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Deep Ocean Pressure Differential Energy Storage

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Abstract

This paper introduces DOPDES (Deep Ocean Pressure Differential Energy Storage), a preliminary concept for exploring energy storage using a flexible, flat, balloon-like bladder filled with seawater at a shallower ocean depth and then moved to a greater depth. The selected baseline case uses a filling depth of 100 m, an operating depth of 600 m and an initial water volume of 5 m^3. The increase in surrounding hydrostatic pressure is calculated as approximately 5.028 MPa. A simplified estimate of water compressibility gives a volume reduction of about 11.43 litres and compression work of about 28.7 kJ (0.0080 kWh). These values describe compression of the water itself , they do not establish the electrical energy that a turbine could generate. The central unanswered question is whether the bladder and outlet arrangement can maintain a useful pressure difference across a turbine. The paper separates selected design parameters from modelling assumptions and identifies the calculations and experiments needed for further study.

1. Introduction

Renewable energy sources such as offshore wind and ocean waves can produce more electricity at some times than is immediately required. Energy storage can help balance production and demand. DOPDES is a proposed underwater storage concept that investigates whether the increase in ocean pressure with depth can be used as part of an energy-storage cycle.

The original idea considered here is a flexible, flat or balloon-like bladder, rather than a rigid pressure chamber. The bladder is filled with seawater at an upper depth, sealed, and lowered to a greater depth. The higher external pressure may deform the bladder and reduce its volume. Water would be directed through a turbine only if the design can maintain a sufficient pressure difference across the turbine. The collapsed bladder would then be returned to the upper depth and refilled.

2. Selected Design Parameters

The following are baseline design choices selected to make a first mathematical study possible. They are not fixed properties of the ocean and have not been validated by a prototype.

Parameter	Symbol	Baseline value
Upper filling depth	h_1	100 m
Lower operating depth	h_2	600 m
Depth difference	Δh	500 m
Initial water volume in	V_0	5.0 m^3

bladder		
Bladder arrangement	—	Flexible flat / balloon-like bladder
Working fluid	—	Seawater

3. Modelling Assumptions

The following assumptions are introduced to simplify the first calculations:

1. Seawater density is taken as constant at 1,025 kg/m³ over the selected depth range.
2. Gravitational acceleration is taken as constant at 9.81 m/s².
3. The bulk modulus of seawater is approximated as 2.2 GPa for the simple compression estimate.
4. The initial water volume is treated as 5.0 m³.
5. The bladder and its valves are assumed not to leak during the idealised calculation.
6. The initial hydrostatic calculations are static; acceleration, waves and transient flow are neglected.
7. The compression estimate treats the bulk modulus as constant and assumes a linear pressure increase.
8. Pipe friction, turbine losses, valve losses, drag and auxiliary power are excluded from the basic hydrostatic calculations.
9. The bladder is assumed to remain flexible, but its actual pressure-volume behaviour is unknown and is not assumed to be successful.

4. Proposed Working Sequence

1. **Filling at the upper depth:** The flexible bladder is positioned at approximately 100 m and filled with about 5.0 m³ of seawater.
2. **Sealing:** The inlet is closed. The pressure and volume inside the bladder at this stage depend on the filling arrangement and must be measured in a real system.
3. **Lowering:** The filled bladder is moved from 100 m to 600 m. The surrounding hydrostatic pressure increases during descent.
4. **Controlled discharge:** The design proposes routing water through a turbine-generator assuming the system can maintain a useful and controllable pressure difference across the turbine . This can generate electricity only if a useful pressure difference exists across the turbine and sufficient water flow is maintained.
5. **Return and refill:** After discharge, the collapsed bladder is returned to the upper depth and refilled. The energy required for this return and refill must be included in the cycle balance.

5. Mathematical Calculations

5.1 Values used

Quantity	Symbol	Value
Seawater density	ρ	1,025 kg/m³
Gravitational acceleration	g	9.81 m/s²
Upper depth	h_1	100 m

Lower depth	h_2	600 m
Initial water volume	V_0	5.0 m^3
Approximate bulk modulus	K	2.2×10^9 Pa

5.2 Hydrostatic pressure at 100 m

Gauge pressure due to a water column is calculated using :

$P = \rho g h$

$P_1 = 1,025 \times 9.81 \times 100 = 1,005,525$ Pa

$P_1 = 1.005525$ MPa ≈ 1.006 MPa (gauge)

Gauge pressure is used here; atmospheric pressure is not included.

