



Trigger-Activated Buoyancy-Controlled Subsea Extraction of Dissolved Hydrogen Sulfide

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Abstract

This study presents a subsea extraction concept for dissolved hydrogen sulfide based on a trigger-activated, buoyancy-controlled mechanism. Unlike conventional systems that rely on continuous pumping, the proposed approach utilizes hydrostatic pressure, phase transition, and density variation to enable self-sustained upward transport. At depth, hydrogen sulfide remains dissolved under high pressure conditions. Upon ascent, pressure reduction induces rapid gas release, generating an effervescent multiphase flow that decreases fluid density and promotes buoyancy-driven motion. The system operates as a mobile subsea platform with controlled buoyancy, allowing positioning at selected depths without fixed infrastructure. Following a minimal external initiation, the extraction process becomes self-sustained through intrinsic physical gradients. The concept suggests a low-energy alternative to traditional subsea extraction methods and provides a framework for accessing dissolved gas reservoirs in anoxic water bodies.

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Abbreviations

API	American Petroleum Institute
atm	Atmosphere (pressure unit)
BCS	Buoyancy Controlled System
D	Deuterium
D₂	Deuterium Gas

GPSA	Gas Processors Suppliers Association
H₂S	Hydrogen Sulfide
MPF	Multiphase Flow
ROV	Remotely Operated Vehicle
TAV	Trigger Activated Vessel
TES	Thermal Energy Storage

Introduction

Hydrogen sulfide (H₂S) is widely present in anoxic marine environments and deep stratified water bodies, where it remains dissolved under elevated hydrostatic pressure conditions. These environments represent significant but largely underutilized chemical reservoirs. Conventional subsea extraction systems typically rely on continuous pumping and fixed infrastructure, which introduce substantial energy requirements and structural constraints, particularly under high-pressure conditions [1-6].

In contrast, natural fluid systems often exhibit transport mechanisms that emerge not from continuous forcing but from transitions in thermodynamic state. One well-known example is the pressure-dependent phase behavior of dissolved gases. When pressure is reduced, gas solubility decreases and phase separation occurs, resulting in rapid gas evolution and the formation of a multiphase flow regime [7-9]. This phenomenon can induce density reduction and buoyancy-driven motion without sustained mechanical input.

Motivated by these observations, this study proposes a subsea extraction concept based on controlled positioning and pressure-triggered activation. The system operates as a buoyancy-controlled, towable vessel that captures gas-rich water at depth and releases dissolved gas through a controlled pressure transition. Unlike conventional approaches, the process is not driven by continuous pumping but by discrete, trigger-activated events.

The operation is inherently cyclic. Each cycle consists of filling a sealed container at depth, isolating the fluid under pressure, initiating a controlled pressure drop, and extracting gas through rapid phase transition. The system then resets and repeats the cycle. In this sense, extraction is achieved through sequential activation steps rather than continuous flow.

This perspective suggests that subsea gas extraction may be reinterpreted as a sequence of state transitions governed by pressure and phase behavior, rather than as a continuously forced transport process. Conventional approaches often involve transporting large volumes of water to surface facilities for processing, followed by reinjection, resulting in significant energy and infrastructure demands. The

proposed framework therefore provides a low-energy alternative to conventional systems and highlights the role of intrinsic physical gradients in enabling fluid transport.

Physical Mechanism

The operation of the proposed system is governed by the interaction between hydrostatic pressure, phase behavior, and buoyancy-driven flow. At depth, dissolved hydrogen sulfide remains stable within the liquid phase due to high pressure conditions. Under these conditions, the fluid is effectively homogeneous, and gas release does not occur.

When the system ascends, the surrounding pressure decreases with depth. This reduction in pressure leads to a rapid decrease in gas solubility, initiating phase separation. Dissolved gas transitions into a gaseous phase, forming bubbles within the fluid. This process occurs progressively along the vertical direction and resembles an effervescent release.

The formation of gas bubbles reduces the effective density of the fluid mixture. As the gas volume fraction increases, buoyancy forces become dominant, generating upward motion. This mechanism is analogous to gas-lift processes in multiphase flow systems but differs in that it is initiated by pressure variation rather than continuous gas injection.

Once initiated, the combined effects of gas expansion and density reduction lead to a self-sustained flow regime. External energy input is no longer required to maintain motion, as the system converts hydrostatic potential into kinetic energy. The process can therefore be interpreted as a transition from a pressure-stabilized state to a buoyancy-driven transport state, triggered by a minimal external action.

