the water reservoir, we chose a polyethylene rectangular tank. It came with a steel platform that was designed to support the maximum amount of water.
- **The Valves:** The system consists of a ball valve for the input (suction valve) and a ball valve for the output (discharge valve).
- **The Piping Network:** PVC tubing and fittings were used to construct the plumbing network, which includes the necessary elbows, tees, reducers, diameter change adapters, and valves.
- **Water Flow Meter and Stop Watch:** The volume of water leaving the pump from the discharge line is measured using water flow meters. In order to calculate the flow rate, a stopwatch is also required.
- **Pressure Gauges:** There are two different gauges that were chosen, one for the suction side and the other for the discharge side of the pump. The discharge side gauge should have a standard precision, whereas the suction side gauge should have a higher precision.
- **The Pump:** A centrifugal pump connected to an electric motor was selected. Pump motor specification includes 1-hp, 220-230 volts, single to three phase conversion, and had an advance inverter with variable frequency controllers that could be programmed for varied speeds and constant or varying torque.
- **Caster Wheels:** Heavy-duty caster wheels were chosen to allow for easy movement of the system from one location to another while also uniformly carrying the weight of the complete system without distortion.
- **Strainers:** At the end of the suction line, which is subsequently connected to the reservoirs, strainers are connected. This allows for particle separation while also protecting downstream equipment (pump, instrumentation) from renegade garbage.

## IV. MATERIAL SELECTION AND SPECIFICATION

Material selection is an important part of the design process for any physical object. The basic purpose of material selection in product design is to minimize cost while maximizing product performance in order to fulfill the product goal. Material selection entails finding the best match between the material's property-profile in its kingdom and the design's requirements (Ashby, 2005).

| S/N | Part | Description of use | Quantity |
|---|---|---|---|
| 1 | Mild steel | It's what the bench frame is made of | 1 |
| 2 | Carbon steel | It's for mounting the pump and motor bed. | 1 |
| 3 | Polyvinyl Chloride (PVC) Pipes | It is used for the piping system | |
| 4 | Fibre glass rectangular tank | It is used for m the reservoir | 1 |
| 5 | Pressure gauges | It is used to take the pressure readings at the inlet and outlet lines | 2 |
| 6 | Ball valves | It is used to control flow | 3 |
| 7 | Water flow meter | It is used to calculate the volume flow rate. | 1 |

Table 1: List of Materials Selection

- **Mild Steel:** One of the most widely utilized construction materials is mild steel. Because of its low carbon concentration, it is referred to as mild steel. Mild steel has a maximum carbon content of 40 points (i.e. 0.4 percent carbon). Other alloying elements, besides carbon, are used to give steel its desirable mechanical characteristics, such as corrosion resistance and strength. Mild steel is extremely strong due to its low carbon content. Even when cold, it is extremely flexible. This indicates that the material has a high tensile and impart strength (Scott et al., 2018). Mild steel was chosen for the bench structure because of its weldability, machinability, and the fact that it is constructed of widely available natural resources.
- **Dimensions of the bench frame:** The bench frame, which is made completely of a 2mm hollow square mild steel of dimension 50mm × 50mm × 2mm. The bench frame has the following dimensions: length = 1270mm, height = 1117.6mm, width = 457.2mm, and overall dimension = 1270mm × 1117.6mm × 457.2mm
  Therefore, the weight of the hollow square mild steel section, W = volume × density
  Recall: The density of mild steel is 7850 kg/m.
  $$\text{Volume} = \text{Area} \times \text{Length} \quad (16)$$
- **Carbon Steel:** Carbon steel is a type of steel that consists of an iron and carbon alloy. In comparison to stainless steel, it has a larger carbon content, a lower melting point, and is more durable. The tensile strength and hardness of carbon steel are both high. The baseplate is made of carbon steel to provide flat, coplanar surfaces on which to install the pump, driver, and reservoir. The baseplate is either welded to the base frame or secured by foundation bolts, providing for vibration-free pump performance and the ability to support the weight of the pump and reservoir without distortion (Towsley, 2009).
- **Polyvinyl Chloride (PVC) Pipes:** PVC is a typical building material that is both robust and light. Plasticizers are used to make it softer and more flexible. PVC (unplasticized polyvinyl chloride) or hard PVC is what it's called when no plasticizers are applied. PVC was chosen for the pipe network because of its hardness, density (when compared to other polymers, it has a specific gravity of about 1.4), and tensile strength. It is also widely accessible and inexpensive. A concentric reducer is utilized at the pump's suction line, whereas an eccentric reducer is used at the discharge line.
- **Fiber Glass Rectangular Tank:** Fiber Glass was designed and built into a rectangular tank that will be used as the reservoir for this test. The tank can hold 90 liters of water at a time.
- **Pressure Gauge:** To measure the pressures at the discharge and suction lines, two pressure gauges are utilized and linked at the suction and discharge lines.
- **Ball valve:** A ball valve is a type of quarter-turn valve that controls flow through a hollow, perforated, and rotating ball. It opens when the ball's hole is parallel to the flow and closes when the valve handle is rotated 90 degrees. Two ball valves were selected and attached to the discharge and suction lines, respectively. Ball valves often allow for partial opening and shutting, making them ideal for this application.

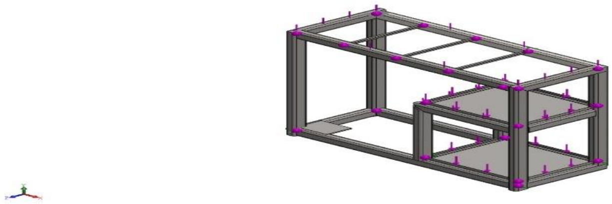
## V. DESIGN CONSIDERATION

### Design of Frame

The bench frame is made of mild steel material which consists of a hollow square dimensions 25.4mm × 25.4mm × 25.4mm. This material was chosen because of its light nature, tensile and impart strength and its ability to resist bending. It consists of two platforms; the first is the lower platform on which the reservoir is mounted and the second upper platform on which the electric motor and centrifugal pump is mounted. Various dimensions of the bed and platform are: length of the bed = 1270mm, height of the bed = 1117.6mm, width of the bed = 457.2mm.

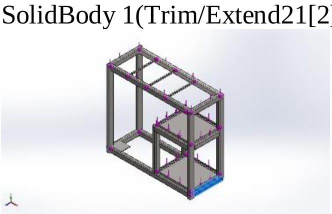
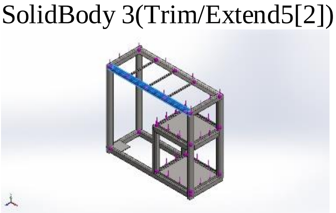
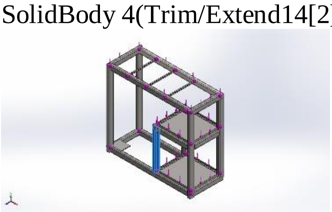
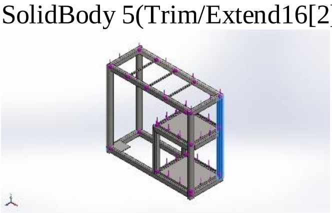
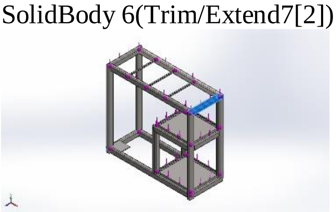
$$\text{Total dimensions of the bed} = \text{length} \times \text{height} \times \text{breath} \quad (17)$$

Total dimensions of the bed = 1270mm × 1117.6mm × 45

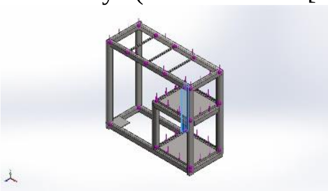
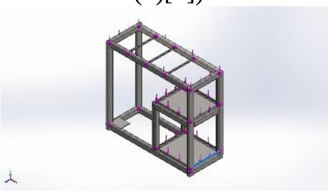
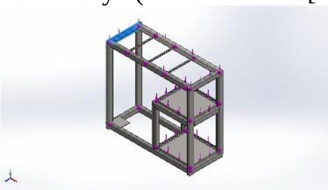
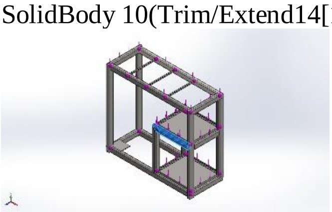
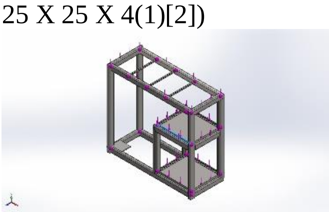
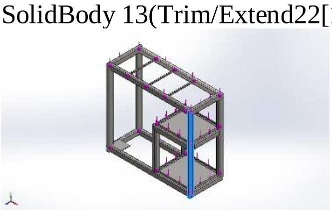


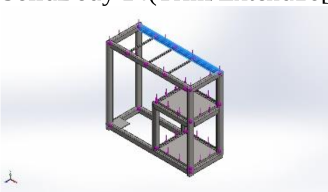
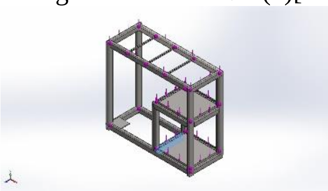
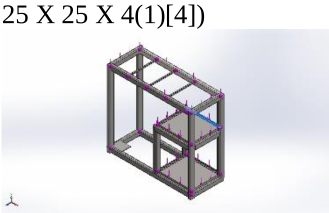
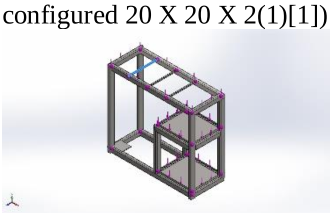
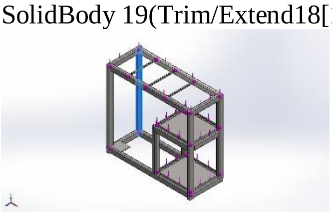
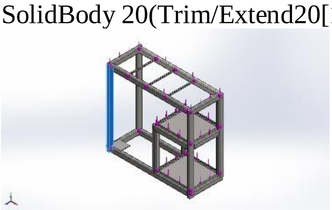
*Model name: UCHE PROJECT*
*Current Configuration: Default<As Machined>*

Beam Bodies:

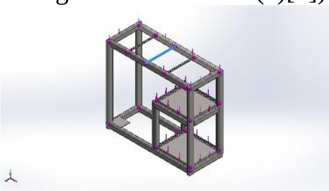
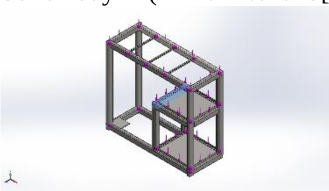
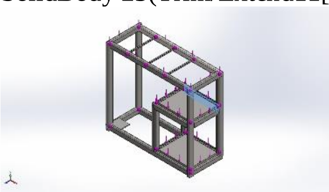
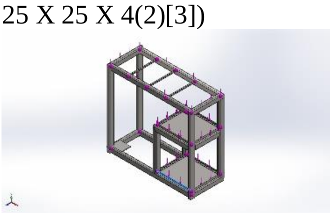
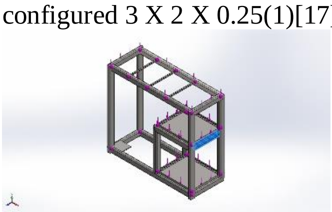
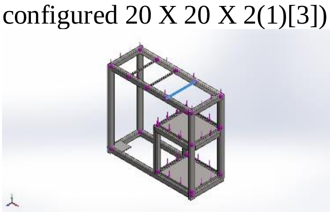
| Document Name and Reference | Formulation | Properties | Document Path/Date Modified |
| --- | --- | --- | --- |
| SolidBody 1(Trim/Extend21[2])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:431.8mm<br>Volume:0.000581968m^3<br>Mass Density:7,800kg/m^3<br>Mass:4.53935kg<br>Weight:44.4856N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 3(Trim/Extend5[2])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:1,270mm<br>Volume:0.00171169m^3<br>Mass Density:7,800kg/m^3<br>Mass:13.3512kg<br>Weight:130.841N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 4(Trim/Extend14[2])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:596.9mm<br>Volume:0.000804492m^3<br>Mass Density:7,800kg/m^3<br>Mass:6.27504kg<br>Weight:61.4954N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 5(Trim/Extend16[2])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:1,117.6mm<br>Volume:0.00150628m^3<br>Mass Density:7,800kg/m^3<br>Mass:11.749kg<br>Weight:115.14N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 6(Trim/Extend7[2])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:457.2mm<br>Volume:0.000616215m^3<br>Mass Density:7,800kg/m^3<br>Mass:4.80648kg<br>Weight:47.1035N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |

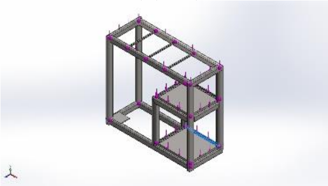
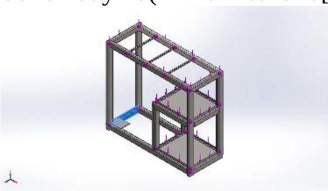
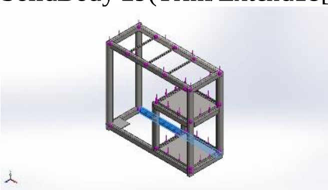
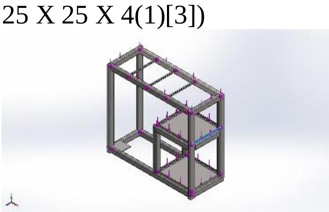
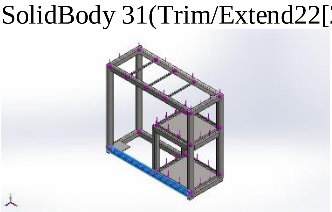
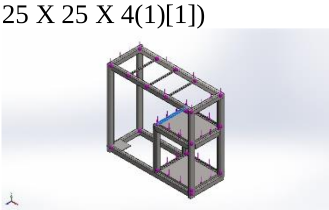
ISSN No:-2456-2165

| | | | |
|---|---|---|---|
| SolidBody 7(Trim/Extend12[2])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:596.9mm<br>Volume:0.000804502m^3<br>Mass Density:7,800kg/m^3<br>Mass:6.27511kg<br>Weight:61.4961N | C:\Users\hausb\ Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 8(Angle iron - configured 25 X 25 X 4(2)[4])  | Beam – Uniform C/S | Section Standard-weldment profiles/iso/angle iron<br>Section Area: 0.000179762m^2<br>Length:455.023mm<br>Volume:8.17947e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.637998kg<br>Weight:6.25238N | C:\Users\hausb\ Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 9(Trim/Extend10[1])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:457.2mm<br>Volume:0.000616215m^3<br>Mass Density:7,800kg/m^3<br>Mass:4.80648kg<br>Weight:47.1035N | C:\Users\hausb\ Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 10(Trim/Extend14[1])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:520.7mm<br>Volume:0.000701799m^3<br>Mass Density:7,800kg/m^3<br>Mass:5.47404kg<br>Weight:53.6456N | C:\Users\hausb\ Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 12(Angle iron - configured 25 X 25 X 4(1)[2])  | Beam – Uniform C/S | Section Standard-weldment profiles/iso/angle iron<br>Section Area: 0.000179762m^2<br>Length:529.265mm<br>Volume:9.51404e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.742095kg<br>Weight:7.27253N | C:\Users\hausb\ Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 13(Trim/Extend22[1])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:1,155.7mm<br>Volume:0.00155765m^3<br>Mass Density:7,800kg/m^3<br>Mass:12.1497kg<br>Weight:119.067N | C:\Users\hausb\ Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |

| | | | |
|---|---|---|---|
| SolidBody 14(Trim/Extend16[1])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:1,270mm<br>Volume:0.00171169m^3<br>Mass Density:7,800kg/m^3<br>Mass:13.3512kg<br>Weight:130.841N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 15(Rectangular tube - configured 3 X 2 X 0.25(1)[15])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:381mm<br>Volume:0.0005135m^3<br>Mass Density:7,800kg/m^3<br>Mass:4.0053kg<br>Weight:39.252N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 16(Angle iron - configured 25 X 25 X 4(1)[4])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/iso/angle iron<br>Section Area: 0.000179762m^2<br>Length:529.265mm<br>Volume:9.51404e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.742095kg<br>Weight:7.27253N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 18(Square tube - configured 20 X 20 X 2(1)[1])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/iso/square tube<br>Section Area: 0.000133699m^2<br>Length:457.2mm<br>Volume:6.11272e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.476792kg<br>Weight:4.67257N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 19(Trim/Extend18[1])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:1,155.7mm<br>Volume:0.00155765m^3<br>Mass Density:7,800kg/m^3<br>Mass:12.1497kg<br>Weight:119.067N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 20(Trim/Extend20[1])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:1,155.7mm<br>Volume:0.00155765m^3<br>Mass Density:7,800kg/m^3<br>Mass:12.1497kg<br>Weight:119.067N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |

ISSN No:-2456-2165

| | | | |
|---|---|---|---|
| SolidBody 21(Square tube - configured 20 X 20 X 2(1)[2])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/iso/square tube<br>Section Area: 0.000133699m^2<br>Length:457.2mm<br>Volume:6.11272e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.476792kg<br>Weight:4.67257N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 22(Trim/Extend13[2])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:457.2mm<br>Volume:0.000616208m^3<br>Mass Density:7,800kg/m^3<br>Mass:4.80642kg<br>Weight:47.1029N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 23(Trim/Extend11[2])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:520.7mm<br>Volume:0.000701791m^3<br>Mass Density:7,800kg/m^3<br>Mass:5.47397kg<br>Weight:53.6449N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 24(Angle iron - configured 25 X 25 X 4(2)[3])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/iso/angle iron<br>Section Area: 0.000179762m^2<br>Length:533.26mm<br>Volume:9.58584e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.747696kg<br>Weight:7.32742N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 25(Rectangular tube - configured 3 X 2 X 0.25(1)[17])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:381mm<br>Volume:0.0005135m^3<br>Mass Density:7,800kg/m^3<br>Mass:4.0053kg<br>Weight:39.252N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 26(Square tube - configured 20 X 20 X 2(1)[3])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/iso/square tube<br>Section Area: 0.000133699m^2<br>Length:457.2mm<br>Volume:6.11272e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.476792kg<br>Weight:4.67257N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |

| | | | |
|---|---|---|---|
| SolidBody 27(Angle iron - configured 25 X 25 X 4(2)[1])  | Beam – Uniform C/S | Section Standard-weldment profiles/iso/angle iron<br>Section Area: 0.000179762m^2<br>Length:533.26mm<br>Volume:9.58584e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.747696kg<br>Weight:7.32742N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 28(Trim/Extend20[2])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:419.1mm<br>Volume:0.000564851m^3<br>Mass Density:7,800kg/m^3<br>Mass:4.40584kg<br>Weight:43.1772N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 29(Trim/Extend18[2])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:1,244.6mm<br>Volume:0.00167744m^3<br>Mass Density:7,800kg/m^3<br>Mass:13.084kg<br>Weight:128.223N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 30(Angle iron - configured 25 X 25 X 4(1)[3])  | Beam – Uniform C/S | Section Standard-weldment profiles/iso/angle iron<br>Section Area: 0.000179762m^2<br>Length:455.023mm<br>Volume:8.17947e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.637998kg<br>Weight:6.25238N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 31(Trim/Extend22[2])  | Beam – Uniform C/S | Section Standard-weldment profiles/ansi inch/rectangular tube<br>Section Area: 0.00134777m^2<br>Length:1,244.6mm<br>Volume:0.00167745m^3<br>Mass Density:7,800kg/m^3<br>Mass:13.0841kg<br>Weight:128.224N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |
| SolidBody 32(Angle iron - configured 25 X 25 X 4(1)[1])  | Beam – Uniform C/S | Section Standard-weldment profiles/iso/angle iron<br>Section Area: 0.000179762m^2<br>Length:455.023mm<br>Volume:8.17947e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.637998kg<br>Weight:6.25238N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |

ISSN No:-2456-2165

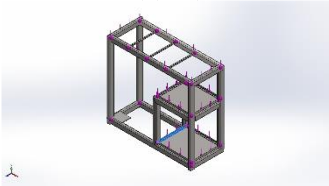
| | | | |
|---|---|---|---|
| SolidBody 33(Angle iron - configured 25 X 25 X 4(2)[2])<br> | Beam – Uniform C/S | Section Standard-weldment profiles/iso/angle iron<br>Section Area: 0.000179762m^2<br>Length:455.023mm<br>Volume:8.17947e-05m^3<br>Mass Density:7,800kg/m^3<br>Mass:0.637998kg<br>Weight:6.25238N | C:\Users\hausb\Desktop\New folder\UCHE PROJECT.SLDPRT<br>Dec 23 08:10:27 2021 |

Table 2: Finite Element Analysis (FEA) for the Bed Frame (Model Information)

