Sustainable Approach to Desalination: A Novel Hydropower Energy Generation System

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Freshwater scarcity is a growing global concern, with the urban population facing water shortages projected to double by 2050, affecting up to 2.4 billion people. Desalination, a potential solution, currently accounts for just 1% of the world's drinking water due to its high cost, energy intensity, and reliance on fossil fuels. Traditional desalination plants consume over 200 million kilowatt-hours daily, generating significant climate pollution, which is counterproductive in addressing water scarcity exacerbated by climate change.

This project proposes a sustainable and low-cost desalination approach using a hydropower energy generation system that harnesses the kinetic energy of seawater. Ram pumps lift seawater to a higher-altitude reservoir, creating potential energy that is converted into electricity through a turbine. This self-sustaining system uses the generated electricity to desalinate wastewater produced during the pumping process, eliminating the need for external energy sources. It is particularly suitable for coastal areas, where 40% of the global population resides within 100 kilometers of a coast.

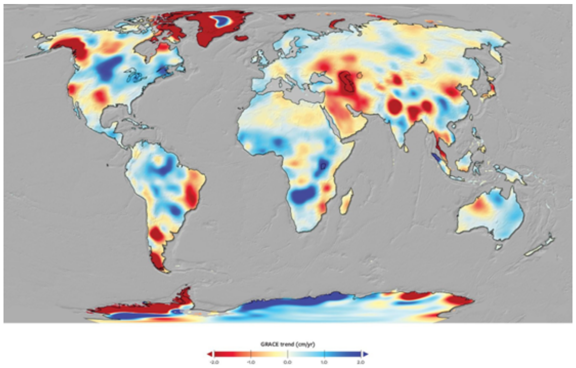
By utilizing a renewable and perpetually available energy source, this approach reduces reliance on fossil fuels and minimizes environmental impact, making it a viable and scalable solution to the global freshwater crisis. The system's adaptability to various coastal environments enhances its potential for widespread application, offering a breakthrough in sustainable desalination technology.

Introduction

As the demand for clean water and sustainable energy intensifies, especially in water-scarce regions, desalination has become an essential technology for converting seawater into potable water. However, traditional desalination methods, such as reverse osmosis and thermal distillation, are highly energy-intensive and often rely on fossil fuels. This reliance not only drives up operational costs but also exacerbates carbon emissions, undermining global efforts to combat climate change. To address these challenges, this paper proposes an innovative system that integrates renewable energy with the desalination process, offering a sustainable solution that aligns with the United Nations Sustainable Development Goals $N°6$: "Clean Water and Sanitation" and $N°7$: "Affordable and Clean Energy." The proposed system operates by harnessing the kinetic energy of seawater, less relying on the need for external energy sources. It comprises three key components:

1. Water Pumping System: Utilizing hydraulic ram pumps, the system captures the kinetic energy of moving seawater to elevate it to a higher altitude. This process requires no external power input, relying solely on the natural flow of seawater to drive the pumps.
2. Hydroelectric Turbine: Once the seawater is stored at a higher altitude, it is released, and the potential energy from its elevated position is converted into electrical energy via a hydroelectric turbine. This renewable energy source provides a consistent and sustainable supply of electricity, which is crucial for powering the desalination process.
3. Water Desalination Plant (WDS): The generated electricity is then used to power a desalination plant, which converts seawater into clean drinking water. The WDS system incorporates the residual water from the pumping process, optimizing resource use and minimizing waste. By using renewable energy to drive the desalination process, the system significantly reduces the carbon footprint associated with water production.

