Remote River Energy System: Flexible Material Pump Design

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Preface

This report details the project work conducted within the Engineering Programme at Swansea University from June 2024 to September 2024.

The submission of this report fulfils the requirements for obtaining the Degree of "Masters in Mechanical Engineering with Honours" as conferred by the Swansea University.

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Declarations

This work has not previously been accepted in substance for any degree and is not being concurrently submitted as a candidature for any degree.

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Abstract

In order to provide a flexible, low-maintenance, and sustainable energy source for isolated locations, the design of a flexible bellows pump for distant river energy systems was started. The major goal was to create a pump that could effectively capture river energy and be simple to install and maintain in areas with inadequate infrastructure. The existing design is replaced by the flexible bellows pump, which offers improved durability and efficiency, making it more suitable for remote locations where access to resources and regular maintenance is limited.

As part of the design process, a thorough SolidWorks model with an emphasis on the flexible bellows pump's kinematics and structural integrity was created. Because of its exceptional flexibility, weather resistance, and durability, reinforced EPDM rubber was chosen as the main component. Because of its superior resistance to ozone, UV rays, and temperature changes, EPDM rubber is perfect for outdoor applications and offers long-lasting performance.

As a consequence of a rigorous material selection procedure employing a Pugh matrix, the flexible bellows pump composed of reinforced EPDM rubber with aramid fibers was selected, and the findings showed that river energy could be effectively transformed into useable electricity. The pump was intended to work at a speed of one meter per second and manage a river flow rate of 0.5 m^3/s. It was able to provide an estimated 2.45 kW of electricity. To ensure smooth operation, the river turbine's rotating motion was converted into linear motion for the bellows using a slider-crank linkage mechanism. Detailed 3D modelling and construction of the pump components, such as the pipe system, piston slider plate, and the entire prototype, were done using SolidWorks. SolidWorks kinematics analysis ensured a robust design that could withstand the dynamic forces found in river conditions. Remote communities find this system especially appealing because of its low maintenance requirements and flexibility in adapting to different river conditions. It is made to cause the least amount of ecological disruption possible. Furthermore, the design is open-source, which promotes global stakeholders' widespread adoption and enhancements.

The flexible bellows pump design, which combines technological innovation with real-world application to satisfy the energy needs of underserved populations, presents a promising path for sustainable energy generation in remote places.

The project aligns with UN Sustainable Development Goal 7: Affordable and Clean Energy.

Key words **:**

Renewable Energy, Sustainability, SolidWorks Modelling, River Energy Hydroelectric power, Adaptable Energy Solution, UN SDG 7: Affordable and Clean Energy

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Notation

A Area (m2)	area (m^2)	L_{jo}	journal bearing length (m)
A_b	Bolt nominal diameter (mm)	l_c	crank rod length (mm)
A_c	crank angle (rad/s)	M	horsepower per square inch (hp/in.^{2}; 1 in.2 = 6.45 cm^2)
B	pad length (m)	P_{jo}	radial load capacity (Pa)
b	pad width (m)	P_{th}	pressure bearing capacity (Pa)
C	average diametral clearance (in.; 1 in. = 2.54 cm)	r	blade radius (m)
C_D	coefficient of drag (dimensionless)	r_c	crank radius (mm)
C_f	coefficient of thrust (dimensionless)	T_f	torque friction (N)
C_L	coefficient of lift (dimensionless)	T_m	mechanical torque (N m)
C_P	coefficient of power (dimensionless)	T_p	pump torque (N m)
C_T	coefficient of torque (dimensionless)	t_{jo}	bearing thickness (in.)
D_1	inner bearing diameter (m)	U	river velocity (m/s)
D_2	outer bearing diameter (m)	U_d	pitch diameter peripheral speed (m/min)
d_{piston}	piston diameter (mm)	$\dot{V}_p$	pump volume flow (m^3/s)
F_b	tensile bolt force (N)	v_{piston}	piston velocity (mm/s)
F_D	drag force (N)	W_{jo}	maximum vertical (weight) load (N)
F_L	lift force (N)	W_{th}	maximum thrust load (N)
F_N	normal force (N)	x_{piston}	piston position (mm)
F_r	friction force (N)	η	lubricant viscosity (Pa s)
f	friction factor (dimensionless)	ϑ_r	river turbine angle (rad/s)

G	groove width (m)	μ	coefficient of friction (dimensionless)
H_{jo}	journal bearing power loss (W)	ρ	density of water (kg/m^3)
H_{th}	thrust bearing power loss (W)	ρ_{part}	density of part (kg/m^3)
I	number of pads (dimensionless)	σ_b	Bolt stress (Pa)
J	polar moment of inertia (m^4)	Ψ	power (W)
k_g	pad/circumference ratio (dimensionless)	ω_r	river turbine angular velocity (rad/s)
ω_{rev}	shaft rotational speed (r/min)	D_I	Bellows inner diameter (mm)
D_o	Bellows outer diameter (mm)	Q	River flowrate (m^3/s)
T	Thickness of bellows (mm)	σ_{alllow}	Maximum allowable stress of bellows (Mpa)
V	Velocity of river (m^3/s)	L	Total length of bellows (mm)
K	Youngs modulus of bellows (Mpa)	V	Total volume of bellows (l)
N	number of stroke per unit time		

1. Introduction

In particular for remote and poor communities, Remote River Energy Systems (RRES) are creative ways to capture the kinetic energy of flowing river water to produce electricity. These systems function similarly to conventional hydropower techniques, in which the flow of water is utilized to turn turbines, which in turn power generators to generate energy. RRES are best suited for distant areas with limited access to resources and maintenance facilities since they can supply a sustainable and renewable energy source without the need for extensive infrastructure, like as dams. This project is an extension of the one that already exists, which aims to improve the longevity and efficiency of RRES in distant areas by replacing conventional designs with flexible bellows pumps. Because of its enhanced design, the pump requires less maintenance and installation, which makes it the perfect choice for remote areas with little access to technical help.

The flexible reinforced Ethylene Propylene Diene Monomer (EPDM) bellow pump design is a crucial element of RRES. This material was selected because of its remarkable resistance to ozone, weathering, and different chemicals. This makes it ideal for the harsh environmental conditions that are frequently present in river environments. In distant locations with limited access to maintenance resources and specialized equipment, the long-term functioning of RRES is contingent upon the robustness and minimal maintenance requirements of EPDM bellow pumps. These systems may consistently and environmentally sustainably transform the natural flow of rivers into a power source by using EPDM, meeting the energy needs of communities that would otherwise be hard to reach with traditional energy infrastructure.

Pumps that use a piston to move back and forth inside a cylinder to transfer fluid are known as positive displacement pumps. These are especially appropriate for uses where precise flow control and high pressure are needed. Nonetheless, a number of issues with piston pumps render them subpar in some circumstances. With time, leaks and decreased efficiency may arise from the extensive wear that the reciprocating action in their operation can cause to the cylinder walls and seals. Regular maintenance is necessary to ensure optimal operation, as the complexity of having several moving parts raises maintenance and repair issues. Since piston pumps reciprocate, the fluid flow experiences pulsations as well, necessitating the installation of dampers or other components to mitigate the effects. Moreover, piston pumps may be large and heavy, which limits their applicability in situations where weight and space are limited. Finally, piston pumps are more expensive and has a very low rotational speed of 22rpm than other types of pumps due to the intricacy and precision involved in their construction.

On the other hand, the idea of utilizing the mechanical force of a water current turbine to power a flexible reinforced EPDM bellows pump has a number of benefits. With this design, mechanical power is transformed into water flow, which powers a hydroelectric generator to provide energy. The bellows pump's adaptability guarantees affordability, longevity, and ease of maintenance, which makes it especially appropriate for the specialized needs of emerging and remote regions. Because of its flexibility, the pump can adapt to variations in river flow and environmental stresses, improving its dependability and performance under a variety of circumstances. The pump may greatly aid in the development of sustainable energy solutions in underserved areas by concentrating on these design concepts.

1.2 Objectives

- **Low-maintenance design**: Remoting locations with scarce resources should be able to use the pump. To ensure that it can be repaired without the need for specialist tools or experience, it must be simple to maintain with little equipment.
- **Durability**: The pump needs to be durable and able to endure a range of environmental factors. Its ability to withstand wear and strain over time is what will guarantee its long-term dependability.
- **Ice resistance**: In order to guarantee reliable performance in colder areas, the pump should be engineered to perform well in scenarios where ice may be present.
- **Cost-effectiveness**: In order to make deployment in developing communities affordable, the design should reduce manufacturing processes and business expenses. Maintaining accessibility for users with limited technological resources and lowering operating expenses require low-tech maintenance.
- **Integration with turbine system**: Create a pump that can effectively transform a water current turbine's mechanical power into water flow, which may subsequently be utilized to power a hydroelectric generator to produce electricity.
- **Flexibility**: To improve its resistance to environmental stresses and variations in river flow, the pump should have a flexible design. Because of its flexibility, sliding seals are not necessary, which lowers the number of possible failure locations and maintenance needs.
- **Open-source accessibility**: Make the design available as open-source so that it can be widely implemented and improved upon by a variety of global stakeholders.
- **Performance optimization**: Aim for a system that can produce approximately 3 kW of electrical output, as shown by analogous remote river energy systems.
- **Suitability for various water types**: The design should be flexible enough to be used in saltwater estuaries and freshwater rivers, providing adaptability in a variety of aquatic conditions.

2.Literature Review

The design of robust and long-lasting pumping systems for distant river energy applications has drawn a lot of interest lately. The design of reinforced EPDM (Ethylene Propylene Diene Monomer) bellows pumps, which provide prospective benefits in terms of dependability, upkeep, and adaptation to changing river circumstances, is the major topic of this research study.

An open-source, low-maintenance turbine design for remote locations was designed and provides a basis for comprehending the context of remote river energy systems [1]. In order to make local manufacture and maintenance easier, they placed a strong emphasis on eliminating complexity and specialized components. According to the authors, "Emphasis is placed on the installation and repair facilities that would likely be present in developing communities, and how these communities would have to interface with the turbine without any external aid, such as with self-repair"[1]. Although this work does not directly address bellows pumps, it does emphasize the significance of reliable, easily maintained designs for remote applications.

The design process involves iterative system design, including concept drawings, initial design calculations, component design revisions, and design reviews [1]. The application of failure modes and effects analysis (FMEA) to improve the design is another point made by the writers. The development of reinforced EPDM bellows pumps can benefit greatly from the thoughtful approach to designing for remote applications.

Their usage of a closed-loop water system, which permits all electronics to be kept onshore, is one of their design's primary characteristics [1]. This approach aligns with the goal of minimizing maintenance requirements and improving safety in remote locations. The authors note that " Every component has been made to be as simple to build as possible utilizing common manufacturing techniques and readily available parts and generic materials" [1]. This design principle of accessibility and simplicity applies directly to reinforced EPDM bellows pumps intended for remote river energy systems.

The authors point out that "simplicity, robustness, and ease of maintenance are crucial factors in the success of remote energy systems" [1]. This idea is in line with the objectives of creating reinforced EPDM bellows pumps for distant river energy systems, where it is crucial to keep complexity and maintenance needs to a minimum.

It also cover how crucial it is to take local resource availability and environmental variables into account while developing distant energy systems [1]. They point out that "successful implementation of pico-hydro systems in remote areas requires careful consideration of local topography, river flow characteristics, and available materials" [1]. This comprehensive method of system design can be immediately applied to the design of bellows pumps for use in distant river applications, where local circumstances adaptation is essential.

In their note that "effective debris management strategies are crucial for maintaining system performance and minimizing maintenance requirements," the authors highlight the significance of debris management in river-based energy systems [1]. This realization emphasizes how important it is to take debris management and protection into account when designing bellows pumps for distant river applications.

Bellows pumps are adaptable tools that are utilized in many different industries because of their capacity to manage a broad variety of materials and provide accurate fluid management. This review of the literature examines the various applications that bellows pumps are currently used in, emphasizing their versatility and efficiency.

Bellows pumps are frequently used in the medical industry in portable medical equipment like air mattresses and blood pressure monitors. These pumps produce air or fluid flow using flexible bellows, giving medicine infusion systems exact control over fluid administration. They are perfect for implantable and portable devices because of their small size, but compared to other pump types, they are usually only used in lower flow rate applications. Bellows pumps are ideally suited for the rigorous sterilizing processes needed for medical applications since they are capable of handling both corrosive and non-corrosive fluids [28].