7.2mm (18)

| Beam Name | Joints | Axial(N) | Shear1(N) | Shear2(N) | Moment1(N.m) | Moment2(N.m) | Torque(N.m) |
|---|---|---|---|---|---|---|---|
| **Beam-1(Trim/Extend21[2])** | 1 | 162.317 | -161.724 | -1.28373 | 0.529748 | -18.3237 | -1.39716 |
| | 2 | -132.025 | -331.774 | -10.3292 | -0.864748 | 24.7936 | -2.14763 |
| **Beam-2(Trim/Extend5[2])** | 1 | 96.7581 | 491.202 | 14.1514 | -6.24192 | 68.816 | 1.79105 |
| | 2 | -92.0843 | 482.863 | -6.51065 | -4.42081 | -63.2292 | 4.26825 |
| | 3 | -93.2924 | 275.096 | -6.54821 | -2.93887 | 38.1968 | 3.06621 |
| | 4 | -94.9827 | 49.1844 | -7.82688 | -1.36171 | 85.1525 | 0.666366 |
| | 5 | -96.7567 | -176.241 | -14.1514 | 0.581335 | 64.6726 | -1.79107 |
| **Beam-3(Trim/Extend14[2])** | 1 | -1,954.63 | -94.2776 | 23.1294 | 15.6003 | 34.9394 | 0.832173 |
| | 2 | 1,954.63 | 94.2776 | -23.1294 | -2.08203 | 20.1622 | -0.832173 |
| **Beam-4(Trim/Extend16[2])** | 1 | 2,505.93 | -46.7134 | 91.6038 | -22.9898 | -9.22093 | -0.72499 |
| | 2 | -455.064 | 128.384 | 2.634 | 9.05861 | -25.9076 | -3.81115 |
| | 3 | -2,505.93 | 46.7108 | -91.6038 | -35.1786 | -20.4413 | 0.724996 |
| **Beam-5(Trim/Extend7[2])** | 1 | -139.357 | -503.906 | -40.9353 | -9.30792 | 30.8456 | 21.1113 |
| | 2 | 139.357 | -496.094 | 40.9353 | -9.40771 | -29.0596 | -21.1113 |
| **Beam-6(Trim/Extend12[2])** | 1 | 1,974.08 | -55.6549 | -28.2609 | -0.100456 | -8.61061 | -0.451188 |
| | 2 | -1,974.08 | 55.6529 | 28.2609 | 16.6179 | -23.917 | 0.45118 |
| **Beam-7(Angle iron - configured 25 X 25 X 4(2)[4])** | 1 | -55.5239 | 57.9831 | 2.77567 | 0.0602829 | 0.694245 | 0.0043753 |
| | 2 | 80.6722 | 76.7685 | -3.51922 | -0.380681 | -1.37987 | -0.00479154 |
| | 3 | 80.6722 | 76.7685 | -3.51922 | -0.380681 | -1.37987 | -0.00479154 |
| **Beam-8(Trim/Extend10[1])** | 1 | -20.8074 | -490.331 | -24.9532 | -5.68332 | 16.1708 | -14.4169 |
| | 2 | 20.8074 | -509.669 | 24.9532 | -5.72527 | -20.5914 | 14.4169 |
| **Beam-9(Trim/Extend14[1])** | 1 | 491.558 | 797.497 | 72.968 | 5.4457 | -19.8866 | 2.16575 |
| | 2 | -407.306 | 807.896 | 89.7625 | -7.1796 | 26.9029 | -0.656658 |
| **Beam-10(Angle iron - configured 25 X 25 X 4(1)[2])** | 1 | -74.1544 | 76.6596 | 4.89387 | -0.00915648 | -1.43548 | -0.0043654 |
| | 2 | -3.54613 | 63.9985 | 2.37607 | 0.0884885 | 1.14971 | -0.00877809 |
| **Beam-11(Trim/Extend22[1])** | 1 | 0.609344 | -0.0716898 | -0.0775552 | -0.00785465 | 0.00731674 | -0.000105642 |
| | 2 | -995.108 | -153.508 | -137.692 | -47.7047 | 29.0545 | -3.06601 |
| | 3 | -0.609344 | 0.0716898 | 0.0775552 | 0.0117742 | -0.0109398 | 0.000105642 |
| | 4 | -3,015.53 | -33.2135 | -94.8453 | -35.6485 | 14.8405 | 0.186647 |
| **Beam-12(Trim/Extend16[1])** | 1 | 38.3013 | -41.0301 | 10.9721 | -5.59623 | -30.17 | -3.15196 |
| | 2 | 1.26674 | 264.747 | -6.93822 | -4.47022 | -3.3529 | -0.933755 |
| | 3 | 2.47483 | 47.3172 | -6.90106 | -2.87316 | 39.6743 | -1.94056 |

ISSN No:-2456-2165

| Beam Name | Joints | Axial(N) | Shear1(N) | Shear2(N) | Moment1(N.m) | Moment2(N.m) | Torque(N.m) |
|---|---|---|---|---|---|---|---|
| | 4 | 4.16516 | -199.212 | -5.62157 | -1.18835 | 18.5764 | -4.25397 |
| | 5 | -38.3021 | 355.99 | -10.975 | 1.20722 | -49.2342 | 3.15195 |
| **Beam-13(Rectangular tube - configured 3 X 2 X 0.25(1)[15])** | 1 | -97.2521 | -266.387 | 6.88073 | 0.454116 | 17.8562 | 1.10513 |
| | 2 | 104.693 | -281.249 | 3.15774 | -0.3487 | -18.2557 | 1.37909 |
| **Beam-14(Angle iron - configured 25 X 25 X 4(1)[4])** | 1 | -3.65557 | 65.8996 | -7.7172 | 0.584323 | 1.34084 | -0.00407561 |
| | 2 | -44.0093 | 80.8013 | -16.7008 | -0.854206 | -1.79645 | 0.0020938 |
| **Beam-15(Square tube - configured 20 X 20 X 2(1)[1])** | 1 | 0.037546 | -1.20799 | 4.83125 | -1.20205 | -0.275913 | 0.246345 |
| | 2 | -0.0375763 | 1.20799 | -4.83125 | -1.0068 | -0.27638 | -0.246345 |
| **Beam-16(Trim/Extend18[1])** | 1 | -774.416 | 27.746 | 23.6864 | 17.7698 | -19.6577 | -1.25505 |
| | 2 | 774.416 | -27.746 | -23.6864 | 8.70214 | -11.3512 | 1.25505 |
| **Beam-17(Trim/Extend20[1])** | 1 | -973.194 | -14.2967 | 67.1311 | 48.8122 | 11.9026 | -1.26251 |
| | 2 | 973.194 | 14.2967 | -67.1311 | 26.2135 | 4.07547 | 1.26251 |
| **Beam-18(Square tube - configured 20 X 20 X 2(1)[2])** | 1 | 1.27864 | -1.69011 | 10.309 | -2.39985 | -0.38725 | 0.139982 |
| | 2 | -1.2787 | 1.69011 | -10.309 | -2.31343 | -0.385468 | -0.139982 |
| **Beam-19(Trim/Extend13[2])** | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | -249.207 | -824.854 | 89.9316 | -5.53954 | -34.2108 | -0.490359 |
| **Beam-20(Trim/Extend11[2])** | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 393.028 | 752.775 | -36.8869 | -2.83424 | -20.857 | -3.27107 |
| **Beam-21(Angle iron - configured 25 X 25 X 4(2)[3])** | 1 | -124.303 | 67.3984 | -6.81214 | 0.457602 | 1.33297 | -0.00966696 |
| | 2 | 106.772 | 57.5606 | -0.227124 | -0.218747 | -0.949554 | 6.88073e-05 |
| | 3 | -124.303 | 67.3984 | -6.81214 | 0.457602 | 1.33297 | -0.00966696 |
| **Beam-22(Rectangular tube - configured 3 X 2 X 0.25(1)[17])** | 1 | -401.731 | -802.63 | -95.1677 | 4.20569 | -28.3212 | 2.32356 |
| | 2 | 458.049 | -747.369 | -55.5815 | -2.17296 | 25.4388 | -0.428802 |
| **Beam-23(Square tube - configured 20 X 20 X 2(1)[3])** | 1 | 6.32453 | -1.77411 | 10.7949 | -2.45744 | -0.404962 | -0.197873 |
| | 2 | -6.32459 | 1.77411 | -10.7949 | -2.47798 | -0.40616 | 0.197873 |
| **Beam-24(Angle iron - configured 25 X 25 X 4(2)[1])** | 1 | -86.8774 | 59.9097 | -0.874171 | 0.198861 | 0.967914 | -4.74504e-05 |
| | 2 | 81.2163 | 59.9514 | -0.759041 | -0.211149 | -0.967921 | 0.000258004 |
| **Beam-25(Trim/Extend20[2])** | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Beam-26(Trim/Extend18[2])** | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | -0.00166562 | -0.000170213 | -4.25232e-06 | -9.65429e-07 | 3.86399e-05 | -1.43756e-07 |
| **Beam-27(Angle iron - configured 25 X 25 X 4(1)[3])** | 1 | -31.9751 | 55.5977 | 2.00599 | 0.0557796 | 0.718132 | -0.0161505 |
| | 2 | 21.5165 | 66.6675 | 4.01536 | -0.125364 | -1.09339 | -0.0115089 |

ISSN No:-2456-2165

| Beam Name | Joints | Axial(N) | Shear1(N) | Shear2(N) | Moment1(N.m) | Moment2(N.m) | Torque(N.m) |
|---|---|---|---|---|---|---|---|
| **Beam-28(Trim/Extend22[2])** | 1 | 232.037 | 325.164 | 12.0624 | -0.800133 | 27.5228 | -1.47922 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | -0.00125351 | -0.00012919 | -3.33109e-06 | -7.57612e-07 | 2.93636e-05 | -1.1274e-07 |
| **Beam-29(Angle iron - configured 25 X 25 X 4(1)[1])** | 1 | -5.61572 | 96.7018 | -23.1329 | -0.912381 | -1.9874 | 0.00926447 |
| | 2 | 1.85065 | 96.3714 | -24.0195 | 0.93329 | 1.98046 | 0.00773203 |
| **Beam-30(Angle iron - configured 25 X 25 X 4(2)[2])** | 1 | 46.2369 | 58.9081 | 0.697447 | -0.0874389 | -0.670669 | 0.0037764 |
| | 2 | -36.5969 | 57.7096 | 0.585193 | 0.0583377 | 0.597631 | 0.000847953 |