This integrated system not only addresses the high energy demands of desalination but also enhances its viability in regions with limited access to conventional power sources. By utilizing the kinetic and potential energy of seawater, the system offers a sustainable and cost-effective solution for providing both clean energy and potable water to coastal communities. The synergy between renewable energy generation and desalination in this approach ensures that essential resources are produced in an environmentally responsible manner, supporting global efforts to transition away from fossil fuels and towards a more sustainable future



A map describing freshwater accumulation (blue) and loss (red), using data from NASA's Gravity Recovery and Climate Experiment (GRACE) satellites. Image Credit: NASA

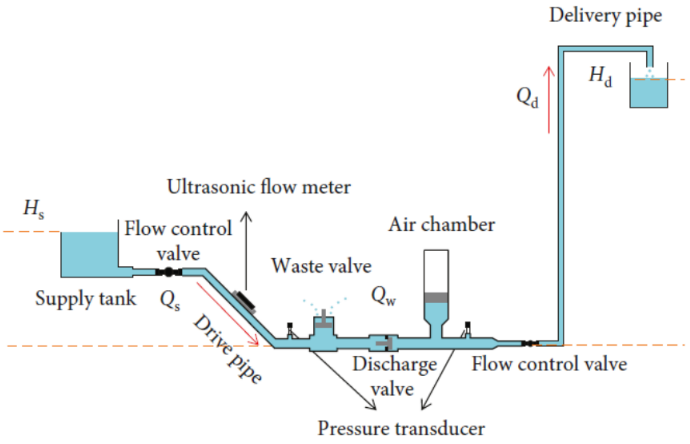


Figure 1. Schematic diagram of a hydraulic ram pump

Methods

System Proposal A novel seawater pumping system is proposed by using an array of hydraulic ram pumps to use the kinetic energy that can be obtained from seawater to pump it to a reservoir at a higher altitude at zero energy cost and no external energy sources, so that it can be later be used as a steady pressurized water source due to the obtained water head for electricity generation by using a hydroelectric turbine. Finally, a WDS uses the generated electricity and the wasted water in the pumping process to produce drinking water. The key equipment for the system to work with only the kinetic energy from the sea water and no additional external energy input for pumping the sea water to a higher level is the hydraulic ram pump. A reference schematic is seen in Figure 1[1].

The hydraulic ram pump needs water to be supplied with a certain amount of kinetic energy, which can be obtained by a water supply head and the own movement of water currents. A water supply head can be created by using a seawall and installing the supply pipes of the hydraulic ram pump at a lower height than the seawall to obtain a supply head.

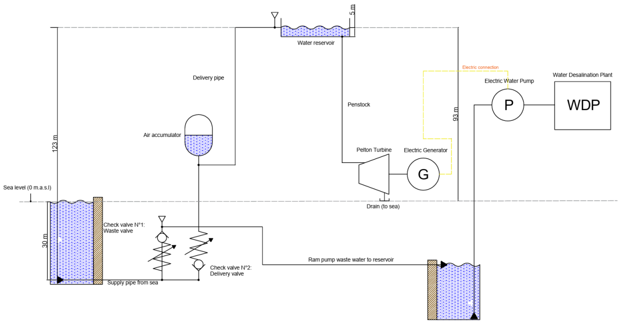


Figure 2. Schematic diagram of complete proposed system

Later, the hydraulic ram pump can lift the water to a higher altitude than the seawall, called the delivery head, to which the water can be pumped and stored in a reservoir. Due to the working mechanism of the ram pump, in this process a fraction of the water input is pumped to a reservoir, and the rest of it is evacuated as wasted water at the same height of the pump.

In a next stage, the stored water in the reservoir can be transported through water pipes to provide pressurized water at heights below the reservoir level, by using the water head difference between heights and the stored potential energy of the seawater in the reservoir. This pressurized water can be used to feed a hydroelectric turbine installed at sea level to maximize the water head, and generate renewable, carbon-free energy.

Finally, the generated electricity can be used to run an electric pump that will evacuate the wasted water by the hydraulic ram pumps and use it to deliver a steady and pressurized flow of water to a Water Desalination Plant, at the required pressure input values for the system to operate properly. Excess generated electricity can also be used to feed the electrical equipment of the plant.

A schematic of the complete system is presented in Figure 2.

For explanation purposes, the system is divided into the following components, which are further developed ahead.