In industrial and laboratory settings, bellows pumps are also widely employed, especially for low-flow, low-pressure metering applications. For example, GRI's Bellows Dosing Pumps are made for accurate chemical metering in settings like silicon chip washers, silver recovery systems, and film and x-ray processors. These plastic-only pumps have a ±1% stroke-to-stroke precision and are long-lasting and resistant to chemicals. They are an affordable option for applications needing reliable fluid delivery because of their higher corrosion resistance and capacity to function without dynamic seals [29].

Bellows pumps are the favored choice in the aerospace and avionics industries due to their excellent reliability and clean operation. Because of their versatility in handling poisonous, abrasive, corrosive, and hazardous materials, they find application in laboratory research, fuel systems, and chemical processing. The straightforward functioning of bellows pumps, which entails the bellows' extension and retraction to generate a vacuum and transfer fluids, guarantees accurate fluid metering with minimum danger of contamination. Because of this, they can be used in situations were keeping the fluid pure is essential [30].

Furthermore, because bellows pumps can manage a wide range of fluid viscosities and temperatures, they are used in water treatment and wastewater treatment systems. They are appropriate for continuous operation in demanding conditions because to their capacity for self-priming and tolerance against dry runs. In fluid transfer applications, the lack of sliding components reduces wear and leakage, guaranteeing long-term dependability and efficiency [29].

Bellows pumps' versatility is further evidenced by the applications they find in blood analysis instruments, detergent dispensers, and thermal therapy equipment. They are a flexible option for a range of applications because of their adaptable design, which enables them to satisfy certain OEM needs. Bellows pumps' adaptability to current systems with little modification increases their attractiveness to a variety of sectors [31].

Bellows pumps are highly advantageous in numerous application domains because of their accuracy, dependability, and versatility. Their adaptability and efficacy in managing a wide range of fluids and operating circumstances are highlighted by their employment in medical, industrial, aeronautical, and environmental applications. The possibility of using bellows pumps in even more creative applications is increasing as technology develops.

In related study, the integration of water pumping systems with renewable energy sources to meet heat demands in zero-emission scenarios in a similar study [2]. The ideas of energy storage and system optimization apply to the design of bellows pumps for distant river energy systems, even if their focus was on larger-scale applications. The authors provided evidence that effective system integration could result in considerable savings on overall system expenses and storage requirements.

Difficulties in implementing remote river turbines, especially the high expenses that prevent their broad use [1]. This emphasizes how crucial it is to create low-maintenance, low-cost pumping options, like reinforced EPDM bellows pumps. This work aligns with the objectives of bellows pump development for river energy systems by highlighting the need for creative designs that are readily manufactured and maintained in remote places.

A study looked at how societal and meteorological factors affected Europe's need for power [2]. Their discoveries regarding the variability of energy supply and demand are important for developing pumping systems that can function well in a variety of scenarios, even if they have little to do with bellows pump design specifically. This study emphasizes how crucial it is to build bellows pump designs with adaptation and flexibility in mind for distant river energy applications.

A comprehensive report on large-scale electricity storage has consequences for pumping system design in remote areas [2]. Smaller-scale bellows pump systems can benefit from the concepts of energy management and storage integration, even if the report focuses on grid-scale storage. The results indicate that the integration of energy storage strategies, including raised water storage, may improve the dependability and effectiveness of bellows pump functions in distant river energy systems.

A technical analysis offered insights into pumping technology and how they could be integrated with renewable energy sources. Although it is primarily focused on waterways, the paper presents a straightforward tool for designing and evaluating pump systems that provides useful insights on how compromised design impacts pump performance. The design of reinforced EPDM bellow pumps for distant river applications could be optimized with the help of this tool [3].

Using intelligent pumping regimes resulted in notable energy savings and a decrease in CO_2 emissions, according to a case study on the subject. According to the study, pumping expenses might be lowered by as much as 80% in certain situations by taking into account a range of factors besides water level. These results highlight the possibility of lowering operating costs and increasing efficiency by integrating intelligent control systems into bellow pump designs for distant river energy applications [3].

Researched concentrated on improving bellows in bellows pumps to increase pumping efficiency [4]. The authors created a technique for maximizing the distribution of stress in pump bellows, which may be useful in the construction of bellows pumps with longer lifespans for distant river energy systems. Their research highlights how crucial geometric design and material choice are to extending the life and performance of bellows pumps.

The development of solar thermal water pumping devices was contextualized historically in their work on low-temperature bellows-actuated solar pumps [5]. Even though technology has come a long way since then, bellows pump designs of today still rely on the basic ideas of employing thermal expansion to create pumping action. This study demonstrates how reinforced EPDM bellows pumps with passive solar heating could be made more efficient for use in remote river applications.

When designing bellows pumps for river energy systems, This work on turbulence modelling in fluid dynamics simulations is pertinent [1]. Their studies on the k-ε turbulence model shed light on computer techniques for fluid flow analysis in pumping systems. Using this information, reinforced EPDM bellows internal geometry can be optimized to reduce pressure losses and raise pump efficiency overall.

Research on cavitation in hydraulic systems is still useful for designing contemporary pumping systems, such as bellows pumps [1]. It is essential to comprehend cavitation mechanisms in order to avoid wear and damage in bellows pumps that are used in fluctuating river conditions. These findings must be taken into account by designers of reinforced EPDM bellows pumps in order to guarantee long-term performance and reliability in remote river energy applications.

A thorough analysis of bellows expansion joints and the impact of design factors on system characteristics [6]. While they concentrated on expansion joints rather than pumps, reinforced EPDM bellows pumps can benefit from many of the same design ideas and material considerations. The authors' examination of material selection, fatigue life, and stress distribution offers insightful information for improving the robustness and efficiency of bellows pump designs.

Studying the floating river and canal turbines developed by Smart Hydro Power offers important insights on how to integrate renewable energy sources in remote locations. Their work on floating and riverbed-mounted turbines shows how small-scale hydropower generating can be used efficiently [1]. This strategy could guide the creation of remote river energy systems, which could provide a more dependable and effective energy source by using the electricity generated to run reinforced EPDM bellows pumps.

According to the Sustainable Development Goals (SDG 7 and 13) of the United Nations place a strong emphasis on the necessity of providing developing communities with access to inexpensive and clean energy [1]. The significance of creating affordable, environmentally friendly pumping options, including reinforced EPDM bellows pumps, for distant river energy systems is highlighted by this global endeavour. A framework for assessing the social and environmental effects of bellows pump designs in remote applications is provided by the UN's goals.

The World Bank Group's efforts to improve energy supply capacity while guaranteeing reliability and affordability align well with the objectives of building efficient bellows pump systems for distant river energy applications [1]. Their emphasis on addressing the requirements of marginalized groups draws attention to the potential benefits of low-maintenance, reasonably priced pumping technologies for enhancing remote areas' access to energy and water resources.

The Open Source Hardware Association's (OSHWA) definition of open-source hardware offers rules for the dissemination and documentation of open-source designs [1]. By using these ideas in the creation of reinforced EPDM bellows pumps, it may be possible to promote local manufacture in isolated areas and increase adoption. Bellows pump technology for river energy systems could be continuously improved and information shared with the use of open-source designs.

As the literature evaluation comes to an end, it becomes clear that there is an expanding body of research on the development and improvement of pumping systems for distant river energy applications. Although there aren't many specific studies on reinforced EPDM bellows pumps, the theories and research from related domains can be quite helpful in developing them. Among the major topics that emerge from the literature are:

- The significance of low-maintenance, low-cost designs for remote applications.
- The possibility of combining intelligent control systems to maximize pumping effectiveness.

- The requirement for designs and materials resistant to adverse environmental conditions.
- The advantages of integrating renewable energy sources with pumping systems.
- The importance of open-source designs in promoting local manufacturing and broad adoption.

For remote river energy systems, the research offers crucial insights into the construction of dependable, environmentally friendly bellows pumps that will enhance marginalized populations' access to energy and water. The techniques are cantered on turbine design, although they are also applicable to EPDM bellows pumps. These ideas for pump systems should be improved in the future, with an emphasis on robustness and ease of maintenance [1].

3.Theory of Flexible Bellows Pump

3.1 Introduction

In order to harness the kinetic energy of flowing water and produce electricity, a flexible bellows pump is designed for a remote river energy system (RRES). The theory behind flexible bellows pump design, the rationale behind updating current designs, and the anticipated results of the new design are all covered in detail in this section.

3.2 Working Principle

The kinetic energy of flowing water is transformed into mechanical energy by a flexible bellows pump, which is then used to produce electricity. The pump is made out of a bellows that is flexible and contracts with the flow of water. This movement propels a diaphragm or piston, which produces a pumping action that circulates water throughout the system.

Because of its adaptability to different flow rates, the bellows consistently performs. The water causes the bellows to expand and shrink as it passes through it. The piston is replaced by bellows in which the crank arm is driving the bellow this motion uses it to produce a pumping action that circulates water throughout the system. This technique produces mechanical energy that can be utilized to power a generator to create electricity.

3.3 Components and Materials

- Flexible Bellows: Composed of robust, pliable materials like synthetic polymers or rubber. It must not deteriorate even after experiencing repeated expansion and contraction.
- Piston/ Diaphragm: Torque on the shaft from the turbine blades is providing mechanical energy from the action of the bellows. often constructed from reinforced plastic or metal.
- Valves: One-way valves guarantee that water flows only in one direction, avoiding backflow and preserving effectiveness.
- Housing: Envelops the bellows and additional parts, offering structural reinforcement and defence against external influences.

The durability and functionality of the pump greatly depend on the choice of materials. The materials used to construct the flexible bellows must be able to endure the severe elements found in a river setting, including exposure to water, debris, and fluctuating temperatures. While the valves must be made to ensure effective functioning and avoid backflow, the piston or diaphragm needs to be strong enough to withstand the mechanical demands of the pumping motion.

3.4 Reasons for Replacing Existing Pumping

3.4.1 Maintenance and Durability

Because of their inflexible parts, traditional pumps frequently need regular maintenance and are prone to wear and tear. Conversely, flexible bellows pumps are made to sustain continuous operation with less maintenance and have fewer moving components. This makes them perfect for isolated locations with limited access to repair facilities and qualified specialists [1].

Some inferred potential problems with existing designs:

- High costs and complexity: Many developing towns find the pricey and intricate designs of existing turbines, which necessitate specialized materials and maintenance, inappropriate [1] .
- Specialist Components: Certain parts, like turbine blades, need to be machined and maintained by experts, which might make it difficult to produce locally and maintain in remote locations [1].
- Manufacturing and Maintenance: The study suggests that current designs may be over-engineered for the intended application and emphasizes the need to minimize the number of components and manufacturing processes in order to reduce costs and complexity[1].
- Installation and repair: Current systems might need more advanced equipment and knowledge that aren't commonly accessible in distant areas, but the new design is meant to be simple to construct and maintain with little help[1].
- Energy system suitability: Existing systems may not be suitable for smaller, off-grid communities due to their size and energy demands, which are often designed for larger settlements[1].

Conventional pump designs frequently depend on inflexible parts that are prone to damage. This may necessitate regular maintenance and repairs, which can be difficult in isolated locations with limited access to facilities and qualified personnel. Flexible bellows pumps, on the other hand, are made to sustain continuous operation with less maintenance and have fewer moving components. They are therefore a more dependable and affordable option for distant river energy systems.

3.4.2 Efficiency and Adaptability

Flexible bellows pumps are capable of adjusting to different flow circumstances while being effective at a variety of water velocities. Variations in flow rates can be difficult for traditional designs to handle, which would diminish their efficiency and increase their wear.

The bellow’s flexibility enhances its performance and endurance by enabling it to absorb shocks and vibration [1].

In settings where the flow fluctuates, traditional pump designs could find it difficult to remain efficient. This may result in decreased functionality and more wear and tear on the parts. Conversely, flexible bellows pumps are able to adjust to different flow circumstances and continue to function well at a variety of water velocities. The bellow’s flexibility increases its performance and endurance by enabling it to absorb shocks and vibrations.

3.5 Slider-crank Linkage Mechanism

A basic mechanical linkage that transforms rotational motion into linear reciprocating motion, the slider-crank mechanism is perfect for uses such as bellows pumps in remote river energy systems. An outline of its operation and use is provided here.