5.3 Hydrostatic pressure at 600 m

$P_2 = 1,025 \times 9.81 \times 600 = 6,033,150$ Pa

$P_2 = 6.033150$ MPa ≈ 6.033 MPa (gauge)

5.4 Difference in surrounding hydrostatic pressure

$\Delta P = \rho g (h_2 - h_1)$

$\Delta P = 1,025 \times 9.81 \times (600 - 100)$

$\Delta P = 5,027,625$ Pa = 5.027625 MPa ≈ 5.028 MPa

This is the increase in ambient seawater pressure between the two depths. It is not automatically the pressure difference across the turbine. The turbine pressure difference is determined by the pressure inside the bladder, the pressure at the turbine outlet, membrane tension and the flow arrangement.

5.5 Mass of seawater in the initially filled bladder

$m = \rho V_0$

$m = 1,025 \times 5.0 = 5,125$ kg

The initial 5.0 m^3 of seawater therefore has a mass of approximately 5,125 kg.

5.6 Compression of the water itself

A simplified estimate of the volume change of water under a pressure increase is obtained from the bulk-modulus relation :

$\Delta V \approx V_0 \Delta P / K$

$\Delta V \approx (5.0 \times 5,027,625) / (2.2 \times 10^9)$

$\Delta V \approx 0.01142642\ m^3 = 11.43$ litres

Thus, the estimated compression of the water itself is approximately 11.43 litres. This is not a calculation of the total collapse of the flexible bladder. The bladder may change its shape and volume by an additional amount, but that behaviour requires a measured or modelled pressure-volume curve for the membrane.

5.7 Approximate work associated with water compression

For a constant bulk modulus and a pressure increase applied gradually, a simple linear estimate of compression work is :

$E_{compression} \approx ½ \Delta P \Delta V$

$E_{compression} \approx 0.5 \times 5,027,625 \times 0.01142642$

$E_{compression} \approx 28{,}724$ J

$E_{compression} \approx 0.007979$ kWh ≈ 0.0080 kWh

This is a simplified estimate for compression of the water only. It is not the turbine's electrical output, and it must not be presented as the energy generated by DOPDES. A real system's recoverable energy depends on the pressure-volume path of the bladder and the actual pressure difference across the turbine.

6. Bladder Geometry and Material

The original proposal is a flexible flat or balloon-like bladder. Its length, width, layer construction and thickness have not yet been specified, so a reliable geometric dimension or membrane-stress calculation cannot be made. In particular, a spherical radius or diameter should not be assigned unless the design is deliberately changed to a spherical bladder.

Possible material families for later investigation include reinforced elastomers and fibre-reinforced flexible polymer composites. No material is selected or proven suitable in this paper. Material selection will require testing for external-pressure resistance, repeated folding, fatigue, seawater exposure, leakage and attachment loads.

7. Buoyancy and Transportation

If the filled bladder displaces approximately 5.0 m³ of seawater, the buoyant force is estimated by :

$F_\beta = \rho\, g\, V = 1{,}025 \times 9.81 \times 5.0$

$F_\beta \approx 50{,}276$ N ≈ 50.28 kN

The weight of the 5,125 kg of water inside is also approximately 50.28 kN. Therefore, the buoyancy of the displaced seawater approximately balances the weight of the water contents alone. The bladder material, valves, frame, tether and ballast change the net force. When the bladder collapses, its displaced volume changes, so its buoyancy also changes.

The transport energy cannot be calculated from the information currently available. It requires the bladder's mass, displaced volume versus depth curve, tether or winch arrangement, and hydrodynamic drag. In general, the mechanical work is found from the integral of net force over the vertical movement.

$W_{transport} = \int F_{net}(z)\, dz$

8. Turbine Output: What Can and Cannot Yet Be Calculated

The 5.028 MPa ambient pressure increase is not necessarily available across a turbine. A freely deforming water filled bladder may approach pressure equilibrium with the surrounding seawater. If the bladder's internal pressure is nearly equal to the water pressure at the outlet, the pressure difference driving flow through the turbine may be small. Membrane tension and the detailed outlet arrangement may alter this, but their effects have not been quantified.