1. Cellular cofferdam seawall
2. Hydraulic ram pump.
3. Hydroelectric generator.
4. Water reservoir.
5. Water Desalination Plant.

Cellular Cofferdam Seawall

The proposed concept for the water adduction system is to obtain sea water using either vertical or a sloped seawall, as seen in Figure 3, with supply pipes installed underneath sea level, so that a constant supply of sea water is ensured for all different sea level conditions.

The supply pipes are proposed to be buried at a depth of 30 meters below sea level. For practicality purposes, the effect of

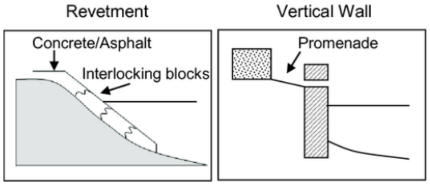


Figure 3. Example of revetment and vertical sea wall

Figure 4. Real life example of Venturo 1000 pump

sea height variation due to low and high tide is omitted in the calculations, as the depth is not within the variations of common tidal ranges, with the highest known value of 16 meters[2]. With this consideration, the defined design supply head for the system is 30 meters.

Hydraulic Ram Pump

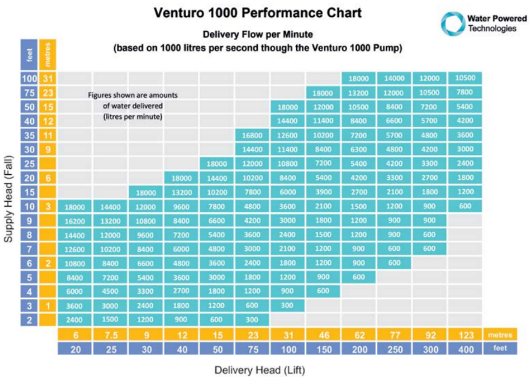
After researching the market to find an appropriate product for the desired system, the Venturo 1000 hydraulic ram pump has been chosen as the optimal solution for the system. This pump is known for currently being the largest ram pump product commercially available and can be fed with an input flow rate of 1 m3/s. Figure 4 displays an example of an installation using the Venturo 1000 pump[3]. The ram pump can be constructed with more corrosion and erosion resistant materials and coating similar like wave and tide pump. Example stainless steel with zinc coating.

Figure 5 displays the performance chart of a hydraulic ram pump from the manufacturer Water Powered Technologies[4].

The chart indicates that the highest delivery head of the Venturo 1,000 is 123 meters at 10,500 liters per minute of supply flow, which is equivalent to 175 liters per second, for each 1,000 liters per second that enter the hydraulic ram pump. This means that in best case, a 17.5% flow efficiency is achieved, and the remaining 82.5% of wasted water will be diverted to a storage facility, to be later used as input for the Water Desalination Plant. This is possible when the delivery head is four times the supply head.

As the supply head has already been established as 30 meters, the delivery head can be determined that will be obtained by the hydraulic ram pump. To do so, we will use the highest delivery head discussed before, and extracting the data from Figure 4, the next values are obtained:

- Supply flow: 1 m3/s (per ram pump).
- Delivery head: 93 m (measured from sea level)
- Delivery flow: 0.175 m3/s (per ram pump).



Venturo 1000 Performance Chart

Water Powered Technologies

Delivery Flow per Minute
(based on 1000 litres per second though the Venturo 1000 Pump)

Figures shown are amounts of water delivered (litres per minute)