3.5.1 Working Principle

The slider-crank mechanism consists of four main components:

1. Crank: A rotating arm connected to a power source
2. Connecting rod: Links the crank to the slider
3. Slider: Moves in a linear reciprocating motion
4. Frame: Provides a fixed reference point

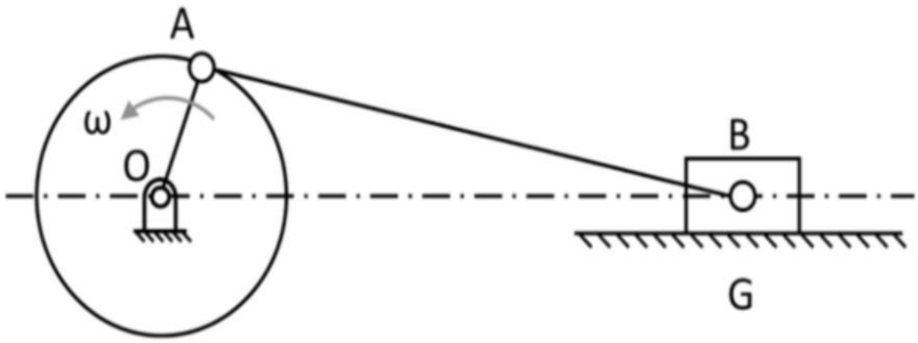


Figure 1: Slider Crank

The connecting rod is driven by the crank's rotation, and this causes the slider to move in a straight line. Kinematic equations that link the components' crank angle (θ) location, velocity, and acceleration control this transition from rotational to linear motion [7].

3.5.2 Advantages for Bellows Pump

1. Simplicity: The slider-crank mechanism is relatively simple, making it easy to construct and maintain in remote locations [7].
2. Reliability: With few moving parts, the mechanism is less prone to breakdowns, crucial for remote applications [7].

3. Efficiency: The direct conversion of rotational to linear motion minimizes energy losses.
4. Adaptability: The mechanism's dimensions can be adjusted to optimize the pump's stroke length and frequency for specific river conditions [8].
5. Cost-effectiveness: The simplicity of the system translates to lower manufacturing and maintenance costs, ideal for remote installations [7].

Remote river energy systems can use the slider-crank mechanism used in bellows pumps to capture the natural flow of rivers and use it to power water pumps in places where traditional power sources are scarce. This use case highlights the adaptability and usefulness of this traditional mechanical coupling in contemporary sustainable energy systems [8] [9].

3.6 Expected Outcomes

3.6.1 Electrical Power Generation

Electrical power is the flexible bellows pump design's main output. The device can produce a steady flow of electricity by using the kinetic energy of flowing water. In remote locations, this can be utilized to power houses, schools, and other establishments, enhancing the standard of living and promoting economic growth [1].

By utilizing the kinetic energy of flowing water, the flexible bellows pump design may provide an endless supply of electricity. In remote locations, this can be utilized to power houses, schools, and other establishments, enhancing the standard of living and promoting economic growth. In addition to minimizing carbon emissions, the system's ability to produce electricity from renewable sources lessens dependency on fossil fuels.

3.6.2 Water Management

The flexible bellows pump can be used for water management in addition to producing electricity. It can provide crucial needs for drinking, sanitation, and irrigation by pumping water to far-off areas. Even in times of low river flow, the system's adaptability guarantees a consistent supply of water [1].

Water management applications for the flexible bellows pump include pumping water for drinking, sanitation, and agriculture. In addition to meeting urgent requirements in isolated villages, this guarantees a steady supply of water even when river flows are low. The system is a flexible solution for a variety of applications due to its versatility.

3.7 Design Specifications

1. General Specifications:
   - Application: Remote River Energy System
   - Power Source : Water Turbine
   - Operating Environment: Outdoor, variable temperatures, exposure to water and potential debris.

2. Bellows Pump Specifications:
    - Material Requirement: Must be flexible and durable.
    - Reinforcement Requirement: Needs added strength for durability and reliability.
    - Operating Pressure: Capable of handling up to 5 bar (500 kPa).
    - Standard Compliance: Must meet EJMA standards for accuracy and repeatability.

3. Wetted Materials Specifications:
    - Bellows: Requires a flexible and durable material.
    - Vales/ O-rings: Must be compatible with the pumped medium.
    - Body: Needs to be constructed from a material resistant to environmental degradation.
4. Drive system specifications:
    - Coupling: Must allow for direct coupling from the turbine shaft to the pump crank mechanism.
    - Gear Reduction: If necessary, must match turbine speed/torque characteristics.
    - Misalignment Tolerance: The system should accommodate potential turbine shaft misalignment.
5. Sealing and Gaskets Specifications:
    - Seals: Must prevent leaks and withstand the operating conditions.
    - Gaskets : Should provide durable and watertight seals.
6. Support Structure Specifications:
    - Foundation: Needs to secure the turbine and pump effectively.
    - Mounting: Must allow for precise alignment of the pump and turbine.
    - Protection: Should include protection against debris and harsh weather conditions.
7. Maintenance and durability Requirements:
    - Ease of Access: Must allow easy disassembly for maintenance.
    - Durability: Must withstand continuous operation and harsh environmental conditions.
    - Redundancy: The design should allow for optional redundant systems or components.
8. Efficiency Requirements:
    - Energy Conversion: Must efficiently convert river flow kinetic energy to mechanical energy.
    - Pumping Efficiency: Should aim for high volumetric efficiency.
9. Environmental Impact Requirements:
    - Minimal Disruption: Intake screens should minimize impact on aquatic life.
    - Sustainability: Materials and processes should be environmentally friendly.

10. Cost-Effectiveness Requirements:
    - Initial Cost: Should be affordable for remote applications.
    - Operational Cost: Must keep operational and maintenance costs low.

11. Scalability and Flexibility Requirements:
    - Scalable Design: The system must be scalable based on water demand.

- Flexibility: Should be adaptable to different river flow conditions and site-specific requirements.

The river's fluctuating flow rates must be considered in the flexible bellows pump's design. The bellows needs to be robust enough to endure continuous operation while still being adaptable enough to react to variations in flow rate. Efficiency is another important factor to take into account because energy losses from turbulence and friction can have a big influence on how well a pump works. Since parts should be freely accessible for inspection and replacement, maintenance is also crucial. Lastly, with an emphasis on sustainability, the environmental effects of the materials and building techniques utilized in the pump should be taken into account.

4. Conceptual and Preliminary Design

4.1 Initial concept sketches with Pugh Matrix

The Design concept sketches and the descriptions for all the concepts is illustrated below For a clear understanding.

Design Concept 1:

In this concept it a dual bellows chamber which is pumped by two connecting rod which is driven by the vacuum pump which is connected via solenoid valve with pump, there is a inlet valve for the flow of water into the chamber, where in when the compression cycle is complete the water is discharged through outlet valve which is shown in fig.2, the main disadvantage of the dual chamber bellows pump is that the weight, ease of maintenances, the length of bellows pump will be a critical issue for this concept hence this concept was not considered further for the remote application.

Design Concept 2:

The economical and effective flexible bellows pump design seen in Figure 3 has a U-shaped one-way valve mechanism for controlling water flow. Its affordability, lightweight design, adaptability, and simplicity of upkeep and assembly are among its benefits. Because of its modular construction, which makes it easy to repair the bellows if broken, it can withstand It's perfect for more development because of these features. In order to improve performance, durability, and provide a final product that is dependable, affordable, and simple to maintain, the design will be modelled in SolidWorks.

Design Concept 3:

Concept is an application of double crank mechanism which is driven by a crank arm or a shaft with double chamber on the either side of the crank rod, in this concept the inlet and outlet vale is given on top of the pump with another valve to stop the

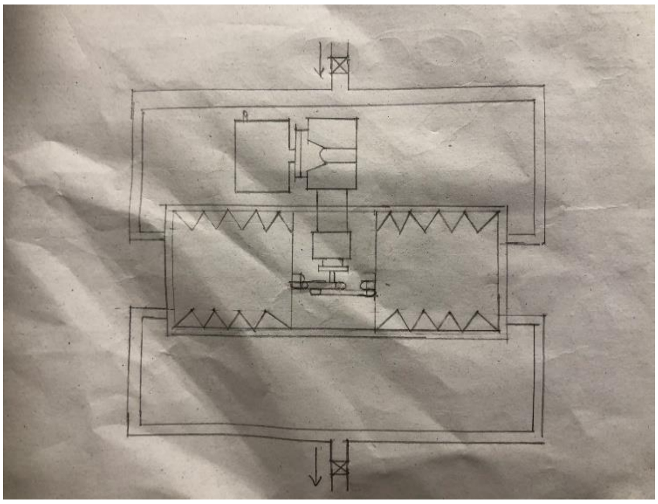


Figure 2: Design Concept 1

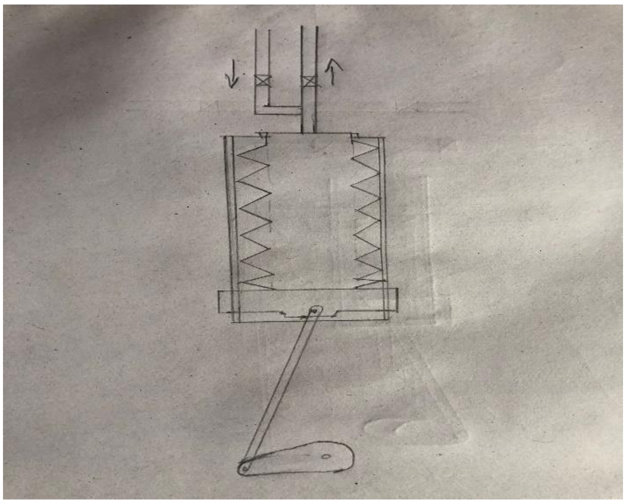


Figure 3: Design Concept 2

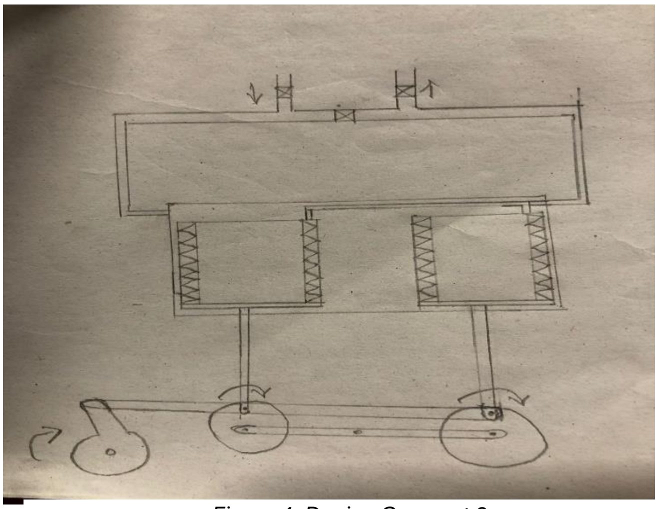


Figure 4: Design Concept 3

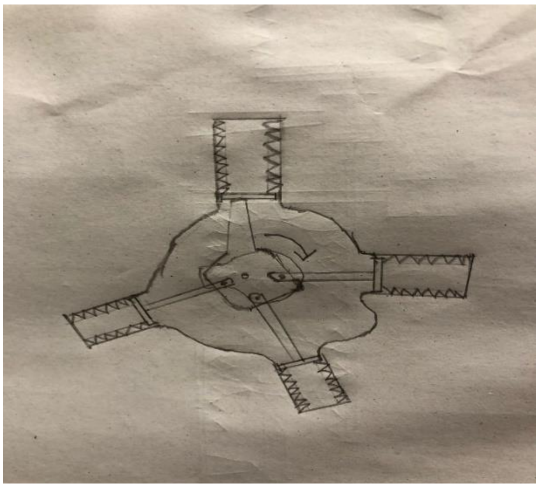


Figure 5: Design Concept 4

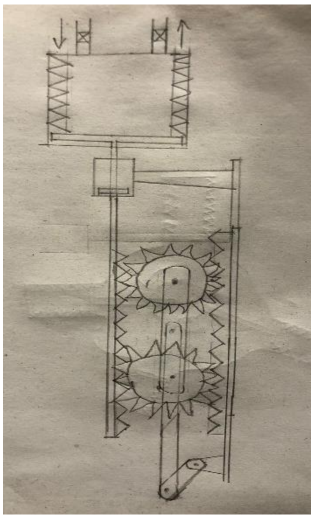


Figure 6:Design Concept 5

flow of inlet flowing through the outlet side. This double crank assembly will be a major factor along with the ease of maintenance, weight, submerging line of the pump, and cost. So this concept was also not considered further for the remote river application.