Table 3: Beams (Beam Forces)

| Beam Name | Joints | Axial(N/m^2) | Bending Dir1(N/m^2) | Bending Dir2(N/m^2) | Torsional (N/m^2) | Upper bound axial and bending(N/m^2) |
|---|---|---|---|---|---|---|
| **Beam-1(Trim/Extend21[2])** | 1 | -120,434 | -28,071.3 | -759,641 | -51,672.1 | 908,146 |
| | 2 | -97,957.9 | -45,822.8 | -1.02786e+06 | -79,427.5 | 1.17164e+06 |
| **Beam-2(Trim/Extend5[2])** | 1 | -71,791.3 | 330,758 | 2.85288e+06 | 66,239.9 | 3.25543e+06 |
| | 2 | -68,323.5 | -234,258 | 2.62127e+06 | 157,856 | 2.92385e+06 |
| | 3 | -69,219.8 | -155,730 | -1.58351e+06 | 113,400 | 1.80846e+06 |
| | 4 | -70,474 | -72,156.8 | -3.53014e+06 | 24,644.7 | 3.67277e+06 |
| | 5 | -71,790.2 | 30,804.8 | -2.68111e+06 | -66,240.5 | 2.78371e+06 |
| **Beam-3(Trim/Extend14[2])** | 1 | -1.45027e+06 | 826,655 | -1.44847e+06 | 30,776.7 | 3.72539e+06 |
| | 2 | -1.45027e+06 | 110,326 | 835,858 | -30,776.7 | 2.39645e+06 |
| **Beam-4(Trim/Extend16[2])** | 1 | -1.85932e+06 | 1.21823e+06 | -382,269 | -26,812.7 | 3.45981e+06 |
| | 2 | -337,642 | 480,014 | 1.07404e+06 | -140,950 | 1.8917e+06 |
| | 3 | -1.85932e+06 | -1.8641e+06 | 847,427 | 26,812.9 | 4.57085e+06 |
| **Beam-5(Trim/Extend7[2])** | 1 | -103,398 | -493,225 | -1.27875e+06 | 780,770 | 1.87538e+06 |
| | 2 | -103,398 | 498,512 | -1.20471e+06 | -780,770 | 1.80662e+06 |
| **Beam-6(Trim/Extend12[2])** | 1 | -1.4647e+06 | 5,323.12 | -356,967 | -16,686.5 | 1.82699e+06 |
| | 2 | -1.4647e+06 | 880,577 | 991,517 | 16,686.2 | 3.3368e+06 |
| **Beam-7(Angle iron - configured 25 X 25 X 4(2)[4])** | 1 | 308,875 | 979,947 | 1.87365e+06 | 98,316.6 | 3.16247e+06 |
| | 2 | 448,773 | 1.20613e+06 | 3.29142e+06 | -107,670 | 4.94632e+06 |
| | 3 | 448,773 | 1.20613e+06 | 3.29142e+06 | -107,670 | 4.94632e+06 |
| **Beam-8(Trim/Extend10[1])** | 1 | -15,438.4 | -301,158 | -670,388 | -533,189 | 986,984 |
| | 2 | -15,438.4 | 303,381 | -853,653 | 533,189 | 1.17247e+06 |
| **Beam-9(Trim/Extend14[1])** | 1 | 364,720 | 288,566 | 824,434 | 80,097.5 | 1.47772e+06 |
| | 2 | 302,207 | 380,445 | 1.1153e+06 | -24,285.7 | 1.79796e+06 |
| **Beam-10(Angle iron - configured 25 X 25 X 4(1)[2])** | 1 | -412,515 | 2.35453e+06 | 4.06564e+06 | -98,094.1 | 6.83269e+06 |
| | 2 | 19,726.8 | 1.6551e+06 | 3.12169e+06 | -197,251 | 4.79652e+06 |
| **Beam-11(Trim/Extend22[1])** | 1 | -452.112 | 416.216 | 303.328 | -3.90704 | 1,171.66 |
| | 2 | -738,337 | -2.52786e+06 | -1.2045e+06 | -113,393 | 4.4707e+06 |
| | 3 | -452.112 | 623.91 | 453.529 | 3.90704 | 1,529.55 |
| | 4 | -2.23743e+06 | -1.88901e+06 | -615,238 | 6,902.9 | 4.74167e+06 |
| **Beam-12(Trim/Extend16[1])** | 1 | -28,418.2 | 296,543 | -1.25075e+06 | -116,571 | 1.57571e+06 |
| | 2 | 939.876 | -236,876 | 139,000 | -34,533.6 | 376,816 |
| | 3 | 1,836.24 | -152,248 | -1.64476e+06 | -71,769 | 1.79885e+06 |
| | 4 | 3,090.41 | -62,970.6 | -770,114 | -157,327 | 836,176 |
| | 5 | -28,418.8 | 63,970.4 | 2.04109e+06 | 116,570 | 2.13347e+06 |
| **Beam-13(Rectangular tube - configured 3 X 2 X 0.25(1)[15])** | 1 | -72,157.8 | 24,063.5 | -740,257 | 40,871.7 | 836,478 |
| | 2 | -77,679 | 18,477.5 | -756,819 | 51,004 | 852,975 |
| **Beam-14(Angle iron -** | 1 | 20,335.6 | 562,484 | 2.84275e+06 | -91,563.3 | 3.42557e+06 |

| Beam Name | Joints | Axial(N/m^2) | Bending Dir1(N/m^2) | Bending Dir2(N/m^2) | Torsional (N/m^2) | Upper bound axial and bending(N/m^2) |
|---|---|---|---|---|---|---|
| configured 25 X 25 X 4(1)[4]) | 2 | -244,821 | 550,822 | 3.6904e+06 | 47,039.7 | 4.48604e+06 |
| Beam-15(Square tube - configured 20 X 20 X 2(1)[1]) | 1 | -280.825 | 1.73665e+06 | -398,622 | 253,886 | 2.13555e+06 |
| | 2 | -281.051 | -1.45456e+06 | 399,297 | -253,886 | 1.85414e+06 |
| Beam-16(Trim/Extend18[1]) | 1 | -574,590 | 941,619 | 814,942 | -46,416.4 | 2.33115e+06 |
| | 2 | -574,590 | -461,125 | -470,582 | 46,416.4 | 1.5063e+06 |
| Beam-17(Trim/Extend20[1]) | 1 | -722,077 | 2.58655e+06 | -493,441 | -46,692.3 | 3.80207e+06 |
| | 2 | -722,077 | -1.38905e+06 | 168,956 | 46,692.3 | 2.28008e+06 |
| Beam-18(Square tube - configured 20 X 20 X 2(1)[2]) | 1 | -9,563.53 | 3.46716e+06 | -559,476 | 144,268 | 4.03619e+06 |
| | 2 | -9,564.01 | -3.34231e+06 | 556,901 | -144,268 | 3.90877e+06 |
| Beam-19(Trim/Extend13[2]) | 1 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 184,903 | 293,539 | -1.41827e+06 | -18,135.2 | 1.89671e+06 |
| Beam-20(Trim/Extend11[2]) | 1 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 291,614 | -150,186 | 864,662 | -120,976 | 1.30646e+06 |
| Beam-21(Angle iron - configured 25 X 25 X 4(2)[3]) | 1 | 691,486 | 909,676 | 3.03053e+06 | -217,225 | 4.63169e+06 |
| | 2 | 593,964 | 952,859 | 2.33666e+06 | 1,546.16 | 3.88348e+06 |
| | 3 | 691,486 | 909,676 | 3.03053e+06 | -217,225 | 4.63169e+06 |
| Beam-22(Rectangular tube - configured 3 X 2 X 0.25(1)[17]) | 1 | 298,071 | -222,859 | -1.1741e+06 | 85,934.2 | 1.69503e+06 |
| | 2 | 339,857 | -115,145 | -1.05461e+06 | -15,858.7 | 1.50961e+06 |
| Beam-23(Square tube - configured 20 X 20 X 2(1)[3]) | 1 | -47,304.2 | 3.55036e+06 | -585,065 | -203,931 | 4.18273e+06 |
| | 2 | -47,304.7 | -3.58004e+06 | 586,795 | 203,931 | 4.21414e+06 |
| Beam-24(Angle iron - configured 25 X 25 X 4(2)[1]) | 1 | 483,292 | 1.03984e+06 | 2.42183e+06 | -1,066.03 | 3.94496e+06 |
| | 2 | 451,800 | 1.00492e+06 | 2.40147e+06 | 5,796.35 | 3.85819e+06 |
| Beam-25(Trim/Extend20[2]) | 1 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 |
| Beam-26(Trim/Extend18[2]) | 1 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 |
| | 3 | -1.23584 | -0.0511579 | -1.60188 | -0.00531665 | 2.88887 |
| Beam-27(Angle iron - configured 25 X 25 X 4(1)[3]) | 1 | 177,875 | 1.03236e+06 | 1.94903e+06 | -362,916 | 3.15927e+06 |
| | 2 | 119,695 | 1.45687e+06 | 2.90044e+06 | -258,615 | 4.477e+06 |
| Beam-28(Trim/Extend22[2]) | 1 | -172,164 | 42,398.9 | 1.14101e+06 | -54,706.8 | 1.35557e+06 |
| | 2 | 0 | 0 | 0 | 0 | 0 |
| | 3 | -0.93006 | -0.0401457 | -1.21732 | -0.00416954 | 2.18752 |
| Beam-29(Angle iron - configured 25 X 25 X 4(1)[1]) | 1 | -31,239.8 | 702,122 | 4.13679e+06 | 208,137 | 4.87015e+06 |
| | 2 | -10,295 | 631,166 | 4.08237e+06 | 173,709 | 4.72383e+06 |
| Beam-30(Angle iron - configured 25 X 25 X 4(2)[2]) | 1 | 257,212 | 863,648 | 1.76159e+06 | 84,841.2 | 2.88245e+06 |
| | 2 | 203,586 | 825,254 | 1.60222e+06 | 19,050.3 | 2.63106e+06 |