Supply Head (Fall)

feet	metres													
100	31									18000	14000	12000	10500	
75	23								18000	13200	12000	10500	7800	
50	15							18000	12000	10500	8400	7200	5400	
40	12							14400	11400	8400	6600	5700	4200	
35	11						16800	12600	10200	7200	5700	4800	3600	
30	9						14400	11400	8400	6300	4800	4200	3000	
25						18000	12000	10800	7200	5400	4200	3300	2400	
20	6				18000	14400	10200	8400	5400	4200	3300	2700	1800	
15				18000	13200	10200	7800	6000	3900	2700	2100	1800	1200	
10	3	18000	14400	12000	9600	7800	4800	3600	2100	1500	1200	900	600	
9		16200	13200	10800	8400	6600	4200	3000	1800	1200	900	900		
8		14400	12000	9600	7200	5400	3600	2400	1500	1200	900	600		
7		12600	10200	8400	6000	4800	3000	2100	1200	900	600	600		
6	2	10800	8400	6600	4800	3600	2400	1800	1200	900	600			
5		8400	7200	5400	3600	3000	1800	1200	900	600				
4		6000	4500	3300	2700	1800	1200	900	600					
3	1	3600	3000	2400	1800	1200	600	300						
2		2400	1500	1200	900	600	300							
		6	7.5	9	12	15	23	31	46	62	77	92	123	metres
		20	25	30	40	50	75	100	150	200	250	300	400	feet

Delivery Head (Lift)

Figure 5. Venturo 1000 hydraulic ram pump performance

Hydroelectric Generator

A hydroelectric unit with an electric power output of 1 MW is proposed to be installed, and the required number of ram pumps to feed the turbine is calculated ahead. Calculations are done using the following formula: $P_{\text{out}} = m \times g \times H_{\text{net}} \times \mu$

- m: mass flow rate, in kg/s.
- g: gravitational constant, in m/s^2
- Hnet: net head
- u: overall efficiency

In this case, we aim to calculate the mass flow rate, as it is a value that will let us estimate the amount of required ram pumps. Mass flow rate is calculated as shown in Table 1.

$$m = \frac{P_{\text{out}}}{g \times H_{\text{net}} \times \mu}$$

To obtain water flow rate, mass flow rate is divided by water density, considering that seawater has a density of $1030 kg/m^3$.

$$Q_{\text{HYDRO}} = \frac{1522.35}{1030} = 1.478\,[\text{m}^3/\text{s}]$$

We now divide the required flow rate by the output flow of pressurized water per unit of ram pump, to obtain the number of required ram pumps:

$$n = \frac{Q_{\text{HYDRO}}}{Q_{\text{OUT}}} = \frac{1.478}{0.1715} = 8.61 \approx 9$$

A minimum of 9 ram pumps will be required to feed the system with enough water to continuously feed a hydroelectric generator of a rated capacity of 1 MW.

Table 1. Calculation of required mass flow rate for 1 MW hydroelectric generator

Variable	Value	Observation
P: power output [kW]	1000	
g: gravit. constant [m/s^2]	9.81	
Hnet: net head [m]	83.7	Considering a 10% loss of the delivery head
u: overall efficiency.	0.8	Assumed efficiency of turbine and generator
m: mass flow rate [kg/s]	1,522.35	

Water Reservoir

A delivery flow of 0.175 m3/s is delivered to a water reservoir installed at a height of 93 meters above sea level, equivalent to 123 meters above the installed height of the ram pumps. Since the hydraulic ram pumps do not pump water at a constant flow, the water reservoir will function as a buffer to provide a steady flow of water and steady pressure levels at the desired application at sea level. For this calculation, it is proposed that the water reservoir holds out enough water to let the system operate for 1 minute without any water input. The nominal delivery flow to the reservoir will be: $Q_{\text{DEL}} = 0.175 \times n\,[\text{m}^3/\text{s}]$

QDEL: delivery flow

n: number of ram pumps of the system

The output flow of pressurized water will be as follows, assuming 2% water losses due to leaks:

$$Q_{\text{OUT}} = 0.98 \times Q_{\text{DEL}} \times n = 0.1715 \times n\,[\text{m}^3/\text{s}]$$

where Q_{OUT} is the output flow of pressurized water.