Design Concept 4:

This is a concept of Radial crank piston mechanism this consists of four chambers in which bellows are placed and actuated by a piston on all four sides of the chamber. A single rotating shaft is used to connect the crank rod or the linking rods to the pistons. So when the shaft rotates in clockwise direction all the four pistons will be actuated. But when it comes to inlet and outlet valve decision it would be difficult to use them where in we have to build in a separate inlet and outlet chamber, but the main goal of our design is to be simple and robust.
Also the other factors like ease of maintenance, cost, weight, assembly will be difficult to be implanted. Hence this was not considered further for the application.

Design Concept 5:

This is a concept of double rack and pinion mechanism, in this case the pinion is actuated be the crank rod which in turns rotates the pinion and makes the other piston end of the rack to move freely to reciprocate the bellows, where in the main intention for this concept is also gear reduction. The same other criteria's like the cost, ease of maintenance, ease of assembly, weight will be a crucial factor for no incorporating this concept in remote areas.

Using a Pugh matrix to develop preliminary concept sketches for a remote river energy system requires a methodical process for assessing various design options. Create a variety of concept designs first, each of which should illustrate a distinct potential approach to capturing river energy. Next, decide on evaluation criteria, including affordability, ease of maintenance, efficiency, and impact on the environment. After that, each concept is methodically compared to a baseline design using the Pugh matrix, and they are then scored according to the predetermined standards. By outlining each concept's advantages and disadvantages, this process aids in selecting the most promising ideas and, in the end, directs the design team toward the most workable and efficient solution for the distant river energy system [32] [33].

Pugh Matrix for Design Concepts:

Criteria	Design 1	Design 2	Design 3	Design 4	Design 5
Buckling Resistance	+	++	+	+	+
Ease of Maintenance	-	++	+	--	+
Cost	--	++	+	--	+

Environmental Impact	-	+	-	-	-
Ease of Assembly	-	++	-	--	-
Weight	--	+	-	--	-
Total Score	-7	11	-1	-9	-1

Table 1: Pugh Matrix for Design Concepts

Legend: (+) Better, (-) worse

In evaluating the concept designs using the Pugh matrix, Design 2 meets all the criteria. This design can be developed and implemented to replace the existing pump manifold with a bellows pump design.

5. Material Selection for Bellows with Pugh Matrix

We will use a Pugh matrix to select the best material for a bellows meant to be used in a remote river application energy system. This matrix will aid in the methodical comparison and assessment of various materials in accordance with the particular design requirements needed for the intended use. The Pugh matrix will assist in determining the best material option by comparing the materials to a number of parameters, including cost, availability, flexibility, durability, and resistance to environmental factors. This method guarantees a thorough and impartial evaluation, which results in the optimal material being chosen for the bellows in the distant river energy system [32] [33].

For the bellows meant for far river applications, a variety of materials including EPDM, PTFE-coated cloth, NBR, and Neoprene were taken into consideration using the design specifications. The resistance of these materials to environmental factors and mechanical forces was assessed. To find the best material for long-term use in isolated locations, a comprehensive analysis was carried out. In this investigation, the Pugh matrix was utilized, with a metal bellows serving as the baseline for comparison. Here is a detailed grading system based on the items mentioned, along with the Pugh matrix analysis.

Pugh Matrix for Bellows Materials:

Legend:

- **S**: Same as baseline
- **+**: Better than baseline
- **-**: Worse than baseline
- **0**: Neutral/No significant difference

Criteria	Weight	Metal Bellows (Baseline)	EPDM	PTFE Coated	NBR	Neoprene
Corrosion Resistance	5	S	+	+	+	S
Ice Resistance	4	S	+	0	0	0
Fatigue Properties	4	S	+	0	0	0
Flexibility	3	S	+	+	+	+
Durability	4	S	+	-	-	0
Cost	3	S	+	-	+	0
Maintenance	2	S	+	0	0	0
Availability	2	S	+	0	0	0
Environmental Impact	3	S	+	+	0	0
Weight	2	S	+	0	0	0
Ease of Maintenance	2	S	++	+	0	0
Total		S	+16	+11	+4	+1

Table 2: Pugh Matrix for Materials

Analysis

- Corrosion Resistance:
    - Materials coated in PTFE and EPDM are more corrosion resistant than metal bellows, which makes them appropriate for situations where exposure to salt water and biological growth is a problem [10] [11].
    - Although they are not as effective as PTFE and EPDM Coated materials, NBR and Neoprene offer a moderate level of corrosion protection.

- Ice Resistance:
    - EPDM is a good material for ice resistance because of its superior resilience to weathering and low temperatures [34] [35].

- Flexibility:
    - Compared to metal bellows, all examined materials (PTFE coated, EPDM, NBR, and Neoprene) are more flexible, which is advantageous for damping vibrations and adjusting misalignments [10] [11] [12].

- Fatigue Properties:
    - Because of its strong fatigue resistance, EPDM remains strong even under cyclic loading circumstances [35] [36].

- Durability:
    - Materials coated with PTFE and EPDM are very strong, having a long service life and being resistant to deterioration [10] [11].
    - Especially in hostile situations, PTFE and EPDM-coated materials are more durable than NBR and Neoprene [38] [39][40] [41].
- Cost:
    - Cost-effective choices like EPDM and NBR offer good performance for less money [10].
    - PTFE Coated materials are more expensive due to their superior properties [11].
- Maintenance:
    - Compared to metal bellows, EPDM requires less maintenance, which helps save operating expenses in remote locations [10].
    - PTFE Coated, NBR, and Neoprene have neutral maintenance requirements.
- Availability:
    - EPDM is a sensible option for remote applications because it is widely accessible and simple to source [10].
    - PTFE Coated, NBR, and Neoprene have neutral availability.
- Environmental Impact:
    - PTFE and EPDM Compared to metal bellows, coated materials are less detrimental to the environment since they are more resistant to deterioration and do not leak dangerous elements [10] [11].

- Weight:
    - Compared to metal bellows, EPDM is lighter, making it easier to handle and install in remote locations. PTFE Coated, NBR, and Neoprene have neutral weight differences.
- Ease of Maintenance:

- Rubber bellows, such as those composed of EPDM, are less demanding on piping systems in terms of maintenance since they absorb vibrations and movements. This feature reduces tension and weariness, which results in fewer maintenance requirements and a longer system lifespan [37].

- PTFE and EPDM Compared to metal bellows, coated materials are less detrimental to the environment since they are more resistant to deterioration and do not leak dangerous elements. EPDM and PTFE Coated materials are easier to maintain assuming that the whole bellow will be replaced when it fails.

- NBR and Neoprene have neutral ease of maintenance.

Based on the Pugh matrix, EPDM is shown to be the best material for bellows in a distant river energy system since it has the highest score among all the characteristics that were analysed. Because it offers a well-balanced combination of corrosion resistance, flexibility, durability, cost-effectiveness, and low maintenance requirements, it is highly suited for the specified application.

5.1 EPDM Reinforced with Aramid fibres

An innovative composite material known as EPDM (Ethylene Propylene Diene Monomer) rubber reinforced with aramid fibers combines the elastomeric qualities of EPDM with the extreme strength and durability of aramid fibers. Because of its special combination of qualities, this composite material is especially well-suited for use in bellows for distant river energy systems. We will examine the material's composition, characteristics, and how EPDM reinforced with aramid fibers works well for remote river energy systems in this in-depth theory.

Material Composition and Properties

EPDM Rubber

A synthetic rubber with superior resistance to weathering, ozone, and UV rays. Its substantial flexibility across a broad temperature range is essential for bellows applications that call for continuous deformation [18] [19] [20].

Aramid Fibers added for strength

Outstanding tensile strength, low density, heat resistance, and dimensional stability are all features of these high-performance fibers. They increase EPDM's mechanical strength, which makes it perfect for bellows in harsh settings like isolated river energy systems [14] [15] [16] [20].

Composite Material: EPDM Reinforced with Aramid Fibers

The resulting composite material combines the strength and stiffness of aramid fibers with the elastomeric qualities of EPDM when it is reinforced with them. This mixture produces a material with the following essential characteristics:

Tensile Strength: The tensile strength of EPDM is significantly increased by aramid fibers, which increases the composite's resistance to high pressure and erratic river currents [18].

Dimensional Stability: The fibers are essential for bellows subjected to a range of weights and climatic conditions because they assist the composite retain its shape under stress [15].

Enhanced Fatigue Resistance: For parts that experience cyclic loading, such as bellows, this composite is perfect. The operational lifespan of bellows is increased by the reinforcement provided by aramid fibers, which enhance EPDM's resistance to considerable wear even after repetitive deformation [16].

Excellent environmental resistance: The combination retains EPDM's natural resistance to ozone, UV radiation, and weathering, making it appropriate for outdoor use in remote river energy systems [17].

Advantages in Remote River Energy Systems

Mechanical Performance:

EPDM with aramid fibers creates a strong composite for river energy systems, resisting dynamic currents due to enhanced tensile strength. [1]. The structural integrity of bellows, which are subjected to continual cyclic loading in river energy systems, depends on this increased strength [14] [20].

Aramid fibers in EPDM enhance dimensional stability, maintaining shape and size under various loads and environmental conditions in river applications. [1]. This characteristic is especially crucial for remote river energy systems, where it is necessary for parts to keep their shape in order to guarantee effective energy conversion and capture [15] [20].

The aramid-reinforced EPDM composite exhibits enhanced fatigue resistance, crucial for flexible components in river energy systems. This improvement extends operational lifespan and reduces maintenance needs, particularly beneficial in remote locations with limited repair access. [13] [16] [20].

Environmental Performance:

Aramid-reinforced EPDM excels in environmental performance for remote river energy systems. It maintains EPDM's resistance to ozone, UV, and weathering, ensuring longevity in harsh outdoor conditions and unpredictable weather patterns. [17] [20].

The aramid-reinforced EPDM composite retains EPDM's excellent resistance to water and polar solvents. This chemical resilience is vital in river environments with diverse pollutants and water chemistry, enhancing component durability and reliability in remote energy systems. [18] [20].

EPDM with aramid fibers maintains elasticity at low temperatures while gaining strength. This crucial property ensures functionality in remote river energy systems exposed to wide temperature variations or cold climates. [19] [20].

Energy Efficiency and Performance:

Aramid-reinforced EPDM's unique properties enhance remote river energy systems' performance. Its elastic deformation captures energy from currents, while aramid fibers improve energy transfer, potentially increasing overall power output in harvesting applications. [14] [20].

The composite's low hysteresis and high resilience minimize energy losses during cyclic deformation. This benefits flexible structures like bellows in river currents, enhancing overall energy conversion efficiency by reducing dissipation. [16] [20].

Durability and Maintenance:

Aramid-reinforced EPDM's durability and low maintenance make it ideal for remote river energy systems. Its strength, fatigue resistance, and environmental resilience allow components to withstand prolonged exposure with minimal degradation. [18] [20].

Because of its endurance, fewer maintenance requirements are necessary, especially for remote locations where regular access for replacements and repairs may be difficult or expensive. The total dependability and cost-effectiveness of remote river energy systems can be greatly increased by the longer component lifespan of this composite [19] [20].

Customization and Optimization:

Aramid-reinforced EPDM offers extensive customization for remote river energy applications. Fiber orientation, volume fraction, and matrix composition can be tailored to meet specific performance requirements. [14].

Fiber orientation in aramid-reinforced EPDM can be optimized to align with primary stress directions in river currents. Adjusting fiber volume fraction balances strength and flexibility, allowing designers to create components ideally suited for specific energy system roles. [15] [20].

Environmental Sustainability:

Aramid-reinforced EPDM enhances environmental sustainability in remote river energy systems. Its lightweight design reduces transportation emissions, while durability minimizes replacements. Over its lifecycle, the composite offers lower environmental impact compared to traditional materials like steel. [17] [20].

The ability to recycle and reuse components constructed of this composite after their useful lives are over is another way that remote river energy systems that use this material might improve their environmental credentials. This is in line with the concepts of the circular economy [19] [20].

To sum up, aramid fiber-reinforced EPDM offers a very beneficial material option for remote river energy systems. It is particularly well-suited for the demanding circumstances found in river habitats because of its outstanding mix of mechanical strength, environmental resistance, energy efficiency, and longevity. Additional uses and refinements of this composite are anticipated as this field of study develops, with the potential to completely transform the functionality and appearance of remote river energy systems [20].