System Architecture

The system is designed as a mobile subsea platform with controlled buoyancy and internal fluid handling capability. It operates independently of fixed seabed installations and can be positioned at selected depths.

The platform consists of a pressure-resistant enclosure containing a fluid chamber, a gas collection volume, and internal flow pathways. Structural design ensures stability under hydrostatic pressure while maintaining functional separation between liquid and gas phases.

Depth control is achieved through a ballast system that regulates the overall density of the platform. By adjusting the volume of seawater within dedicated compartments, the system can descend, stabilize at a desired depth, or ascend. Neutral buoyancy allows the system to remain suspended without anchoring.

At operational depth, fluid exchange with the surrounding environment allows gas-rich water to enter the internal chamber. Upon ascent, pressure reduction induces gas release within the chamber and along the internal flow path. The released gas accumulates in the upper section of the system, where separation occurs.

The platform may be repositioned horizontally through external towing or autonomous control, enabling operation across different locations. This mobility eliminates the need for rigid pipelines and allows flexible deployment.

Cyclic Operation (Scene-Based Description)

The system operates in a cyclic manner consisting of deployment, stabilization, charging, ascent, and collection phases. The cycle is governed by controlled valve operations that isolate and subsequently release the pressurized fluid.

During deployment, ballast tanks are filled to increase density, allowing the platform to descend to the desired depth. Once the target depth is reached, the system achieves neutral buoyancy and remains suspended with minimal energy input.

In the charging phase, gas-rich water enters the system and fills the internal chamber. The system remains in a pressure-stabilized state until ascent is initiated.

Ascent is triggered by releasing ballast water, reducing the system's density. As the platform rises, decreasing pressure induces gas release within the fluid. Bubble formation reduces mixture density and enhances upward motion.

The ascent phase becomes self-sustained as gas evolution increases buoyancy. Upon reaching the surface, gas is collected and separated, while liquid is discharged or retained.

The operation of the system can be described as a sequence of distinct stages, each corresponding to a controlled physical state of the container. The process evolves through filling, isolation, pressure release, gas extraction, and reset.

Scene 1 — Descent and Positioning

The subsea container is lowered to the target depth and stabilized using buoyancy control. At this depth, hydrostatic pressure is high, and the system reaches equilibrium with the surrounding environment. The container remains suspended without anchoring, maintaining its position with minimal energy input.

Scene 2 — Filling (Water In)

Intake valves are opened, allowing surrounding water to enter the container. The incoming fluid is rich in dissolved hydrogen sulfide due to the high-pressure environment. The container fills completely, and no gas evolution occurs at this stage.

Scene 3 — Sealing (Isolation)

Once filled, all intake and discharge valves are closed. The container becomes a sealed high-pressure volume. The dissolved gas remains stable within the liquid phase, and the system is now prepared for extraction.

Scene 4 — Surface Link (Connection)

A flexible hose connects the sealed container to a surface vessel. This vessel provides control, monitoring, and gas collection capability. The system remains sealed while the connection is established.

Scene 5 — Opening Event (The “Bottle Cap”)

A controlled valve is opened, linking the high-pressure internal chamber to a lower-pressure region. This moment is analogous to opening a pressurized bottle. The sudden pressure drop destabilizes the dissolved gas.

Scene 6 — Gas Release (Effervescence)

Dissolved hydrogen sulfide rapidly transitions into the gas phase. Bubbles form and expand throughout the fluid volume. The process is vigorous and self-driven, producing an effervescent multiphase flow.

Scene 7 — Gas Transfer (Gas Out)

The released gas rises and is directed through the hose toward the surface vessel. Gas flow is driven by pressure difference and buoyancy. The gas is captured and

stored at the surface without continuous pumping.

Scene 8 — Liquid Discharge (Water Out)

After gas extraction, the remaining liquid—now depleted of dissolved gas—is discharged back into the surrounding environment. The container is emptied of processed fluid.

Scene 9 — Reset

Valves are returned to their initial configuration. The container is ready to receive fresh water from the environment. The system returns to the initial state.

Scene 10 — Repeat

The cycle begins again. Multiple containers can operate in staggered sequences to provide continuous overall gas production.



Figure 1: Overview of the buoyancy-controlled, towable subsea extraction system.