For a reservoir to hold enough water to let the system operate for 1 minute, the following amount of water should be stored:

$$V_{\text{RES}} = 0.175 \times n \times 60 = 10.5 \times n\,[\text{m}^3]$$

With the considered formula, Table 2 shows the required volume of stored water and proposed dimensioning of the reservoir for the estimated 9 ram pumps required for the system to output a constant 1 MW of energy output, and to allow a maximum water head drop of 5 meters:

As the required volume of reservoir is close to 100 m3, several commercial options of prebuilt water storage tanks of such capacity exist in the market, which facilitates the construction of such system. An example of such a storage tank is displayed in Figure 6[5].

The next step is to calculate the obtained water pressure for the system, using as reference point sea level, with a height of zero meters. Calculation of water pressure is done with the following formula:

$$P = \rho \times g \times h$$

Where: P is the water pressure in Pa (Pascals), ρ is the density of water in kg/m^3, 1.030 kg/m^3 for seawater, g is the gravitational constant in m/s^2, $9.81 m/s^2$ at sea level, and h represents the height in m, which will depend on the water level of the reservoir.

Figure 6. Example of 100 m3 fiberglass water storage tank

When the water reservoir is at maximum capacity, the obtained pressure is:

$$P_{\text{Max}} = 1,030 \times 9.81 \times 93 = 939,699.99\,[\text{Pa}]$$

Converting to Bar, where 1 Pa = 0.00001 Bar:

$$P_{\text{Max}} = 939,699.99\,\text{Pa} = 9.40\,[\text{Bar}]$$

When the water reservoir is at minimum capacity, the obtained pressure is:

$$P_{\text{Max}} = 1,030 \times 9.81 \times 88 = 889,178.4\,[\text{Pa}]$$

Converting to Bar:

$$P_{\text{Max}} = 889,178.4\,\text{Pa} = 8.89\,[\text{Bar}]$$

Water Desalination Plant

As a proposed application that can use the generated electricity from the system, while also using the wasted water from the hydraulic ram pump pumping process.

Several technologies for water desalination currently exist, which can be classified in thermal and membrane techniques. The most widespread technologies are Reverse Osmosis (RO), Multistage Flash Distillation (MSF) and Mult effect Distillation (MED), as their current worldwide installed capacity is 65% for RO, 21% for MSF, 9% for MED, and 5% for other technologies[6].

Table 2. Sizing of water reservoir for 9 ram pumps and 1 MW hydroelectric generator

N° of ram pumps	Volume of reservoir [m3]	Length [m]	Breadth [m]	Height [m]
9	94,5	4,58	4,58	5

Since RO is currently the most widely spread technology and being currently used for desalination purposes in several locations in the United States such as the Santa Barbara Desalination Plant[7], a RO water desalination plant is the proposed technology for the desired application. This type of technology usually requires a water inlet pressure in the range of 55 – 68 Bar to work[8]. This water input pressure levels will be achieved through electric pumps fed by the 1 MW hydroelectric generator.

Levelized Cost of Electricity Calculation and Comparison

In this section, an estimation of the Levelized Cost of Electricity (LCOE) is presented. To perform the calculation, all capital expenses and operational expenses of the system must be estimated. Table 3 presents an estimation of capital and operational expenses of the system

Next, the yearly generated energy is calculated, considering the 1 MW hydroelectric plant is expected to operate at nominal capacity during an entire year. The energy plant capacity is mainly decided by two factors – maintenance and energy source. For example, the capacity of a nuclear plant is approximately 90%. Unlike other green energy sources, the proposed system uses perpetual sea water as a resource, regardless of weather conditions. The ram pump only has two moving parts – the discharge and waste valve, which makes it very durable and requires low maintenance. One example shows that the ram pump has been running 24/7 for nearly 100 years. Therefore, allowing for 2-3 weeks of annual maintenance (3-5%) is a reasonable deduction, leading to a 95% capacity factor.

The calculation is performed as follows:

$$\text{Yearly energy [MWh/year]} = 1\text{MW} \times 8760\text{hours} \times 0.95 = 8,322.00\,\text{MWh/year}$$

With the CAPEX, OPEX, and yearly energy generation, the Levelized Cost of Energy (LCOE) can now be calculated. A typical discount rate for the project of 4.85% will be assumed, along with a lifetime of 20 years, which is standard in the industry. The calculations are displayed in Table 4.