6. Proposed Design Concepts

The proposed design outlines the specific materials, configurations, and methodologies that will be employed to meet the above specifications. This section describes the solution to the problem as defined by the specifications.

12. Material Selection:
    - Bellows Material: EPDM (Ethylene Propylene Diene Monomer) rubber will be used due to its excellent flexibility, durability, and resistance to weathering, ozone, and extreme temperatures. This makes it ideal for the variable and harsh conditions expected in a remote river energy system.
    - Reinforcement: The bellows will be reinforced with Aramid fibers or spiral wire to provide the necessary strength and durability, ensuring it can handle the operational pressures and environmental conditions.

13. Wetted Materials:
    - Bellows: Reinforced EPDM rubber is chosen for its chemical resistance and ability to withstand continuous flexing.
    - Valves/O-rings: EPDM will be used, depending on the specific chemical and temperature resistance required.
    - Body: Polypropylene or stainless steel will be used, selected for their resistance to corrosion and durability in outdoor environments.

14. Drive System Design:
    - The drive system will feature a direct coupling from the turbine shaft to the pump crank mechanism. If necessary, a gear reduction system will be integrated to match the turbine's speed and torque characteristics, ensuring optimal performance.
    - The design will accommodate potential misalignment in the turbine shaft, ensuring reliable operation even with minor installation inaccuracies.

15. Sealing and Gaskets:
    - High-quality nitrile or Viton seals will be used for all moving parts and connections to ensure leak prevention.
    - EPDM or PTFE gaskets will be employed at all flange connections to provide durable and watertight seals, crucial for maintaining system integrity in outdoor conditions.

Figure 7: Reinforced EPDM Bellows

16. Support Structure Design:
    - A steel foundation will be used to securely anchor the turbine and pump, with adjustable mounting brackets for precise alignment.

- The system will include protective housing or screens to shield critical components from debris and weather, enhancing longevity and reliability.

17. Maintenance and Durability Features:
    - The design will allow for easy disassembly of the pump and valves, ensuring that maintenance tasks can be carried out with minimal disruption.
    - Materials and reinforcements will be selected for their ability to withstand continuous operation in harsh environments, maximizing durability and reducing the need for frequent maintenance.

18. Efficiency Optimization:
    - The design will focus on high volumetric efficiency for the bellows pump, ensuring that the maximum possible volume of water is moved per stroke, increasing overall system efficiency.
    - Energy conversion efficiency will be a priority, with the drive system and pump designed to maximize the conversion of kinetic energy from the river flow into mechanical energy.

19. Environmental Considerations:
    - The design will incorporate environmentally friendly materials and sustainable processes where possible, aligning with modern environmental standards.

20. Cost-Effectiveness Strategies:
    - The design will aim to be cost-effective, balancing initial investment with long-term operational and maintenance savings, making it suitable for deployment in remote areas.

21. Scalability and Flexibility:
    - The system will be designed with scalability in mind, allowing it to be expanded or adjusted based on the specific water demand and flow conditions at different sites.
    - Flexibility in the design will ensure that the system can adapt to varying river flow conditions, making it suitable for a wide range of remote locations.

22. Prototyping and Testing Plan:
    - A prototype of the bellows pump system will be developed and subjected to rigorous testing under various conditions to validate performance, durability, and efficiency.
    - Field trials will be conducted in a remote location to monitor real-world performance, maintenance needs, and environmental impact over time, providing valuable feedback for further refinement.

7. Initial Formulas for Bellows

Using flow rate, crank length, crank torque, and angular velocity (omega) from the below

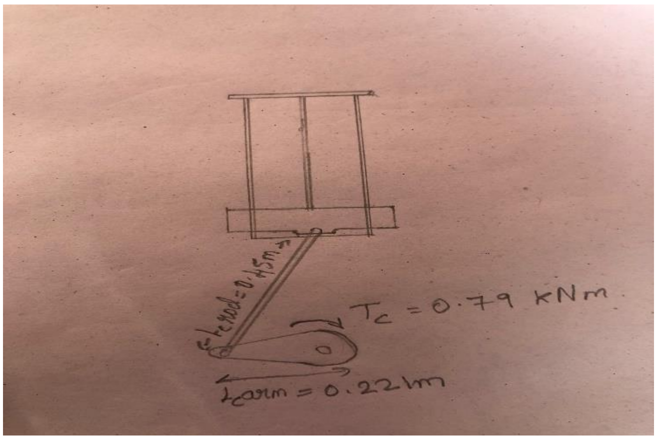


Figure 8: Dimensions of existing design

figure 8, the formulas has been written for determining rubber bellows size and displacement volume in a distant river energy system.

It should be noted that several formulas will be derived from first principles because the sources do not specifically address the particular application.

- Inner Diameter of bellows (D_i):

  The inner diameter can be calculated using the flow rate (Q) and flow velocity (v):

$$D_i = \sqrt{\frac{4Q}{\pi v}}$$

The volumetric flow rate equation serves as the source of this formula [21].

$$Q = A * v = \frac{\pi D_i^2}{4} * v$$

- Outer Diameter bellows (D_o):

  The outer diameter can be estimated by adding twice the wall thickness (t) to the inner diameter:

$$D_0 = D_i + 2t$$

To find (t):

Thickness of the bellows Is given by:

$$t = \frac{P * D_{avg}}{2 * \sigma \text{allow}}$$

The above equation is related to design and analysis of bellows, particularly in determining the thickness required to withstand the certain pressures and stresses.

Explanation of the Equation

- t: Represents the thickness of the bellow.
- P: Denotes the internal pressure that the bellow must withstand.
- di: Refers to the internal diameter of the bellow.
- σ_{allow} : Is the allowable stress for the material, which is determined based on material properties and safety factors.

Origin and context

This kind of equation is based on material mechanics and pressure vessel design concepts, where a component's thickness is determined to make sure it can safely handle internal pressure without going above the material's permissible stress. A special issue in engineering these components is matching the demand for flexibility with the necessity to withstand internal pressures in bellows design [47].

The permitted level of stress (σ_{allow}) is frequently established using rules from standards like the ASME Boiler and Pressure Vessel Code, which provide instructions for computing stress limits to prevent failure under particular circumstances [48].Empirical elements and safety considerations unique to the use of bellows in industrial settings are probably incorporated into the equation.

- Length (L):

  The length of the bellows can be related to the crank length (Lc):

$$L = k * L_c$$

where k is a factor that takes into consideration the extra length required for installation and flexibility.

- Displacement Volume (V):

  The displacement volume per revolution can be calculated using the effective cross-sectional area and the crank length:

$$V = \frac{\pi[D_i^2 + D_0^2]}{8} L_C$$

- Force (F):

  The internal pressure and the bellows effective area determine the force that the device produces.

$$F = P * A$$

  where:

  - F is the force exerted by the bellows.
  - P is the internal pressure within the bellows.
  - A is the effective area of the bellows

- Area of bellows (A):

$$A = \pi \frac{(D_{avg})}{4}$$

$$D_{avg} = \frac{D_i + D_0}{2}$$

Crank Torque (T):

From the figure 9 below we have the existing stroke length to calculate the torque.

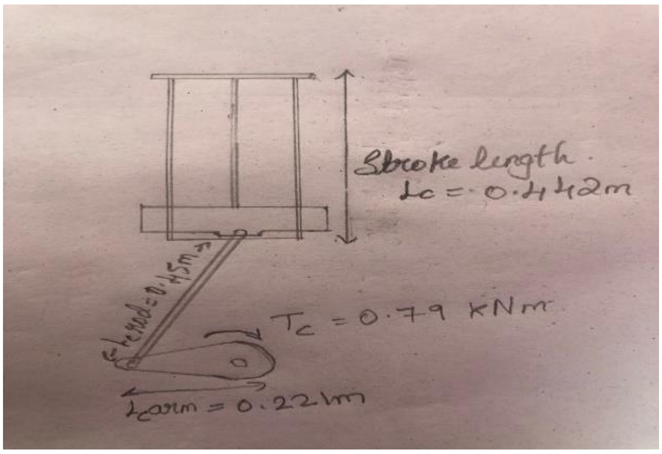


Figure 9:Dimension of L_c

The crank torque can be related to the pressure difference (ΔP) across the bellows and the effective area:

$$T = \frac{\Delta P * \pi \, [D_i^2 + D_0^2]}{8} L_C$$

- Power (P) :

The power generated can be calculated using the torque and angular velocity:

$$P = \Delta P * Q$$

The rubber bellows in a remote river energy system can be designed using the foundation these formulas give. It's crucial to remember that while using these formulas, rubber's unique qualities such as its flexibility and resistance to water should be taken into account.

When designing the system:

1. Based on the features of the river and the required energy production, calculate the appropriate flow rate (Q).
2. Based on the energy harvesting system's mechanical design, determine the proper crank length (Lc).
3. Choose an appropriate angular velocity (ω) that takes into account the natural flow of the river and maximizes energy extraction.
4. When selecting materials and thicknesses for the bellows construction, keep things like flexibility and durability in mind.

The above mentioned formulas to design the bellows was considered from the following references [21] [22] [23] [24] [25].

7.1 EPDM Rubber Properties.

Theory on Maximum Allowable Stress, Young's Modulus, and Factor of Safety for EPDM Reinforced with Aramid Fibers in Remote River Energy Systems

Maximum Allowable Stress

Aramid fiber reinforcement significantly enhances the mechanical properties of EPDM rubber, including its maximum permissible stress. With tensile strength up to 3,600 MPa and excellent thermal stability, aramid fibers improve the overall performance and longevity of the composite. This reinforcement boosts the material's resistance to mechanical stress and environmental degradation, making it more durable under demanding conditions.

The addition of aramid fibers can significantly increase the tensile strength of EPDM composites, raising it from 7–21 MPa to values as high as 22.02 MPa, as indicated by tear strength improvements in tests. Based on these gains, the maximum permissible stress for EPDM reinforced with aramid fibers can be estimated. Using a conservative factor of safety (FoS) between 5 and 10, the allowable stress for the composite may range from 2.2 MPa to 4.4 MPa. [26] [27].

Young's Modulus

EPDM rubber is flexible with a low Young's modulus, typically between 1 and 10 MPa. However, incorporating aramid fibers, which have a much higher Young's modulus (70 to 200 GPa), significantly increases the stiffness of the composite. The final Young's modulus of the EPDM/aramid composite depends on the fiber content and the quality of the fiber-rubber matrix interface. This reinforcement leads to a notable improvement in the mechanical properties of the material.

Research has demonstrated that aramid fibers enhance the mechanical characteristics of EPDM composites, resulting in enhanced tear strength and less dimensional alterations under stress. This points to a significant rise in Young's modulus, which would improve the composite's suitability for uses needing greater stiffness and load carrying capability [26] [27].

Factor of Safety

In engineering, the factor of safety (FoS) accounts for long-term degradation, environmental factors, and material variability, especially in rubber polymers like EPDM. Due to rubber's susceptibility to ozone, UV rays, and mechanical fatigue, a higher FoS is recommended. For EPDM rubber bellows in remote river energy systems, an FoS of 5 to 10 is typically sufficient, ensuring durability under unexpected stresses and strains. This range helps prevent premature failure in harsh conditions. [26] [27].

7.2 Calculations for Bellows

We will be computing the initial values for the design purpose of bellows using the formulas from 4.6.

The 6-inch pump flow rate, river flow rate, crank rod length, crank arm length, angular velocity (omega), and stroke length have all been used to calculate the bellows' dimensions based on Craig's pump model. Based on the design objectives and operational needs of the model, these characteristics provide the basis for establishing the best bellows specifications [45] [46].

Now from the excel we have the values,

Length of the crank rod = 0.45m.

Length of crank arm = 0.221m.

Stroke Length (L_c) = 0.442m.