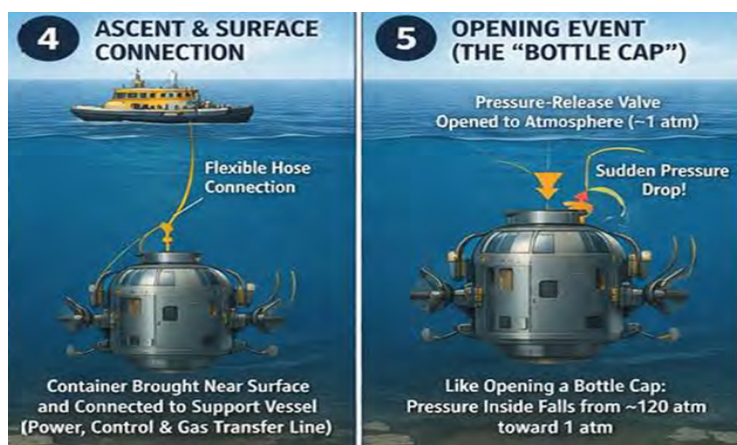


Figure 2: Variation of hydrostatic pressure with depth and its role in gas solubility.

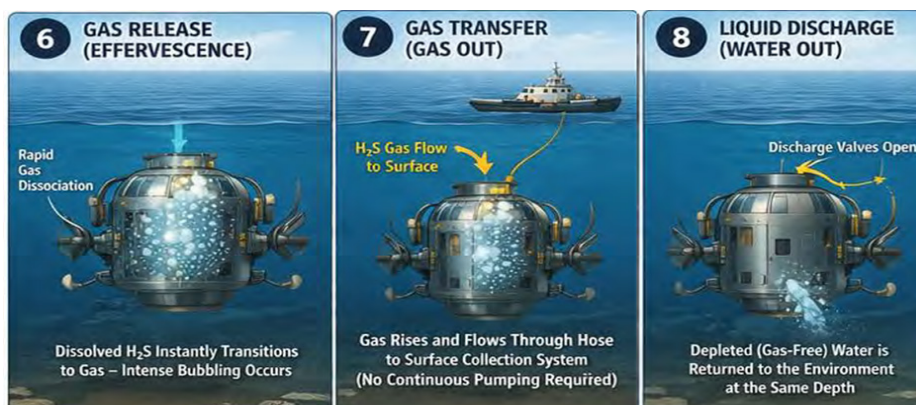


Figure 3: Pressure-induced phase transition of dissolved gas during ascent.



Figure 4: Internal configuration of the integrated subsea vessel.



Figure 5: Schematic representation of the cyclic extraction process.

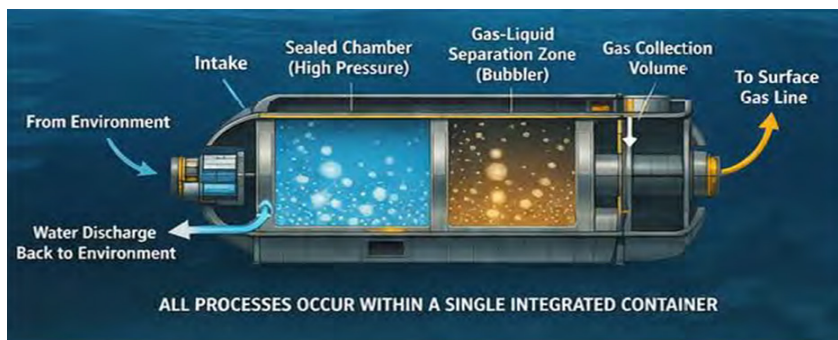


Figure 6: Scene-based illustration of the pressure-triggered extraction sequence.

- KEY FEATURES**
- ✓ Single Integrated Vessel – No Separable Modules
 - ✓ “Water In – Water Out; Gas Retained”
 - ✓ Cyclic Batch Operation with Controlled Valves
 - ✓ Minimal Energy: Only for Control, Ballast & Friction
 - ✓ No Continuous Pumping Required
 - ✓ Operates at Any Suitable Depth (~120 atm)
 - ✓ Environmentally Gentle: Water Returned to Same Layer

Figure 7: Complete system diagram illustrating cyclic operation, gas release, and surface transfer.

Comparison with Conventional Systems

Conventional subsea extraction systems rely on continuous pumping and fixed infrastructure to transport fluids from depth to the surface. These systems require sustained energy input to overcome hydrostatic pressure and frictional losses, leading to increased operational cost and complexity.

In contrast, the proposed system operates without continuous pumping. Fluid motion is not maintained by external forcing but emerges from pressure-induced phase transition and buoyancy effects. Once initiated, the system transitions into a self-sustained regime in which hydrostatic gradients perform the primary work.