Finally, for the sake of comparison, Table 5 presents the list of LCOE trends by renewable energy technology in year 2022, including the LCOE of the proposed system. Table 5[14]. LCOE Comparison with Other Renewable Energy Technologies

The proposed system has an estimated LCOE of 40.94 USD/MWh, which is lower than most other widely spread renewable energy technologies. The LCOE of solar energy, for example, ranges between 30 and 180 USD/MWh. It must be considered that this is a gross estimation, and that the capital and operation costs can be further reduced with a more precise identification of all the involved costs for the system. Also, due to economies of scale, the installed cost per megawatt could be further reduced if larger installations are to be built.

Besides the low LCOE among renewable energies for the proposed system, the proposed system has several advantages against other technologies. The most important is the widespread availability of the energy resource, which is in this case the kinetic energy of seawater that can be harnessed at the coast. This enables the construction of this system in any location along the coast, which is also very convenient as many important cities are located close to the coast. Other renewable energy sources can only be effectively harnessed at very specific and restrained locations, such as traditional hydroelectricity used close to rivers, geothermal energy located in remote areas with volcanic activity, and wind energy that is available at specific locations with adequate geographical conditions. While solar energy availability is higher, the challenge of this technology is the large areas required to produce a considerable amount of electricity. This difficulty is overcome by the proposed system, as the occupied areas are smaller, and the expected overall environmental impact is also reduced.

Another important advantage is the reduced expected operation and maintenance costs of the system. The hydraulic ram pumps are made of simple components and its expected lifespan is above 50 years with very few maintenance requirements[4], and the hydroelectric component can reach a lifespan of 100 years[15], as it is based on well-developed and mature technology. On the other hand, the expected lifespan of wind turbines usually reaches 20 - 25 years[16], and lifespan of solar panels reaches at most 25 - 30 years without a considerable degradation in power output[17]. Finally, this system also has the advantage of being able to operate at nominal capacity through the entire year, only stopping for maintenance purposes or in case of unexpected shutdowns. This allows the system to reach a high-capacity factor, expected to be around 95%. Other renewables, such as wind and solar, use very variable and difficult to predict sources as input, which leads to lower capacity factors, 30-50% for wind and 15-20% for solar[18], and less efficient use of the installed electric equipment.

Construction of Small-Scale Model

This demonstration aims to elucidate the hydraulic ram pump operation, not only in elevating water uphill but also in

Table 3 Estimated Capital and Operational Expenses of the System

Description	Unit Cost	Unit	Quantity	Total Cost	Comment
Capital expenses					
Cellular cofferdam [USD]	300.000,00	Global	1	300.000,00	Source:[9]
Hydraulic ram pumps [USD]	16.666,66	Piece	9	150.000,00	Source: direct communication with manufacturer
Prebuilt water reservoir	60,00	USD/m3	100	6.000,00	Source:[10]
Penstock	500,00	USD/kW	1000	500.000,00	Source:[9]
Hydroelectric power plant [USD]	1.901,46	USD/kW	1000	1.901.460,00	Source:[11] ,[12]
Total CAPEX	2.857.460,00				
Operation expenses	3% of CAPEX yearly			114.298,40	Source:[13]
Total OPEX (20 years)	2.285.968,00				

Table 4 LCOE Calculation of the Proposed System

Parameter	Value
CAPEX [USD]	2.857.460,00
Yearly OPEX [USD]	114.298,40
Energy production [MWh/year]	8.322,00
Discount rate [%]	4,85%
Project lifetime [years]	20
LCOE [USD/MWh]	40,94

Table 5. LCOE Comparison with Other Renewable Energy Technologies

Technology	LCOE [USD/MWh]
Proposed System	40,94
Solar PV	49,00
Geothermal	56,00
Bioenergy	61,00
Hydropower	61,00
Offshore wind	81,00
CSP	118,00
Wave	570,00

generating electricity through the integration of a micro-hydro turbine. This exposition will employ common materials to construct a functional model, rendering the principles of fluid dynamics and energy conversion tangible and comprehensible.