Omega (ω) = 0.62 Hz

Pump Flow rate (Q) = 9.29 l/s

Area = 0.0172 m^2

Now to find below inner diameter we have,

$$D_i = \sqrt{\frac{4Q}{\pi v}}$$

Where, Q = 9.29 l/s

We know, $V_{pump} = Q$

Now, $v = Q \times A$

$v = 0.00929 \times 0.0172$

v = 0.5401 m/s

$$D_i = \sqrt{\frac{4 \times 0.00929}{\pi \times 0.5401}}$$

$$D_i = 0.148\ m$$

Now to find outer diameter of bellows we have

$$D_0 = D_i + 2t$$

$$D_0 = 0.148 + 2 \times 0.115$$

$$D_0 = 0.378\ m$$

To find Length of the bellows we have,

We can also find the length based on the volume of bellows then we have,

$$L = \pi \times \frac{\frac{V}{[D_i^2 + D_0^2]}}{8}$$

$$L = \pi \times \frac{\frac{0.0286}{[0.148^2 + 0.378^2]}}{8}$$

$$L = 0.424m$$

Now to find Displacement Volume we have,

$$V = \frac{\pi[D_i^2 + D_0^2]}{8} L_C$$

$$V = \frac{\pi[0.148^2 + 0.378^2]}{8} \times 0.442$$

$$V = 0.0286\, m^3 \approx 28\, L$$

Convolution of bellows

The corrugated structure that makes up a bellows' main functional element is referred to as the convolution of bellows. These convolutions are essential for giving the bellows the strength and flexibility it needs to perform well in a variety of settings, such accommodating thermal expansion or dampening mechanical vibrations in pipe systems.

Key Aspects of Bellows Convolution

- Structural Core: The main structural characteristic that separates bellows from regular pipes are the convolutions. They offer the requisite strength and flexibility to manage pressure variations and mechanical movements [42].

- Geometric Parameters: Numerous geometric criteria, including as pitch, height, arc radius, wall thickness, and plies count, are involved in the construction of bellows convolutions. These factors, which include stiffness, stability, fatigue life, and compressive strength, have a major impact on the bellows' performance qualities [42].

Because it offers flexibility and the ability to endure internal pressures, the convolution design is crucial to the bellows' ability to perform well under a range of operating situations.

So now,

Number of convolution assuming the normal length we have,

$$N = \frac{L}{P}$$

$$N = \frac{2.21}{0.263}$$

$$N = 8$$

Where $P \approx h$

So,

$$h = \frac{D_i + D_0}{2}$$

$$h = \frac{D_i + D_0}{2}$$

$$h = 0.263\ m$$

Now to calculate the Area of bellows we have,

$$A = \pi\ \frac{(D_{avg})}{4}$$

$$D_{avg} = \frac{D_i + D_0}{2}$$

$$D_{avg} = 0.263\ m$$

Now,

$$A = \pi\ \frac{0.263}{4}$$

$$A = 0.054\ m^2$$

Now, To find torque

$$T = \frac{\Delta P * \pi[D_i^2 + D_0^2]}{8} L_C$$

$$T = \frac{500000 * \pi * \ 0.164788}{8} * \ 0.442$$

$$T = \ 14.30\ KNm$$

Now, To find Power

$$P = \Delta P * Q$$

$$P = 500000 * 0.00929$$

$$P = 4645\ W\ \approx\ 4.645 kw$$

Parameters	D_i	D_0	L	N	t	A	V
Values of Bellows	0.148 m	0.378 m	0.424 m	8	0.12m	0.054 m^2	28 L

Table 3 : Dimensions of Bellows

8. Bellows Design

Based on a comprehensive options analysis and a great deal of background study, this project has produced precise SolidWorks drawings that show a much better mechanical design. Advanced engineering techniques have been incorporated into the rebuilt components to improve their durability and performance. Through the resolution of significant issues found in the analysis, the design seeks to maximize usefulness, enhance effectiveness, and satisfy the necessary technological requirements. In order to guarantee that the finished product will satisfy project objectives and industry standards, these SolidWorks models provide the framework for the subsequent stages of development and testing.

Design optimization has advanced significantly with the switch from a standard pump manifold to a rubber bellows pump, especially in sectors where cost-effectiveness, efficiency, and dependability are critical. There was a purpose behind this modification. The bellows pump was chosen over the previous design because it offers a number of significant advantages, such as lower maintenance costs, lighter weight, and the use of more flexible materials. The new design is better in many applications because of all these characteristics that add to its overall superiority.

A

B

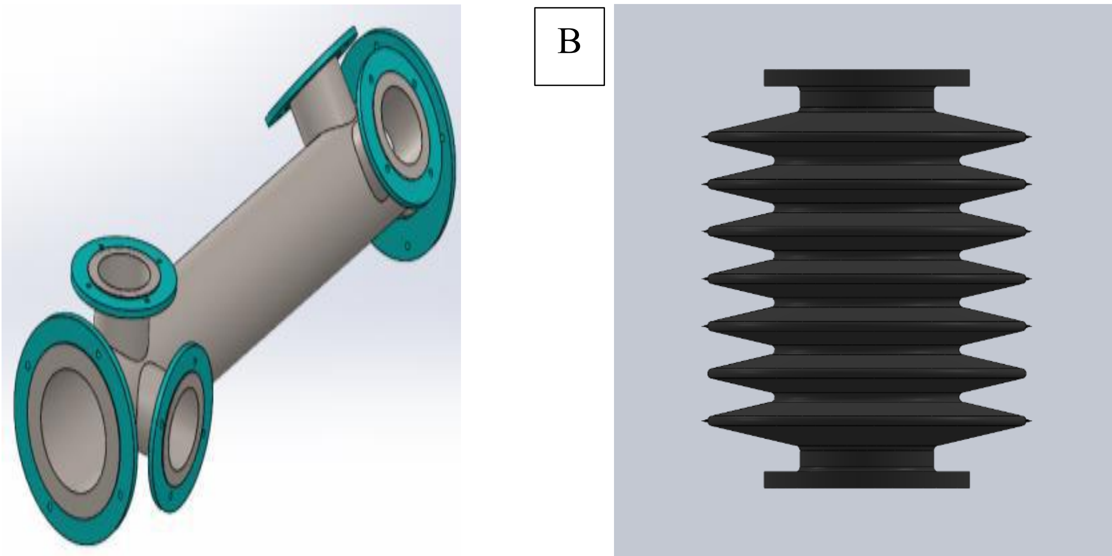


Figure 10: Design Optimization From Pump Manifold to Bellows Pump a) Old Design b) New Design

Let's start by examining the outdated pump manifold design, which is shown in the picture with the letter "A." Rigid parts that are closely coupled make up the manifold system. In many industrial environments where fluid management is essential, this older design is widely used. Even while this design has shown to be effective in the past, it is not without its issues. The system's inflexibility presents the first difficulty. Because the manifold is made up of several solid components, it can't withstand vibration, variations in pressure, or environmental and corrosion fluctuations while in use. These forces have the potential to cause damage over time, especially around the joints and seals. Leakage is more likely to occur in these regions, which could reduce the system's effectiveness which require maintenance. This maintenance is not only expensive, but it also causes downtime, which is undesirable because continuous functioning is essential [46].

The weight of the original manifold design is another major problem. The rigid and connected portions of the manifold's structure make it generally heavier than more contemporary options. This extra weight may result in greater difficulties during operation, including higher energy consumption, transportation issues, and more involved installation processes. The total cost of operation may go up with heavier systems since they are more difficult to manage and require more assistance [46].

On the other hand, the new design, depicted in image "B," substitutes a bellows pump composed of rubber or a comparable flexible material for the original manifold. There are several advantages to this straightforward change. The adaptability of this new design is among its most obvious benefits. The bellows pump may expand and shrink as needed because to its accordion-like structure, which sets it apart from the manifold's stiff components. The bellows pump is far more adaptable to withstand vibration and fluctuations in pressure because of this. The bellows pump is better suited to sustain a constant flow in conditions where fluid dynamics are subject to fluctuations without sustaining damage.

Furthermore, the bellows pump's use of rubber or other flexible materials considerably lowers the system's overall weight. This weight loss is important for several reasons. Lighter systems require less effort and money to ship because they are simpler to install and move. The smaller weight also means that less energy is required to run the pump after it is installed, which could eventually result in cheaper energy expenses. The bellows pump is clearly superior in situations where it is necessary to minimize weight, like in mobile systems or small areas [3].

Using Appendix A's method and parameters, the thickness of the bellows was determined to be 120mm. For the intended purpose, this value is deemed excessive because it would produce an extremely thick and heavy bellows. It is necessary to choose a more suitable thickness in order to guarantee the bellows' effectiveness and functionality.

Additional examination, including stress analysis, is necessary to assess the strains that the bellows experiences in various operating scenarios. This will make it easier to determine the minimal thickness needed to preserve structural integrity and avoid failure. The bellows will be designed with the help of the stress analysis results to minimize weight and material consumption while meeting the necessary performance criteria.

Beyond just reducing weight, using rubber or flexible materials also has the significant advantage of being less expensive. Rubber is typically less expensive when it comes to manifold systems than more stiff materials. This reduces the cost of producing the pump from the ground up as well as the cost of replacing parts. Furthermore, the bellows pump will last longer and require less maintenance because of rubber's toughness and resistance to cold. Because of its long-term endurance, there will be less downtime and maintenance expenses [3] [18].

The bellows pump's ease of maintenance is largely due to its straightforward design. The system is simpler to check and maintain as there are fewer moving elements to worry about. Because of its numerous interconnected components and several failure locations, the traditional manifold design is more difficult to diagnose and repair. Conversely, the bellows pump reduces the number of these weak points because of its straightforward construction, which leaves fewer parts vulnerable to damage. The bellows pump can be serviced more quickly and easily because to this reduction in complexity, which also lowers maintenance costs and downtime [17] [19].

The bellows pump design also has the benefit of being able to withstand stress and vibration. Systems are frequently exposed to continuous movement and pressure fluctuations in industrial applications. The original manifold design's stiff structure can't handle these circumstances well since wear and tear results from mechanical loads being passed straight to the components. But the bellows pump's flexible construction enables it to withstand these strains, protecting the device and prolonging its life. In demanding situations, the bellows pump is a more dependable choice due to its resilience to tougher circumstances [22] [23].

There are multiple ways in which the bellows pump performs better than the traditional manifold design in terms of total system efficiency. By reducing the number of possible points of failure, the streamlined design smother fluid transfer while simultaneously lowering the danger of leaks. The rubber bellows function better overall because they can withstand pressure fluctuations more skilfully, preserving steady flow rates.

8.1 Pipe System

A pipe system's design optimization is clearly demonstrated in the supplied graphic. The first design, designated 'A,' displays a convoluted configuration of 4-inch PVC pipes, fittings, and valves. The new design designated 'B,' on the other hand, uses 2-inch PVC pipes and presents a much simpler system. Several benefits result from this switch from a complex to a simple design, including optimal fluid flow, less weight, easier maintenance, easier assembly, and less cost.

Ease Of Maintenance

The streamlined design's ease of maintenance is one of its main advantages. The extensive network of pipes and fittings in the sophisticated design might make it difficult to inspect, clean, or repair. Leaks and clogs are more likely when there are several valves and connections. On the other hand, the more plain layout and reduced number of components in the simpler design make it easier to access and maintain. Frequent cleaning and inspections may be carried out more effectively, lowering the possibility of expensive repairs and downtime [37].

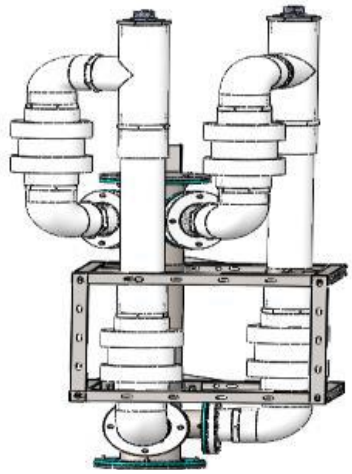
Ease Of Assembly

It is also simpler to construct due to the streamlined design. A higher degree of skill and knowledge is needed to ensure correct installation and component alignment due to the complicated design. . There is a greater chance of mistakes or leaks because of the many fittings and connections. Because of its standardized connections and reduced number of components, the simpler design is less likely to cause assembly problems. This can shorten the installation process, save money, and raise the system's general quality [37].

Reduced Weight

Compared to the 4-inch pipes used in the complex design, the 2-inch PVC pipes utilized in the simpler design result in a significant weight reduction. This weight loss has a number of benefits. First, it can lessen the strain on auxiliary buildings, which might save money on building new infrastructure or modifying already-existing infrastructure. Furthermore, lighter components are less likely to be damaged during delivery or installation because they are simpler to handle and move. And last, lighter loads may also result in cheaper shipping [39] [26].