Table 4: Beam Stresses

ISSN No:-2456-2165

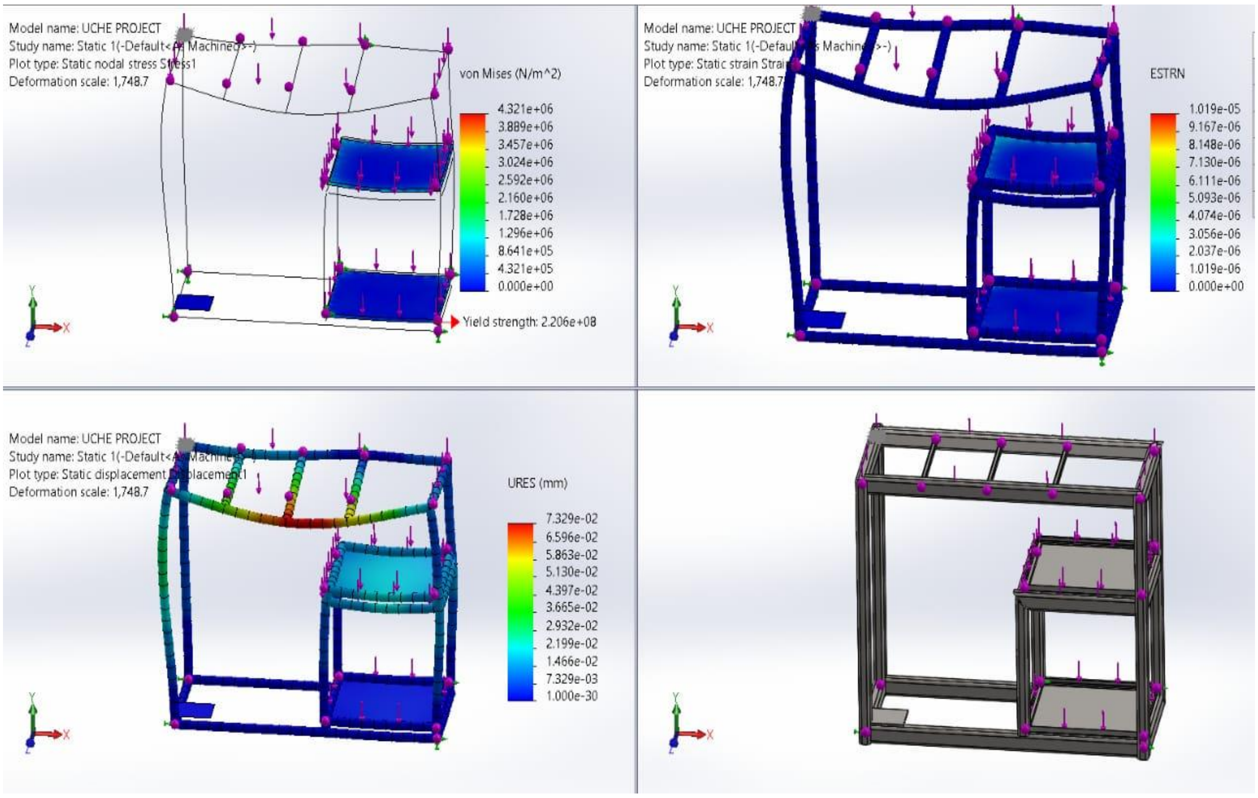


Fig 1: Study Results for the stresses, strain and displacement of the bench frame

*A. Design of Pipe*

The design of a pipe involves the determination of inside diameter of the pipe and its wall thickness as discussed below: Inside diameter of the pipe: The inside diameter of the pipe depends upon the quantity of fluid to be delivered, Di = Inside diameter of the pipe, Do = outside diameter of the pipe, V = velocity of fluid (meters/min), Q = Quantity of fluid (liters/min), and the quantity of fluid flowing per minute has been recorded.

$$Q = \text{Area} \times \text{velocity} = \frac{\pi d^2}{4} \times V \quad (19)$$

Therefore the diameter of the pipe can be calculated.

Also the stress cylinder wall of the pipe can be calculated using Lame's formula:

$$\sigma_{t\ max} = \frac{p_i^2(r_o^2 + r_i^2)}{(r_o^2 - r_i^2)} \quad (20)$$

where;
$\sigma_{t\ max}$ = maximum tangential stress (MPa)
$p_i$ = internal pressure in the pipe (kPa)
$r_i$ = internal radius of pipe
$r_o$ = external radius of pipe
The thickness of the pipe may be calculated using Lame's equation in order to sustain the internal fluid pressure;

$$t = R\left[\sqrt{\frac{\sigma_t + p}{\sigma_t - p}} - 1\right] \quad (21)$$

Where;
T = thickness of the pipe
R = Inner radius of the pipe,
P= Intensity of internal pressure
$\sigma_t$= tangential stress

The pipe's strength may be calculated using the standard ASTM D1785 table, table3.6 in Appendix A, which shows that the $\sigma_t$ for 1" PCV pipe is 581lb.

Converting 581lb to Mega pascal (MPa);

581lb =263.77

Therefore,

$\sigma_t$ (MPa) $= \frac{F}{A}$ (22)

$\sigma_t = \frac{263.17 \times 9.81}{\frac{\pi \times 0.0254^2}{4}} = 5.1$MPa

A safety factor of 2.5 is used, Therefore, Allowable tensile strength;

$\sigma_{ta} = \frac{5.1 \times 10^6}{2.5} = 2.04$ MPa

### *B. Design of Pump*

The pump is a single-stage centrifugal pump with a one-horsepower motor. The impeller is developed using the design flow rate, pump head, and pump specific speed as the foundation. As a result, design data are necessary to create a centrifugal pump. The design parameters are as follows while calculating the design.

Flow rate, $Q_{max} = 35$ l/min

Head, $H_{max} = 35$m

Speed, n = 2850 rpm

Gravitational acceleration, g = 9.81 m/s²

Density of water, ρ = 1000 kg/m³

Specific speed is used to categorize impellers based on their performance and proportions, independent of their actual size or operating speed.

Specific Speed: $n_s = 3.65n\frac{\sqrt{\square}}{\square^{1/4}}$ (23)

A pump's capacity, also known as volume flow rate, is the amount of water pushed per unit time. The capacity is proportional to the velocity of the flow in the suction pipe.

Capacity: Q = AV (24)

Where A and V are area of pipe and volume flow rate respectively.

### *C. Water Power and Shaft Power:*

Water power is the power transferred to the water by the pump. The flow rate and pump head must be determined in order to compute water power. As a result, in order to deliver a specific level of power to the water, more power must be provided to the pump shaft. This is referred to as brake power. The pump's efficiency dictates how much more power is required at the shaft.

The connection below determines the water power.

$N = \rho gHQ$ (25)

The shaft power is:

Shaft power = water power/ $\eta_o$ (26)

Pump efficiency: $\eta_o = \eta_m \times \eta_v \times \eta_r$ (27)

Maximum shaft power: $M_{max} := \alpha_1 \, {}^{\rho gHQ}/_{\eta_o}$ (28)

Where; $\alpha_1$ is the safety factor in charge condition of the work onthe pump.

### *D. Design of the Reservoirs*

Fiber glass was used to construct the reservoirs. The material is made up of various composite materials, plastic resin, and glass fiber, as the name suggests. When loaded, plastic resins have a high compressive strength but a low tensile strength, whereas glass fibers have a high tension strength but do not resist compression. GRP becomes a material that resists both compressive and tensile forces well due to the compatibility of each material overcoming the deficiencies of the other. The material was obtained in sheet form, with a thickness of 5mm, and was cut into various measurements and designed to the necessary shaped vessel using

ISSN No:-2456-2165

adhesive material for connecting. Water is pumped from the sump tank (large reservoir) and released into the measuring tank as part of the overall design (smaller reservoir).

*E. Dimension of the Sump Tank;*

Height of the reservoir = 558.8mm
Length of the reservoir = 469.9mm
Breath of the reservoir = 457.2mm
Total volume of reservoir =length × breath × height (29)
Total volume of reservoir = 558.8mm × 469.9mm × 457.2mm
Therefore total volume of the circular tank = 120051630.864mm³ = 120.05L

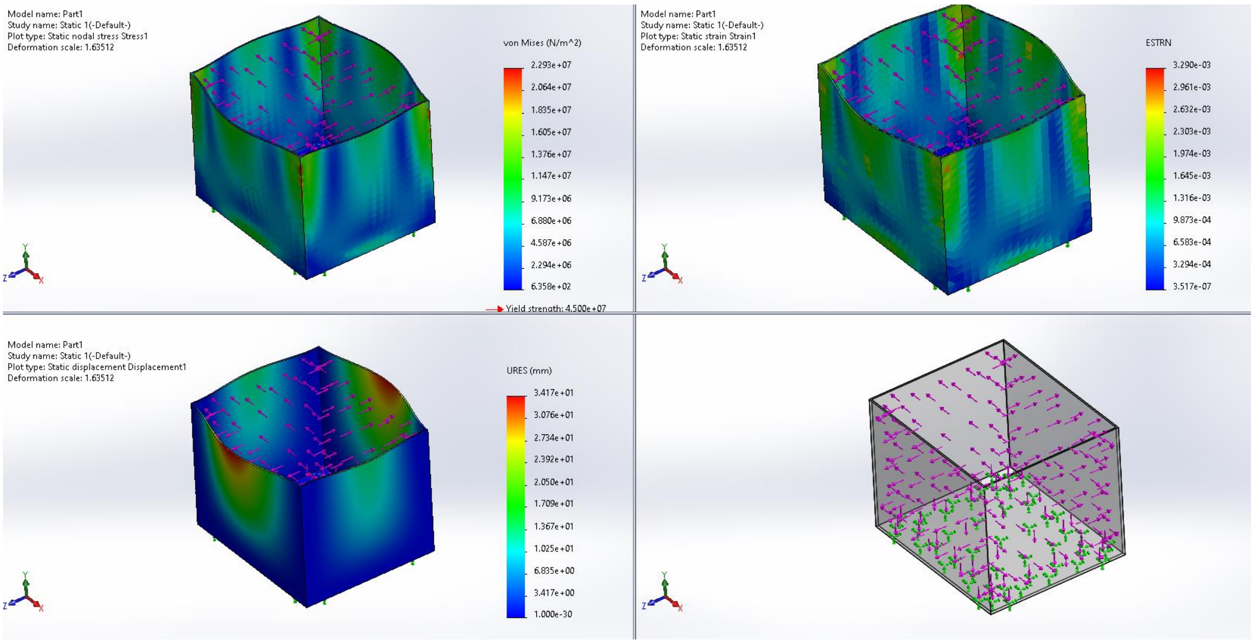
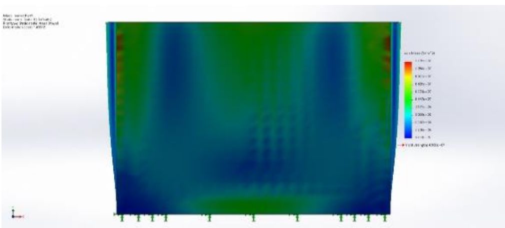



Fig. 2: Finite Element Analysis (FEA) for the Sump Reservoir

| Name | Type | Min | Max |
|---|---|---|---|
| Stress1 | VON: von Mises Stress | 6.358e+02N/m^2<br>Node: 6874 | 2.293e+07N/m^2<br>Node: 14550 |
| <br>Part1-Static 1-Stress-Stress1 | | | |

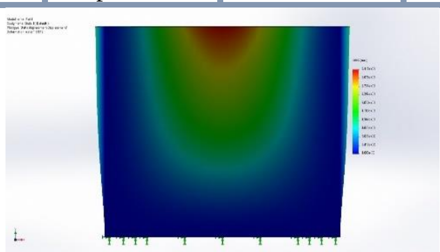
| Name | Type | Min | Max |
|---|---|---|---|
| | | | |
| | | | |
| Displacement1 | URES: Resultant Displacement | 0.000e+00mm<br>Node: 178 | 3.417e+01mm<br>Node: 19933 |
| <br>Part1-Static 1-Displacement-Displacement1 | | | |

Fig. 3: Study Results for the Static Stress and Displacement of the Reservoir

*F. Dimension of the Measuring Tank;*

Height of the reservoir = 431.8mm
Length of the reservoir = 457.2mm
Width of the reservoir = 431.8mm

Total volume of reservoir = length $\times$ breath $\times$ height (30)
Total volume of reservoir = 457.2mm × 431.8mm × 431.8mm
Therefore total volume of the circular tank = 85245506.928mm³ = 85.25L

## VI. THE MANUFACTURING METHODOLOGY

A. *Machining:* This refers to any of the different procedures for cutting raw material into a specified form and size using a controlled material-removal process. Cutting, drilling and grinding are the machining procedures employed in this design.