Materials

- **Reservoir:** A 5-gallon bucket, ensuring adequate water supply from a garden faucet.
- **Conduit:** A 25-foot length of ½ inch PEX pipe, selected for its flexibility and durability.
- **Pump:** A ½-inch ram pump.
- **Delivery Mechanism:** A ¾-inch standard garden hose, tasked with conveying the pressurized water to its designated destination.
- **Support Structure:** A 14-foot ladder, providing the necessary elevation for demonstrating the pump's capacity to lift water uphill.
- **Energy Conversion Unit:** A 5V mini water turbine, capable of converting the kinetic energy of flowing water into electricity.
- **Voltage meter.**
- **Volume measure bucket.**

Procedure:

1. **Establishment of Head:** Position the bucket in a slope backyard, establishing a 3/4/5-foot head, defined as the vertical distance between the water level and the pump inlet.
2. **Conduit Installation:** Securely affix one extremity of the PEX pipe to the bucket's base, allowing the conduit to ascend without twitch, and put weight on top of the pipe to reduce the water hammer vibration.
3. **Pump Integration:** Connect the opposing extremity of the PEX pipe to the ram pump's inlet, situating the pump in a small water collection pool.
4. **Delivery System Configuration:** Affix a standard garden hose to the ram pump's outlet, poised to transport the elevated water.
5. **Turbine Positioning:** Connect the turbine to the other end of the garden hose.
6. **Voltage Meter Measuring:** Connect the voltage meter to the terminals of the mini water turbine, enabling the measurement of the voltage level of generated electricity.

Figure 7. Header, Ram pump, Delivery, Micro turbine voltage measurement

7. **Priming:** Open the bucket valve, then open the ram pump's inlet valve, facilitating the expulsion of entrapped air, ensuring unimpeded water flow.
8. **Flow Initiation:** Open the ram pump outlet valve. Observe as gravity propels water through the PEX pipe, initiating the pump's operation and activating the turbine.
9. **Pressure Buildup, Delivery, and Electricity Generation:** The ram pump's internal mechanism, harnessing the kinetic energy of the descending water, generates a surge of pressure. This force propels a portion of the water uphill through the garden hose. Simultaneously, the flowing water engages the turbine, causing it to rotate and produce electricity, as evidenced by the readings on the voltage meter. A video of the operating system is included in the footnotes: [19].

Results of Small-Scale Model Operation Table 6 shows a summary of the measured results of the operation of the small-scale model.

Table 6. Measured voltage output for different head height and delivery volume for the experiment.

Head height [ft]	Delivery height [ft]	Delivery volume [l/min]	Voltage [mV]
3.2	13.7	0.75	250
3.8	13.7	0.98	290
4.4	13.7	1.1	320
5	13.7	1.4	370

Overall, the system shows a positive correlation between head height, delivery volume, and generated voltage. As the head height increases, the ram pump can push more water uphill at a higher flow rate, which in turn drives the turbine faster and generates more electricity. Increasing the head height from 3.2ft to 5ft resulted in a 56% increase in delivery volume (from 0.75 to 1.4 L/min) and a 48% increase in voltage (from 250 to 370 mV), demonstrating that head height has a significant impact on the system's performance. The delivery volume increased steadily with increasing head height, which suggests that the system is well-suited for applications where higher water delivery is desired. The generated voltage also showed a consistent increase with higher head heights, indicating that the mini turbine efficiently converts the water flow into electricity.

However, further research is necessary to address some limitations that arise. The data only covers a limited range of head heights and as a result, it is unclear how the system would perform at even higher or lower head heights. The voltage measurements are provided in millivolts (mV). To assess the true electrical output, the current must be measured and the power in watts must be calculated. Efficiency calculations are missing from the data. Future work should focus on better understanding its potential for practical applications by researching the conversion efficiency of the turbine and the overall efficiency of the system.