A



B

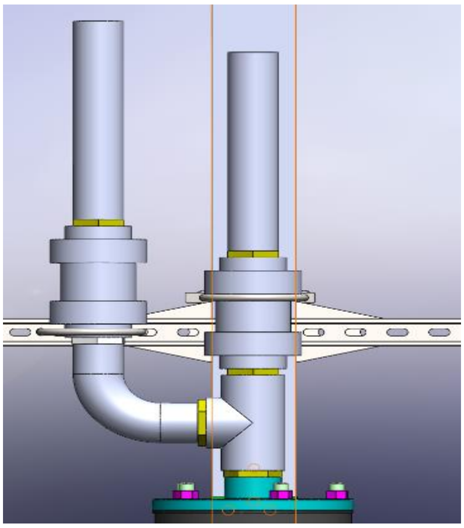


Figure 11: Design Optimization of Pipe System a) Old Design [46] b) New Design

Lower Cost

In general, the simpler design is less expensive than the more complicated one. The new design uses fewer fittings and pipes with smaller diameters, which reduces the cost of materials. Furthermore, the system's decreased complexity may result in less expensive installation. Over the course of the system's lifetime, the streamlined design may also result in lower labor expenses for maintenance and repairs.

Improved Transportability

The new system is easier to move because of its lighter weight and more straightforward design. More effective packaging techniques can be used to minimize damage during travel and save shipping costs for smaller pipes and fittings. This is especially crucial for projects taking place in isolated areas or places with restricted access [39] [26].

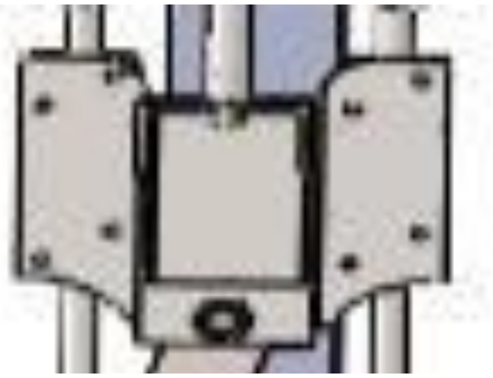
Optimized Fluid Flow

In some cases, the streamlined design can actually result in better performance, even if it may appear paradoxical in terms of fluid flow. The fluid's velocity may rise due to the pipes' smaller diameter, improving mixing and heat transfer. Furthermore, removing pointless bends and fittings can lower head losses and increase system efficiency [21].

8.2 Piston Slider Plate

The piston slider plate plays a crucial role in various mechanical systems, such as hydraulic cylinders and pneumatic actuators. Its design directly influences the performances and efficiency of the systems. In many cases, the initial design may not be optimal, leading to suboptimal performance or manufacturing challenges [7].

A



B

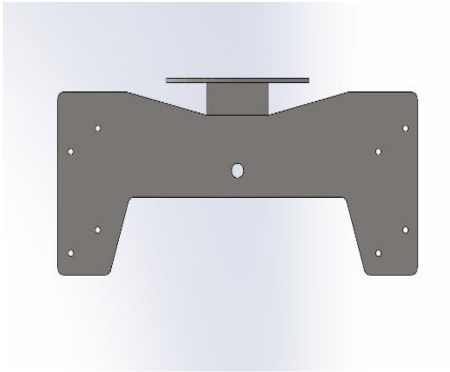


Figure 12: Design Optimization Piston Slider Plate a) Old Design [46] b)New Design

Based on the bellows dimensions, it was determined that the old design of the piston slider plate was not supporting the bellows. So, a new design was developed that provide better support for the bellows while maintaining desired functionality [4].

Eliminating superfluous material was one of the new design's primary improvements. This streamlined the manufacturing process and decreased the plate's weight. The machining procedures needed to make the plate were greatly reduced by getting rid of extra material, which saved money and improved productivity [17] [18].

The new design might also include other improvements, including lower quality surface finishing or the use of better-performing materials, in addition to the modifications in material and shape. These adjustments may improve the piston slider plate's longevity and performance even more [18].

8.3 Assembly Prototype

The two pictures (Figures A and B) show how the assembly and design optimization process progresses, showing how a more complicated and convoluted system (A) evolved into a more straightforward and efficient assembly (B). This is a major reconfiguration, where a more straightforward but more efficient solution using flexible bellows is used in Favor of a traditional assembly that depends on a more complex and stiff structural design.

Figure A: Old Assembly

The old assembly is depicted in the left-hand figure (Figure A) as a mechanical system with a massive, stiff frame supporting several components that seem to be closely coupled. This arrangement probably consists of a number of mechanical fixtures as well as a pump or fluid-handling system with numerous pipe connections.

- Structural Complexity: Numerous fixed parts, such as metal bars, bracing, and connecting points, are visible in the assembly. Although sturdy, this intricate frame construction seems heavy and labour-intensive to assemble and maintain [46].
- Movement Limitation: Owing to its permanent design, the system is probably less flexible and more vulnerable to strain or damage from thermal expansion, misalignment, or mechanical vibrations. As a result, the system's efficiency would gradually decline, and installation and operation would require more accuracy [46].

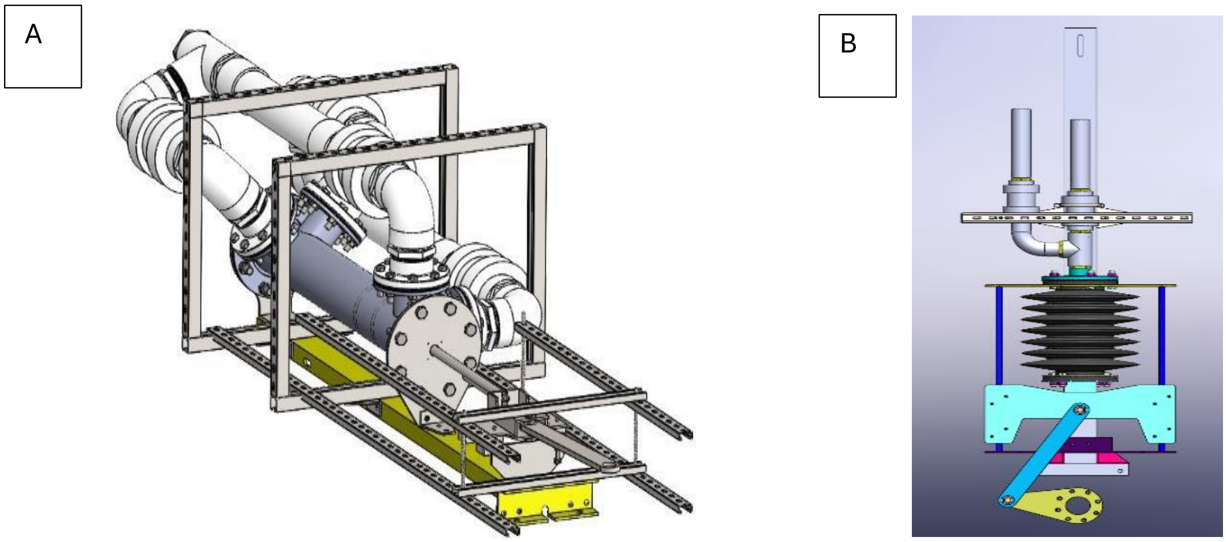


Figure 13: Assembly Optimization a) Old Assembly [46] b) New assembly

- Energy and Resource Intensive: Because of the complex mechanical arrangement, more materials and precise manufacturing would be needed, which would increase production and assembly costs and energy usage [46].

Figure B: New Assembly with Flexible Bellows Pump

The revised assembly, which incorporates flexible bellows into the system, offers a more elegant and straightforward solution on the right (Figure B). Many significant advantages are introduced by this revised assembly, which enhances usability and functionality.

The utilization of flexible bellows, which give the system flexibility, is a crucial component of the new design. Bellows can withstand expansion, movement, and vibrations, which lessens the system's mechanical stress. Because of its flexibility, the system can withstand a wide range of stresses and circumstances without losing its structural integrity [4] [6] [24].

- Reduced Assembly Complexity: The number of pieces and connection points in the new assembly is significantly less than in the old assembly due to its flexible architecture. Because of its simpler design, there is less work and assembly required, which improves efficiency during building and operation. The system is now simpler to install, modify, and maintain thanks to this enhancement [22] [23] [47].
- Vibration Handling: The flexible bellows significantly reduce vibration, which in stiff assemblies might result in serious damage or misalignment. The technology maintains stability and dependability even in surroundings with fluctuating mechanical conditions because it permits regulated movement. This adaptability ensures smoother operation and less frequent maintenance by lowering the strain on system components and assisting in maintaining the system's integrity over time [4] [12] [23].
- Space and Material Efficiency: The new assembly uses less space because it has fewer parts and a smaller design. It uses less resources and takes up less space, which lowers costs and promotes a more environmentally friendly design [6] [47].

Comparative Analysis

Moving from the old assembly (A) to the new design (B), we can see that mechanical systems are becoming more modular and flexible. The bellows assembly offers a more intelligent and adaptable alternative to the previous setup's reliance on inflexible structures and intricate mechanical connections. There are numerous observable advantages to this change:

- Improved Durability and lifespan: Bellows' flexible design reduces stress and the chance of mechanical failure, extending the system's lifespan [4].
- Enhanced Flexibility: The system's robustness and adaptability are increased by its capacity to withstand changing operating conditions without the need for realignment or recalibration [6] [4].

Ease of Maintenance: The new design requires less maintenance time and effort because it has fewer components. A system is generally more reliable the fewer moving parts it has since there is a less likelihood of failure [42] [43].

8.4 Bellows, Piston Slider Plate and 2inch Flange Collar Engineering Drawings

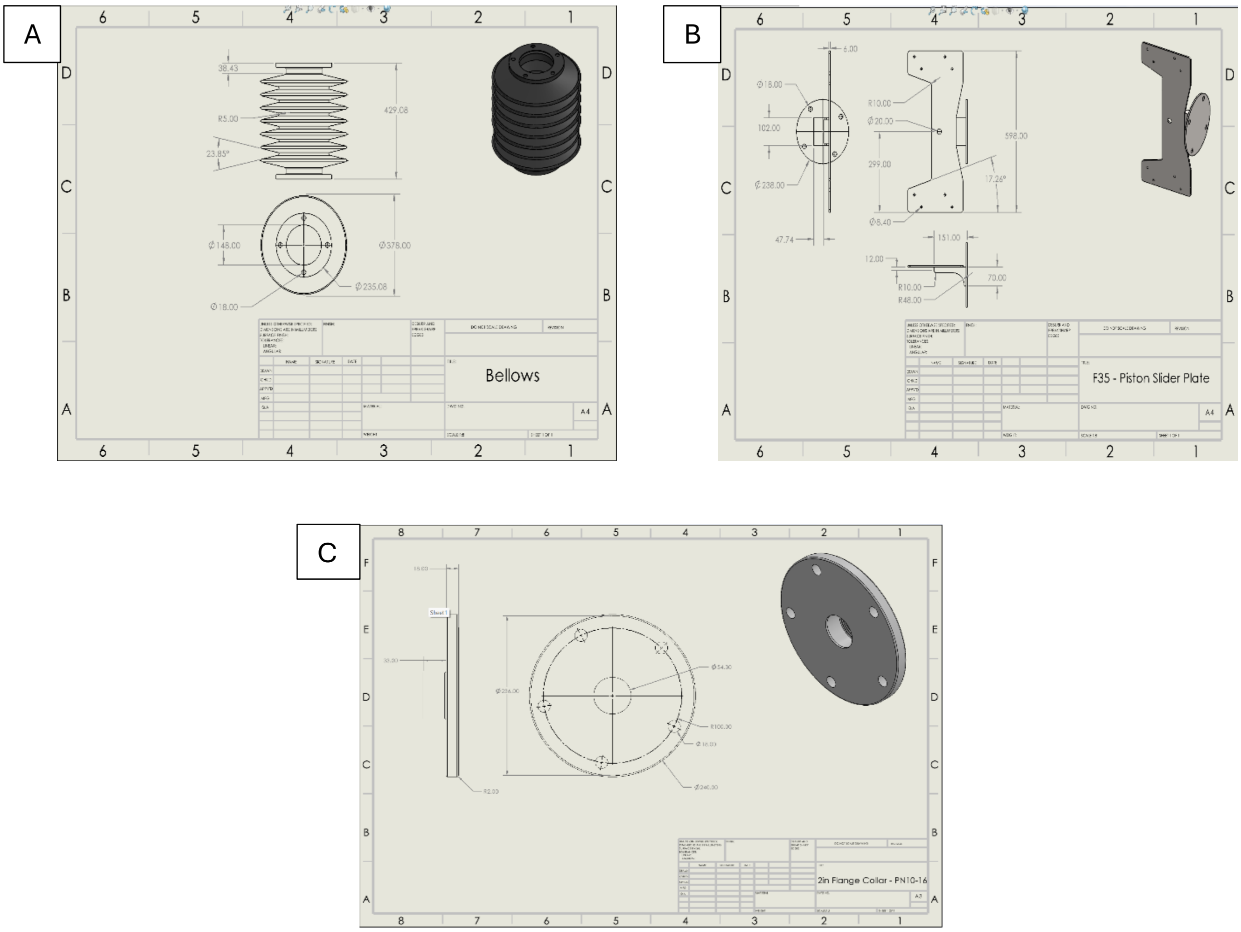


Figure 14:a) Bellows Drawing b) Piston Slider plate drawing c) 2inch Flange Collar Drawing

Two intricate technical engineering drawings, designated as Figure 14 along with two subfigures, Figure A and Figure B, make up the image.