- **Cutting operation;**
- **Drilling operation;** this is a cost-effective method of removing a considerable amount of metal in order to create a semi-precision round hole or cavity. This is done in order to drill holes for fasteners.
- **Grinding operation;** this is a cutting operation that involves the use of abrasive particles. By eliminating any leftover undesired components from the surface, the grinding operation improves the surface polish and tightens the tolerance. Grinding machines are used to manufacture items that are the same form, size, and finish.

**B.** *Joining:* The following is a list of the methods that were utilized in the joining operation:

- **Welding;** the hollow mild steel square pipe is heated and melted using gas welding and arc welding in some areas in this procedure, resulting in the linked portions functioning as one. It's utilized to produce the frame.
- **Adhesive;** Polymers are the most well-known adhesives, allowing various materials to be joined at temperatures below 200°C. Adhesive bonding (also known as gluing or glue bonding) is a wafer bonding technique that involves the use of an intermediary layer to link substrates of various materials. It is used to connect pipes and fittings in this case, and the kind used is araldite. Araldite is a high-performance adhesive that bonds ceramics, wood, chipboard, glass, metal, and most hard plastics. Free of solvents, heat and cold resistant, as well as water and oil resistant. Three essential characteristics must be met in order to generate a good surface for adhesive bonding of plastics: To develop a strong boundary layer, the provided material's weak boundary layer must be eliminated or chemically changed.
- **Degreasing;** the adhered is to be wiped with solvent or an aqueous detergent solution to clean the surface of any oils following degreasing process. After degreasing, a good test to determine cleanliness of the surface is to use a drop of water. If the drop spreads on the surface, a low contact angle and good wettability has been achieved, which indicates the surface is clean and ready for application of the adhesive. If the drop beads up or retains its shape, the degreasing process should be repeated.
- **Abrasion;** to roughen the surface and remove any loose material, the adherent is sanded or grit blasted using an abrasive substance. In comparison to a relatively smooth surface, rough surfaces make stronger connections because they have a larger surface area for the adhesive to attach to. After abrasion, the adherent should be cleaned with solvent or an aqueous detergent solution to remove any oils or loose particles, and then dried. The glue is then applied when this process is completed.
- **Coating;** this is a coating that is applied to an object's surface, also known as the substrate. The coating can be applied for ornamental, utilitarian, or both purposes. The coating may be an all-over coating that covers the entire substrate or a partial coating that just covers sections of the substrate. Car paint was employed in the coating process of this device, which has the dual purpose of preserving the substrate while also being beautiful.

Plate 1: Cutting operations

Plate 2: Joining Operations

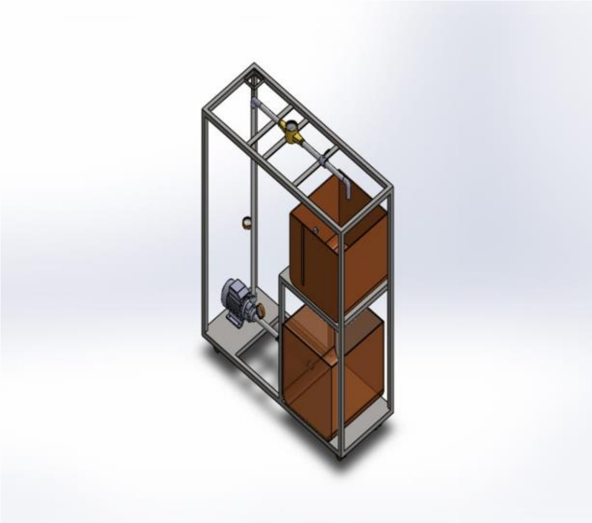
Plate 3: Grinding and Smoothening Operations

*C. Fabrication Methodology*

Various methods were examined in the development of the centrifugal pump test rig, including:

- **Research:** This step entails carefully considering information sourcing, data gathering, and data assessment from the internet or other sources in order to gain the knowledge needed to build the centrifugal pump test rig.
- **Data compilation**: In this step, the acquired data from the study is integrated and examined in order to arrive at a certain operation sequence. The designer can follow the data compilation process to design the equipment step by step.
- **Material selection:** This process involves the cost of materials used for the manufacturing process, with the goal of lowering production costs while improving the quality and dependability of the chosen material.
- **Design:** Following the material selection, the pieces chosen are considered and their dimensions are computed.
- **Fabrication:** Work is done on the many pieces that make up the system at this step to get them to the shape and size necessary for the design. Various manufacturing procedures are carried out in this process.
- **Assembly;** this entails bringing all of the various sections or parts that have been worked on together to make the system. The reservoirs were attached to the frame after the frame was completed. We installed the electrical pump and connected the pipes to it; the horizontal pipe from the pump's suction side was linked to the reservoir, while the vertical pipe from the pump's discharge side was connected to the reservoir. As the discharge line links to the receiving reservoir, the water flow meter was also attached.

Finally, powering the whole unit and testing.



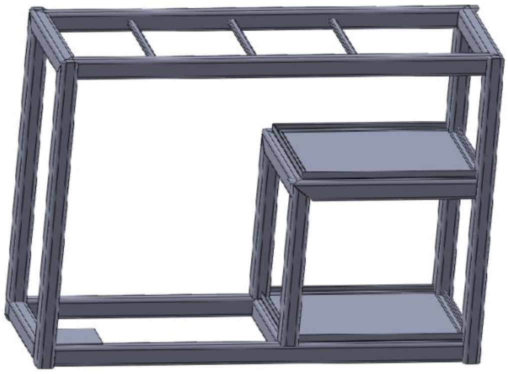


Plate 4:A pictorial view of the finished Centrifugal pump test bed

## VII. METHODS

### *A. Procedure*

Make sure the advanced inverter is turned on and the pump is adjusted to 50% before starting the motor. The pump speed will be increased by the interface until it reaches the desired value. Start the motor by closing the ball valve on the discharge line. Check to see whether the discharge pressure of the pump rises. If the pump does not release pressure after ten seconds, it is most likely dry and has to be primed. Close the flow meter cap and start the pump again to prime the pump, or partly close and open the inlet valves a few times to help prime the system and remove any bubbles stuck inside the valve mechanism. Make sure the intake valve is completely open.

To give a flow rate of Q = 0, close the ball valve. (Be aware that if the ball valve is closed or almost closed, the back pressure created is outside of normal operating norms, and the pump may not work smoothly.) As the trial goes, the pump should begin to run more smoothly.) Allow the pump to run for a few minutes before collecting data; during this time, open and close the discharge valve as needed and monitor the suction and discharge pressure gauges.

Allow the readings of the water flow meter and the pressure gauges to stabilize and record the values at each increment by opening the gates valve (discharge valve) in modest increments.

Tabulate a list of your findings. When the discharge valve (head valve) was closed, the load on the pump increased and the motor speed fell; however, when the discharge valve was opened, the load on the pump decreased and the motor speed rose.

Repeat the operation with the advanced inverter Variable Frequency Drive (VFD) at 60 percent, 80 percent, 90 percent, and 100 percent of the manufacturer's specified pump speed. Tabulate your data of suction pressure, discharge pressure, flow rate, pipe diameter, input power, torque at each speed, and efficiency each time.

Switch off the pump, and if you're not going to do another workout right away, turn off the complete system and drain the water from the reservoir.

*B. Bill of Engineering Measurement and Evaluation*

One of the most essential elements that were carefully examined during the design of the centrifugal pump test bed was material selection. The cost of the materials required for the centrifugal pump test bed's design and construction. The materials' availability on the market, as well as their appropriateness for the design, were taken into account. Transportation, typing or photocopying, communication, and incidental costs might all be ascribed to other expenses. The materials obtained, as well as their cost and purchased amount, were recorded in the table below;

| **S/N** | **Part** | **Quantity** | **Cost (#)** |
|---|---|---|---|
| 1 | Flow control valve | 2 | 6,000 |
| 2 | Water Flow meter | 1 | 4,500 |
| 3 | Advanced inverter | 1 | 9,000 |
| 4 | Stop watch | 1 | 500 |
| 5 | Valves | 5 | 5,000 |
| 6 | Pressure gauges | 2 | 6,000 |
| 7 | Centrifugal Pump (0.5hp) | 1 | 9,000 |
| 8 | Fittings | 5 | 27,240 |
| 9 | Adhesive | 2 | 5,400 |
| 10 | Bench Frame | 1 | 17,000 |
| 11 | Polyvinyl Chloride (PVC) Pipes | 6 | 1,500 |
| 12 | Polyethylene Circular tank | 1 | 25,500 |
| 13 | Caster wheels | 4 | 4,000 |
| 14 | Strainers | 2 | 1000 |
| | | **Total** | **121,640** |

Table 5: Bill of Engineering Measurement and Evaluation (BEME)

## VIII. RESULTS AND DISCUSSION

*A. Results and Calculation*

On a copy of the single pump test sheet or in the table below, note the results.

Calculate the volume flow rate from the volumetric measuring tank if one was utilized, from

$$: \dot{Q} = {}^{Q}/_{t} \tag{31}$$

Calculate the manometric head from

$$: H = \frac{(P_2 - P_1)}{\rho g} \tag{32}$$

The hydraulic power can be calculatd from:

$$W_{out} = \rho g H \dot{Q} \tag{33}$$

Calculate the overall efficiency from: $$h = \frac{W_{out}}{W_{in}} \tag{34}$$

For the data of the constant speed and constant voltage tests, plot the pump characteristics as a single graph of manometric head against volumetric flow rate.

For each set of findings, plot graphs of hydraulic power and total efficiency against flow rate. This graph may be used for interpolation to generate values that can be used to construct contours of constant hydraulic power and constant efficiency onto the pump characteristics if needed.

Before plotting the numerous graphs required to characterize a centrifugal pump, make sure to enter your calculations and findings in the tables on the following page.