Discussion

This experiment demonstrates the potential of using a ram pump with a micro turbine for generating electricity from flowing water. The system shows a promising correlation between head height, delivery volume, and generated voltage, suggesting its suitability for small-scale power generation in situations with sufficient head height.

In comparison to other non-hydropower renewable energies, upscaling this system for saltwater use brings forth numerous advantages. The abundance and accessibility of seawater, covering over 70% of the Earth's surface, provides a limitless resource for the ram pump. Unlike some renewables, seawater is consistently available, day and night, irrespective of weather conditions. This accessibility, coupled with the system's potential for offshore deployment or integration into existing infrastructure, sets it apart from land-intensive wind and solar farms.

The low-impact nature of ram pumps is noteworthy. Unlike wind and solar farms, which can disrupt ecosystems and require substantial land clearance, ram pumps leave a minimal environmental footprint. Their potential offshore deployment or integration into existing structures mitigates concerns about terrestrial impact.

The simplicity of ram pumps, characterized by few moving parts, translates into low maintenance compared to other renewable technologies. This simplicity not only reduces operational costs but also enhances reliability. The modular nature of ram pumps allows for distributed power generation, offering flexibility in deployment sizes and locations, which can be advantageous for remote areas, minimizing transmission losses and bolstering energy security.

Compared to traditional hydropower renewable energies like water dams or tide, the advantages of ram pumps become more apparent. Ram pumps exhibit lower environmental impact, as they don't require significant land modification or disrupt ecosystems. Unlike dams, they don't block waterways or alter natural water flow, minimizing harm to aquatic life. Additionally, the flexibility and scalability of ram pumps contrast with the expensive and location-limited nature of large dams.

In terms of cost-effectiveness, ram pumps emerge as a simpler and less expensive alternative to large hydropower dams or complex tidal energy systems. The modular design simplifies deployment and repairs, further reducing costs. Accessibility is a notable advantage; unlike dams limited to specific locations with high head heights, ram pumps can operate near the shore, enhancing their usability.

From a technical standpoint, the reliance on the natural flow of water provides reliable and predictable power, contributing to greater grid stability. Moreover, the system's potential resilience to seawater corrosion, with proper material selection and protection, ensures long-term functionality. The integration of the pump with desalination technology introduces a dual benefit, providing freshwater and clean energy simultaneously, addressing critical global needs.

Conclusion

Scaling up the ram pump and turbine system for seawater application holds tremendous promise for clean and renewable energy generation, offering substantial advantages over conventional renewables. The small scale model evidences this novel approach's feasibility, in which electric voltage readings were measured at various heights, demonstrating the system's ability to generate electricity efficiently. This empirical validation provides a foundation for further development and deployment of the system in real-world scenarios. The observed benefits, including abundance and accessibility of seawater, simplicity, and low cost position this technology as an innovative approach in addressing freshwater scarcity, solving the main challenges that hold desalination back today. The scalability and adaptability of the system make it suitable for coastal regions worldwide, presenting a transformative opportunity to mitigate water scarcity while advancing renewable energy adoption. Several potential directions for further development and enhancement of the seawater pumping system emerge, aiming to optimize efficiency, sustainability, and adaptability. Continuous advancements in pump design and materials may offer opportunities for reduced energy losses and enhanced water pumping capabilities. In addition, because this was done on my own, consulting experts in the field about the viability of the solution based on their experience and insights could provide valuable guidance for refining the system's performance and addressing any potential challenges. Looking towards the long run, collaborative efforts with stakeholders, including local communities, government agencies, and environmental organizations, will be crucial for the successful implementation and widespread adoption of this innovative solution. By leveraging the power of seawater for sustainable energy generation and freshwater production, we make significant strides towards a more resilient, equitable, and environmentally sustainable future.

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