The hydraulic energy delivered to a turbine must be calculated from the actual pressure difference across it over the discharged volume :

$E_{hydraulic} = \int \Delta P_t(V)\, dV$

$E_{electrical,out} = \eta_t \times E_{hydraulic}$

Here, ΔP_t is the measured or modelled pressure difference across the turbine and η_t is the turbine-generator efficiency. Neither the pressure volume curve nor the turbine operating point is currently known, so a defensible turbine output cannot yet be stated.

For comparison only, transferring 5.0 m³ of water through a conventional 500 m hydraulic head corresponds to $\rho g V \Delta h$:

$E_{reference} = \rho g V_0 \Delta h = 25{,}138{,}125$ J

$E_{reference} = 6.983$ kWh

This 6.983 kWh figure is a conventional hydraulic-head reference, not a prediction of DOPDES output. The bladder system does not automatically obtain this energy merely because the two depths differ by 500 m.

9. Complete Cycle Energy Balance

DOPDES is intended as an energy storage system, not an energy source. A complete cycle must include all electrical and mechanical energy used to fill, move, control and reset the bladder. A first energy balance can be written as :

$$E_{net} = E_{electrical,out} - E_{filling} - E_{transport} - E_{auxiliary}$$

A round-trip efficiency can be defined as the useful electrical energy returned divided by the electrical energy supplied during charging :

$$\eta_{RT} = (E_{electrical,out} / E_{electrical,in}) \times 100\%$$

The terms must be defined consistently for the actual system boundary. Pumping, winch operation, pipe and valve losses, turbine generator losses, controls, and any energy needed to restore the bladder to its initial state must be included. Since these quantities are not yet known, no numerical net energy or round-trip efficiency is claimed in this paper.

10. Main Limitations and Research Questions

1. Can the flexible bladder withstand the external pressure at 600 m without rupture, leakage or permanent damage?
2. What is the bladder's pressure-volume relationship during descent and discharge?
3. Can the bladder maintain enough pressure above the surrounding water to drive a turbine?
4. How much energy is required to lower, recover, refill and control the bladder?
5. How do repeated folding and pressure cycles affect material fatigue and service life?
6. Can the complete system achieve a useful round-trip efficiency after all losses are included?

11. Future Work

A possible next stage of the study would be to develop a membrane model that relates external pressure, internal pressure and bladder volume. A small-scale pressure-vessel experiment could then measure deformation and leakage under controlled conditions. The outlet and turbine arrangement should be tested separately to measure the real pressure drop, flow rate and electrical output. Finally, a full-cycle model should include filling, transport, discharge and reset energy. The operating depths and bladder capacity can then be varied to identify promising design conditions.

12. Conclusion

DOPDES is a preliminary student research concept based on a flexible flat or balloon-like seawater bladder moved between two ocean depths. For the selected baseline case of 100 m and 600 m, the increase in surrounding hydrostatic pressure is 5.028 MPa. A simplified bulk-modulus calculation

estimates that 5.0 m³ of water would compress by about 11.43 litres, corresponding to approximately 28.7 kJ or 0.0080 kWh of compression work for the water itself.

These calculations establish initial physical quantities but do not prove that the system can generate useful electricity. The key unresolved issue is whether the flexible bladder can maintain a sufficient pressure difference across a turbine while operating through a complete cycle. The energy needed for filling and transportation must also be measured. DOPDES should therefore be treated as a research idea requiring further modelling, material testing and experimental validation, rather than as a demonstrated energy storage technology.

References and Further Reading

The following established subject areas should be consulted when developing the next version: (1) fluid mechanics and hydrostatics,(2) thermodynamics and bulk modulus of liquids, (3) mechanics of flexible membranes and composite materials, (4) hydraulic turbines and fluid machinery, and (5) energy-storage system efficiency. Specific textbook editions and research articles should be added after the literature review has been completed. No experimental result or external research finding is claimed in this preliminary paper.

Statement of Scope

This document is intended to communicate the proposed arrangement and its initial calculations for academic feedback. The selected parameters are starting design choices, the modelling assumptions are simplifications; and the turbine output, structural safety and overall feasibility remain unverified.