ISSN No:-2456-2165

| Pump inlet Suction Pressure [Bar] | Pump outlet Delivery Pressure [Bar] | Total Head H [m] | Pump Speed N [RPM] | Pump Torque T[Nm] | Hydraulic Power $W_{out}$ [W] | Flow rate Q[m³/s] | Total Power Input [W] | Efficiency [%] |
|---|---|---|---|---|---|---|---|---|
| -0.00196133 | 0.583155 | 5.97 | 2850 | 0.302 | 0 | 0 | 90 | 0 |
| -0.00196133 | 0.343233 | 3.52 | 2850 | 0.369 | 4.627 | 0.000134 | 110 | 0.042 |
| -0.00196133 | 0.2647796 | 2.72 | 2850 | 0.395 | 5.550 | 0.000208 | 118 | 0.047 |
| -0.00196133 | 0.1569064 | 1.619 | 2850 | 0.476 | 5.674 | 0.000357 | 142 | 0.039 |
| -0.00196133 | 0.0392266 | 0.419 | 2850 | 0.519 | 1.9196 | 0.000467 | 155 | 0.012 |

Table 6.0: Characteristic reading of the pump taken at Constant Pump speed: 2850 rpm

*B. RESULTS*

The performance test results are plotted in a graphical fashion, with power input vs flow rate ($W_{in}$ vs $Q$) for pump speed: 2850 rpm on one graph, head versus flow rate ($H_p$ vs $Q$) for same pump speed on another graph, and efficiency versus flow rate ($\eta_p$ vs $Q$) for same pump speed on a final graph. The experimental $H_p$ vs $Q$, $W_{in}$ vs $Q$ and $\eta_p$ vs $Q$ graphs are described, and comments on the influence of pump speed are offered.

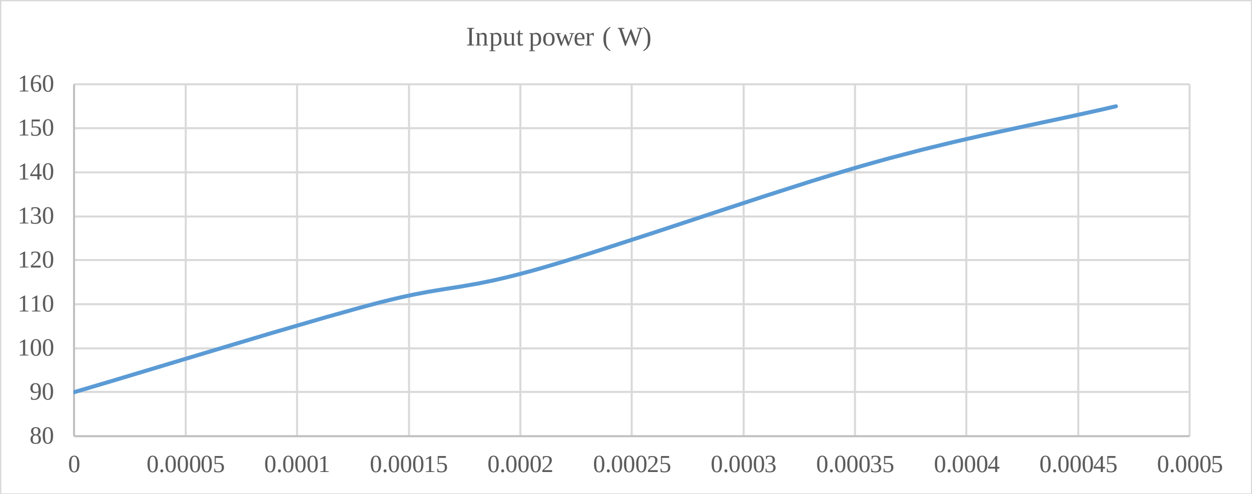



Fig 4: A graph showing power input against flow rate, with the centrifugal pump's characteristic curve measured simultaneously at 2850 rpm. The flow rate and shaft power are depicted in relative units.

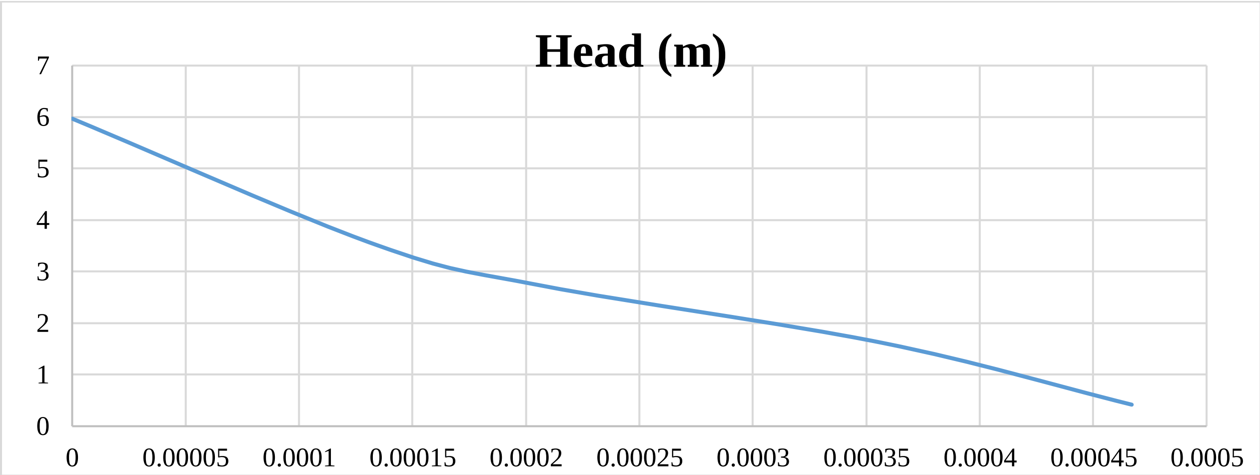



Fig. 5: At constant speed of 2850 rpm, a graph of head vs flow rate is used to determine the centrifugal pump's characteristic curve. The flow rate and shaft power are shown with relative units.

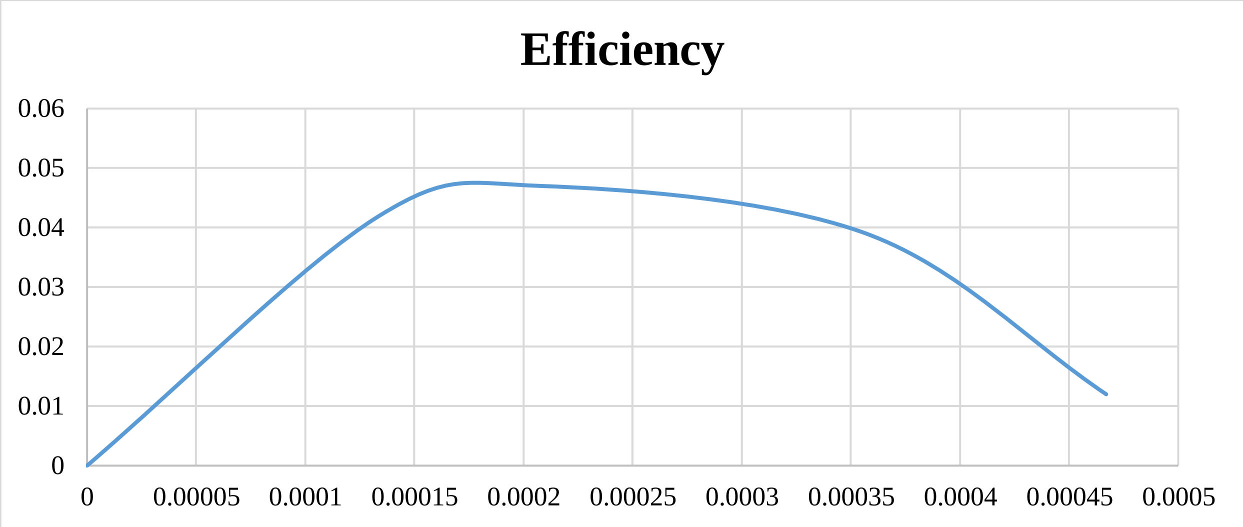



Fig 6.0: Resulting graph of Efficiency against flow rate estimates for a centrifugal pump driven by a 0.5Hp motor and frequency converter at constant pump speed of 2850rpm.

*C. DISCUSSION*

The H-Q and $h_o$-Q curves are used to form the braking power (BP) or shaft power (SP) vs flow rate (Q) curve for a pump. The BP-Q curve's shape is determined by the pump's particular speed and impeller design. Figure 4.0 illustrates that for radial flow impellers, BP rises to a peak and then falls somewhat as Q rises from zero. BP grows progressively from a nonzero value as Q increases for mixed flow impellers. Axial flow impellers, on the other hand, have a maximum BP when Q is 0 and gradually drop as Q grows. To reduce the start-up load on axial flow pumps, the discharge-side valve (or discharge valve) should be open to the atmosphere when they are turned on. When radial flow and mixed flow pumps are started, the discharge-side valve should be closed.

The head-discharge curve (H-Q curve) is a graph that shows how a pump's head corresponds to the amount of water pushed per unit time (i.e., discharge of the pump). In general, as a pump's discharge increases, the head generated by the pump gradually decreases (Fig. 5.0). The design head or normal head, and the design discharge or normal discharge of a pump are the head and discharge values that correspond to the greatest efficiency.

The H-Q curve changes form depending on the speed. As discharge (Q) grows from zero, the head of radial flow impellers reduces just little before rapidly dropping. Mixed and axial flow impellers have less severe H-Q curve slope shifts than radial flow impellers. In circumstances where head must stay practically constant while Q fluctuates, radial flow impellers working on the flat region of their H-Q curves function effectively (e.g., as in set-move systems where the number of operating laterals varies during the irrigation season). When a reasonably constant Q is sought but H is predicted to fluctuate (e.g., water sources such as a well, small stream, or small reservoir), impellers with greater specific speeds will likely work the best.

Fig. 6.0 shows the pump efficiency against discharge ($h_o$-Q) curves for common centrifugal pumps. As Q rises from zero, the overall efficiency ($h_o$) of a pump steadily grows to a peak, then drops as Q rises higher. For a particular type of impeller, there is usually just one peak efficiency.

Specific speed, impeller design, and pump discharge all affect potential pump efficiency. The greater capacity pumps should have the maximum efficiency, according to this figure. The types of materials used in construction, the finish on castings, the quality of machining, and the type and quality of bearings used all affect overall efficiency ($h_o$). Impellers with extraordinarily smooth surfaces, for example, are more efficient than impellers with rougher surfaces.