Figure A: Bellows Drawing

- The bellows component, which is commonly utilized in mechanical systems for sealing or movement absorption, is depicted in this subfigure as its technical representation.
- The bellows is depicted from both the top and front in the drawing. The top view displays the circular shape of the bellows, while the side view demonstrates its compressible, corrugated structure.
- The drawing has annotations for important dimensions. The bellows has an outside diameter of Ø 378.00 *mm* and a compressed height of 424.00 *mm* overall. The circular section's inner diameter (ID) is Ø148.00 *mm*, and the item has a holes that is defined to be *Ø18*.00 *mm*.
- On the right side, there is also a 3D rendered model of the bellows that provides a visual representation of the component's actual appearance.

Figure B: Piston slider plate Drawing

- The technical drawing for a piston slider plate, which is probably a component of an assembly comprising pistons and sliders in a mechanical system, is shown in this subfigure.
- Three viewpoints are presented in the drawing: a side view, a front view, and a top view that reveals features. These views aid in the visualization of the plate's intricate geometry and the holes and cutouts it contains.
- The most important measurements are the distances between features, the hole diameter of Ø10.00 *mm*, and the plate thickness (6.00 *mm*). The part is notable for appearing to have mounting holes and angled cutting.

Figure C: 2Inch Flange Collar Drawing

- Side View: This view presents a basic profile of the circular collar and indicates the thickness of the flange collar, which is measured at 18.00 *mm*.
- Top View: This view reveals the round shape of the flange collar and details its dimensions, which include an outer diameter of Ø236.00*mm* and equally spaced bolt holes. The inner circular hole (for the pipe) is indicated as having a diameter of *Ø54.30 mm,* whereas the bolt holes have a diameter of Ø18.00 *mm.*

All three subfigures represents high quality mechanical drawings used in manufacturing to communicate the precise specifications of each part to engineers and machinists.

8.5 Exploded and Assembly Drawings

Three intricate technical drawings for an assembly of a flexible bellows pump are shown in the picture. Figure 15 is identified with subfigures A, B, and C.

Figure A: Exploded Drawing

- An exploded view of the complete Flexible Bellows Pump assembly is displayed in this diagram. To show the various elements and how they relate to the system as a whole, each component is visually divided.
- A corresponding bill of materials (BOM) table, which contains specific information about each part, including the part name, material, and amount, is numbered and references the parts. Bolts, gaskets, sliders, bellows, and other mechanical pieces are among the constituents.

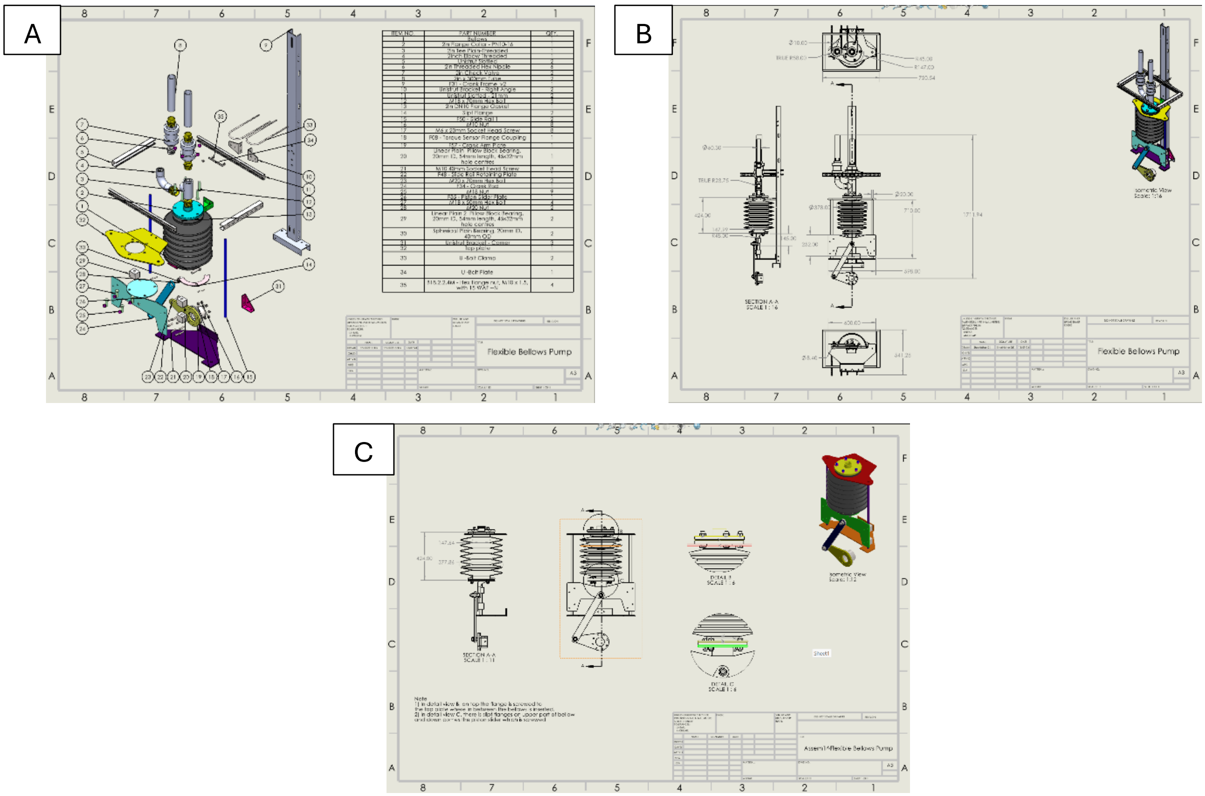


Figure 15:a) Exploded Drawing b) Whole Assembly Drawing c) Detailed Drawing of Bellows Assembly

- Understanding how the different parts fit together and are assembled requires this vision.

Figure B: Whole Assembly Drawing

- The fully built Flexible Bellows Pump is shown in this subfigure from various orthographic perspectives, including the side and front. These views show dimensions for essential features of the assembly, including overall height, width, and the placement of parts.
- For a better understanding of how the assembled elements interact, a 3D isometric perspective is also provided.
- Precise markings and measurements steer the building and examination procedure, guaranteeing precise assembly.

Figure C: Detailed Drawing of Bellows Assembly

- The bellows component's particular details within the assembly are the subject of this subfigure. A deeper look at the bellows' dimensions, construction, and connection points is provided by the three different perspectives (side, front, and sectional) that are offered.
- To better understand the relationship between the bellows and adjacent assembly components, a three-dimensional picture is also included.

The entire guide for comprehending, producing, and assembling the Flexible Bellows Pump is provided by these meticulous technical drawings. The assembly drawing illustrates how the parts fit together, the exploded view aids in part identification, and the detailed drawing concentrates on particular crucial parts like the bellows. When combined, they offer engineers, machinists, and assembly technicians all the information they require.

9. Result

The investigation culminated in the creation of a flexible bellows pump for remote river energy systems using reinforced EPDM rubber. Key results include:

- Selection of EPDM reinforced with aramid fibers as the optimum material for the bellows, based on a Pugh matrix analysis comparing several materials.
- Development of a conceptual design with a U-shaped one-way valve mechanism for controlling water flow, selected as the most promising concept based on characteristics like affordability, lightweight construction, adaptability, and ease of maintenance.
- Creation of thorough design specifications covering issues like dimensions, operating pressure, materials, driving system, sealing, support structure, maintenance requirements, efficiency targets, and environmental considerations.
- The bellows was developed at an operating pressure of 5 bar (500 kPa), suitable for the proposed distant river energy application.
- Modelling and analysis of the bellows pump design using SolidWorks to enhance performance and durability.
- The bellows' computed thickness of 120 mm is deemed to be excessive. To find a more suitable thickness, this value needs to be reevaluated using stress analysis, especially in the bellows convolution edge.
- Once the optimal thickness has been determined, the bellows can be manufactured and tested to verify its performance and durability.

10. Conclusions and Recommendations

Conclusion

The flexible bellows pump design employing reinforced EPDM rubber offers a viable alternative for remote river energy systems. Key conclusions are:

- The selected materials and design provide a blend of durability, flexibility, and resistance to environmental conditions needed for distant applications.
- The pump design tackles important issues of remote energy systems including low maintenance requirements, adaptability to variable river conditions, and cost-effectiveness.
- The use of reinforced EPDM allows for effective energy conversion from river flow to mechanical energy while reducing environmental impact.
- The modular and basic design permits easy maintenance and repair in remote regions with minimal resources.

Recommendations

Based on the study results, the following recommendations are made:

- Perform comprehensive field testing in different river conditions to verify the prototype's durability and performance.
- To increase productivity and cut expenses, further refine the design through iterative prototyping and testing.

- Provide thorough installation and maintenance instructions designed to be used in isolated areas with little access to technical expertise.
- Investigate possible joint ventures with regional producers in the intended areas to facilitate economical manufacturing and delivery.
- Study the system's effects on the environment over an extended period of time in various river habitats.
- Examine the possibility of combining with more renewable energy sources to build hybrid systems that have higher reliability.
- Provide training courses on system installation, maintenance, and operation for the nearby communities.
- Keep looking into cutting-edge materials that can improve the longevity and effectiveness of the pump.

Future research should focus on:

- Maximizing the longevity and efficiency of reinforced EPDM bellows by optimizing their geometric design.
- Creating intelligent control systems that are especially suited to bellows pump operations in changeable river environments.
- Looking into how to improve pump performance by integrating passive solar heating or other renewable energy sources.
- Evaluating the longevity and upkeep needs of reinforced EPDM bellows pumps in isolated river settings through long-term field research.
- Exploring the potential for standardized, modular designs that can be easily manufactured and maintained in remote locations.
- Further investigation into submersible piston pumps may be necessary to improve the water's pressure impact in remote river energy systems. Compared to conventional designs, these pumps, which are renowned for their capacity to function completely submerged, may produce an output of water pressure that is higher and more reliable. More research on submersible piston pumps may result in higher energy capture efficiency, particularly in settings with erratic or low water flow.

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Appendix

To find Thickness of bellows *t,*

We have,

$$t = \frac{P \times d_i}{2 \times \sigma \text{allow}}$$

Now from 4.6.1 assuming rubber properties we know ,

We get factor of safety as 3

E Modulus of elasticity is 5

Maximum tensile strength for EPDM reinforced with aramid fibers is 8 *Mpa*.

So,

$$\sigma allow \ = \frac{tensile\ strength}{S \cdot E}$$

S and *E*: These terms are less commonly defined in standard bellow equations, but they could represent specific factors or coefficients related to the design, such as shape factors or material efficiency factors.

$$\sigma allow \ = \frac{8}{5 * 3}$$

$$\sigma allow \ = 0.53\ Mpa$$

The operating pressure for bellows is considered as 5 bar

$$t = \frac{P * D_{avg}}{2 * \sigma allow}$$

$$D_{avg} = \frac{D_i + D_0}{2}$$

$$D_{avg} = \frac{0.148 + 0.378}{2}$$

$$D_{avg} = 0.263$$

$$t = \frac{5 \times 10^5 \times 0.263}{2 \times 0.53 \times 10^6}$$

$$t = 0.12m$$

The value for thickness is 0.12*m* which is approximately 120*mm* which is a very thick material, this as to be reconsider and requires recalculation with stress analysis in one portion of the bellows convolution edge to get a precise value for thickness of the bellows.

Figure 16: Single Convolution of Bellows