## IX. CONCLUSION

The design and building of a centrifugal pump test bed are the focus of this project. Mild steel square hollow pipes, PVC valve gauge taps, PVC pipes, a flow meter, and a cast iron centrifugal surface pump were used to build the centrifugal pump test bed. The goal of this study was to find the best material for a laboratory fluid flow apparatus that allows for the measurement of flow in pipes and the deduction of various pump curve features at varied constant speeds with the same diameter impeller blade. The materials were sourced locally, and the building was completed at the university workshop. The centrifugal-pump, as previously said, is a hydraulic machine that uses centrifugal force to transform mechanical energy into hydraulic energy. The centrifugal pump is powered by an electric motor and pulls fluid (water) from a water storage tank before delivering it to a tank via a flow control valve. We were able to use the demonstration unit to do all of the experiments required to completely describe a centrifugal pump at varied constant speeds with the same impeller diameter blade. Because centrifugal pumps are used to transport liquids from one location to another, they are an effective tool for teaching students the relationships between pressure or head, volumetric flow rate, shaft rotational speeds, and input and output powers, effectively bridging the gap between theory and practice. The test bed is designed to give students an instructional tool that they may use to conduct various

ISSN No:-2456-2165

experiments to show the physical and functional links between these characteristics.

## REFERENCE


[1.] Abdulhadi, L. (2017). Fluid Dynamics of Aviation Gas Turbine Engines, (Unpublished B.Sc.). Western Kentucky University.

[2.] Agarwal, M.K. (2015, March 18). System One Centrifugal Pumps. Oil & Gas Product News, P.8.

[3.] Ahmed, F.S. (2015). Centrifugal Pump Test Rig. Retrieved July 18, 2019 , from www.researchgate.net

[4.] Aknouche, S.U. (2003). Impact of Tip Clearance Flow on a Centrifugal Impeller Pump Performance, (Unpublished M.Sc.) Massachusetts Institute of Technology, Cambridge.

[5.] Anagnostopoulous, J.S. (2009). A Fast Numerical Method for Flow Analysis and Blade Design in Centrifugal Pump Impellers.Computer and Fluids, 38: 284 – 289.

[6.] Angela, O.N. (2017, March 24). Cheers to the Largest Centrifugal Pump in South Africa. Engineering News, P.12.

[7.] ANSYS,.(2012). 14.5.7 CFX, Solver Theory Guide. Ayad, A.F. ,Abdalla, H.M. and El-Azm, S.A. (2014). 3-D Numerical Study of the Effect of Impeller Blades Slot on the Centrifugal Pump Performance Using CFD, Presented at the 16th International Conference on Applied Mechanics and Mechanical Engineering, Egypt.

[8.] Baoling C., Desheng C. &Canfei W. ( 2013, November 13). Performance of Centrifugal Pump with Different-type Open Impeller.Springer. P. 5

[9.] Bedford, S.W. (2007). Fluid Mechanics (9th Edition), New York: Mc Graw-Hill.

[10.] Bheru Singh (2018) Centrifugal Pump.Retrieved July 28, 2019 from www.skyfilabs.com/project-ideas/centrifugal-pump

[11.] Candad, J.A.(2008). Characterization of a Centrifugal Pump Impeller under Two- Phase Flow Conditions, Journal of Petroleum Science and Engineering, Vol. 63, page 18-22.

[12.] Cengel, Y.A. and Cimbala, J.M. (2006). Fluid Mechanics Fundamentals and Applications (1st Edition), New York: Mc Graw-Hill.

[13.] Dieter-Heinz H & Ali N. (1999, November 1). The Requirements to Successful Centrifugal Pump Application. Science Direct. P. 19

[14.] Echoscan, A. (2007). Centrifugal Pump Test Bench. Retrieved July 18, 2019 , from www.echoscaninc.com

[15.] Edward J. Watts. (1962). Operation and Maintenance of Centrifugal Pumps, American Water Works Association, Vol. 54, Issue (6). 450 – 490

[16.] Emmanuel, M. & Nyaga, N. (2018). Design of Organic Rankine Cycle for Olkaria Geothermal Power Plant, (Unpublished B.Sc.). University of Nairobi.

[17.] Engineering (2014). Thefreedictionary.com. Retrieved July 30,2019 from www.thefreedictionary.com/centrifugal+pump

[18.] Engineering (2015). Collinsdictionary.com. Retrieved July 30, 2019, from www.collinsdictionary.com/amp/engish/centrifugal-pump

[19.] Falter, H.D. (2005). Design of Pumps for Test Bed, Fusion Engineering and Design, Issue (1-4). Page 205-209.

[20.] Francis, C.M. (2019, January 28). Centrifugal Pump Line. The News, P.19.

[21.] Fernandez J., Blanco E. & Jorge P. (2004, June 12). Performance of a Centrifugal Pump running in Inverse Mode.ResearchGate.P. 21

[22.] Gulich, J.F. (2010). Centrifugal Pumps, Springer.

[23.] Hamid M. Siddique and ArshadAfzal. (2018). Design Optimization of the Centrifugal Pumps, Mathematical Problems in Engineering, Issue (8), (pp. 76 – 90)

[24.] Hassan M. B., Wael H. A. (2014, December 09). Common Problems in Centrifugal Pumps.Wiley Online Library.P. 23

[25.] Khin, C. T. &Mga, M.K. &Khin, M.A. (2008), Design and Performance Analysis of Centrifugal Pump, World Academy of Science, Engineering and Technology.

[26.] LadislaoReti "Francesco di Giorgio (Armani) Martini's Treatise on Engineering and Plagiarists" Technology and Culture, Vol. 4, Issue(3) (Summer, 1963), (pp. 287-298)

[27.] LI, W. (2013). Effects of Flow Rate and Viscosity on Slip Factor of Centrifugal Pump Handling Viscous Oils, Pump Technology.

[28.] Lyle F. A. (2009), Albright's Chemical Engineering Handbook, USA: CRC Press

[29.] Mary, E.B. (2008). Design of Centrifugal Pump Test Bed, (Unpublished B.Sc.). Western Kentucky University.

[30.] Mathias Bode (1996) Universal test rig concept for centrifugal and positive displacement pumps. Retrieved July 25, 2019 from www.sciencedirect.com/science/article/abs/pii/S0262176299808402

[31.] Nally, M.C.(2015). Pump and Seal. Retrieved July 19, 2019 , from www.mni.com/14-html/14-02.htm

[32.] Neal C. (2004). Design Analysis of a Centrifugal Disc Pump for Automotive Applications, unpublished B.Eng. Coventry University

[33.] Oqla H. Dhaimat and Bassam A. Al-Helou(2004). The role of centrifugal pumps in water supply, Journal of applied science, issue (3) (pp. No 406 – 410)

[34.] Prasuhn, A.L. (1980). Fundamentals of Fluid Mechanics (5th Edition), Boston: Houghton Mifflin Col.

[35.] Pump. (2012). Merriam-webster.com. Retrieved July 30,2019, from www.merriam-webster.com/dictionary/centrifugal%20pump

[36.] Regina M. M. (2007), Introduction to Chemical Processes, Principles, Analysis, Synthesis, Singapore: Mc Graw Hill

[37.] Richard T, Richard C. B, Wallace B. W & Joseph A. S. (2011), Analysis, Synthesis and Design of

Chemical Processes, 3rd Ed., New Delhi: Asoke K. Ghosh, PHI
[38.] Robert, W. Stephen, S. Wei-Chug, C. and Morgan, W. Comparison of Unshrouded Impeller Analysis and Experiment, Presented at the 37th Joint Propulsion Conference and Exhibit.
[39.] R. Daayakar U. Sridhar and Reddy S. Phaneendra.(2017). Design and Analysis of Centrifugal Pump ,International Journal for Scientific Research and Development, Issue (10), (pp. 2321-2400)
[40.] Robert C, Kevin S & Joel L. (2007).Centrifugal Pump Test Bed: A Senior Capstone Project, unpublished B.Eng. Western Kentucky University
[41.] Sagar, T. (2019, July 19). Global Pumps for Oil & Gas Market 2019 – Centrifugal Pumps, Positive Displacement Pumps. All Industry News, P.10.
[42.] Sharma, N. (2017). Design, Fabrication and Performance Evaluation of a Test Rig. Retrieved July 20, 2019 from www.pdfs.sematicscholar.org
[43.] Shojaeefrad, M.M. (2012). Numerical Study of the Effect of Some Geometric Characteristics of a Centrifugal Pump Impeller that Pumps a Viscous Fluid, Computer and Fluids, Vol. 60, page 61-70.
[44.] Stepanoff, A.J. (1957). Centrifugal and Axial Flow Pumps, London: John Wiley &Sons.
[45.] Street, R.L. (1996). Elementary Fluid Mechanics (7th Edition), New York: John Wiley & Sons.
[46.] Susan, R.R. (2006). Thin Hydrofoil Analysis, Design Proceedings of the Romanian Academy, Series A, Vol. 7, No. 2, page 117-126.
[47.] Sinnott R. K. (2002), Chemical Engineering, England: Coulson & Richardson
[48.] Sverre S. F. (2013). Design of Centrifugal Pump for Produced Water, unpublished, M. Eng. Norwegian University of Science and Technology
[49.] Sean M. (2016, December 15). Pump Sizing: Bridging the Gap Between Theory and Practice. Aiche.P. 9
[50.] Sharon J. Rockwell (2012) Characteristics of Centrifugal Pumps.Retrieved July 24, 2019 from www.pumpsandsystems.com/topics/pumps/characteriastics-centrifugal-pumps
[51.] Tanvir, H.S. (2016). Design, Construction and Analysis of an Impact of Jet Apparatus, (Unpublished B.Sc.). Ahsanullar University of Science and Technology.
[52.] Technik, I.E. (2018). Pump Test Facility. Retrieved July 20, 2019 , from www.ksb.com
[53.] Technology.(2013). Britannica.com. Retrieved July 30, 2019, from www.britannica.com/technology/centrifugal-pump
[54.] Technology.(2016). Yourdictionary.com. Retrieved July 30,2019 from www.yourdictionary.com/pump
[55.] Verma, P.S. (2011, June 16). Centrifugal Pump. My News Desk, P.14.
[56.] William C. L, Gary J.P. (2005), Standard Handbook of Petroleum and Natural Gas Engineering, 2nd Ed., United Kingdom: Elsevier
[57.] Walter, E.L. (1984). Understanding Centrifugal pumps and piping systems, 1st Ed.,Pennwell Corp.
[58.] White, F.M. (1986). Fluid mechanics, 2nd Ed., McGraw Hill, New York.
[59.] Yuliang Z. & Zuchao Z (2013) Experimental Study on a Centrifugal Pump with an Open Impeller during Startup Period. Retrieved July 28, 2019 from https://www.researchgate.net/publication/257705162_Experimental_Study_on_a_Centrifugal_Pump_with_an_Open_Impeller_during_Startup_Period
[60.] Zhang Y., Jinglai W. &Yunqing Z (2015) Design Optimization of Centrifugal Pump using Basis Function Metamodels.Retrieved July 28,2019 from https://journals.sagepub.com/doi/full/10.1155/2014/457542