Another key distinction lies in infrastructure requirements. Traditional systems depend on rigid pipelines, which are subject to structural constraints under high-pressure environments, including material limitations and dimensional reduction effects. The proposed approach eliminates these constraints by employing a mobile platform that does not require permanent subsea installations.

Furthermore, the ability to operate at adjustable depths allows the system to adapt to varying environmental conditions. This flexibility is not available in fixed systems and provides an advantage in accessing spatially distributed gas reservoirs.

Potential Application Domains

The proposed system is particularly relevant for environments where dissolved gases accumulate under high-pressure conditions. Large anoxic water bodies represent a primary application domain, as they contain significant concentrations of hydrogen sulfide.

Deep marine basins with stratified layers are of particular interest due to their stable pressure regimes and persistent gas content. In such environments, the system can be deployed at selected depths to access gas-rich zones without disturbing the overall structure of the water column.

Localized gas-rich lakes and enclosed basins also present potential application opportunities. These systems often exhibit strong pressure and compositional gradients, making them suitable for buoyancy-driven extraction mechanisms.

Beyond direct gas extraction, the system may serve as a platform for studying pressure-dependent fluid behavior and multiphase transport under controlled conditions.

Limitations and Engineering Considerations

Despite its conceptual advantages, the proposed system introduces several engineering challenges that must be addressed.

Hydrogen sulfide is highly toxic and corrosive, requiring careful material selection and sealing strategies. Long-term exposure to H₂S may degrade structural components and affect system reliability.

Multiphase flow behavior within the system can lead to instability, particularly during rapid gas release. Flow regime transitions, such as bubbly to slug flow, may influence performance and require detailed analysis.

Control of ascent velocity is another critical factor. Excessive gas release may result in rapid buoyancy changes, potentially compromising system stability. Therefore, ballast regulation and flow management must be carefully designed.

Scaling the system to larger capacities may introduce additional challenges related to structural integrity, control complexity, and operational safety.

Environmental Considerations and Broader Context

The proposed system operates on the principle of in situ extraction, where water is processed within a controlled vessel and subsequently returned to its original environment. This approach avoids large-scale transport of bulk fluid to surface facilities, thereby reducing energy consumption, infrastructure requirements, and associated environmental disturbance.

In conventional systems, the need to pump and process large volumes of water at the surface introduces both energetic and ecological burdens. By contrast, the present method minimizes fluid displacement and maintains operation within the natural pressure-defined environment. The discharged liquid remains within the same depth range from which it was extracted, limiting perturbation of stratified layers.

Hydrogen sulfide is a naturally occurring component of anoxic marine systems, and the proposed extraction process does not introduce new chemical species into the environment. Instead, it selectively removes dissolved gas while returning the remaining fluid. Localized effects may occur and should be evaluated in site-specific implementations; however, the overall approach is inherently conservative in terms of environmental interaction.

Beyond primary gas extraction, pressure-driven phase behavior may influence the distribution of chemical species within the system. While the present study does not target compositional modification, it is noted that isotopic variants can exist within natural environments. Under high-pressure conditions and controlled phase transitions, subtle variations in composition may arise.

Such considerations are not central to the operation of the system but may be of interest in broader contexts where chemical composition and separation processes are relevant. In this sense, the system provides a platform not only for extraction but also for controlled interaction with pressure-dependent fluid behavior.

Discussion

The results of this study suggest that subsea extraction processes may be reinterpreted through a framework based on activation rather than continuous forcing. Instead of maintaining system operation through sustained energy input, the proposed approach relies on initiating a transition that allows intrinsic physical gradients to dominate.

This perspective highlights the role of hydrostatic pressure not as an obstacle, but as a resource that can be utilized to drive system behavior. The system leverages naturally occurring conditions to enable transport processes.

In addition to its engineering implications, the approach may have broader relevance in contexts where pressure-dependent phase behavior influences fluid composition. Variations in solubility and phase transition dynamics may affect the distribution of chemical species, suggesting potential avenues for further investigation. High-purity isotopic gases are known to have significant economic value in special-

ized applications, which further motivates interest in pressure-based separation phenomena.

The concept therefore represents not only a technical alternative but also a shift in how subsea processes may be approached, emphasizing activation and natural gradients over continuous control. In contrast, the present approach performs extraction in situ through a cyclic, pressure-triggered mechanism, eliminating the need for bulk fluid transport. Water in – water out; gas retained.

Conclusion

This study presents a trigger-activated subsea extraction concept based on buoyancy-controlled operation and pressure-induced phase transition. The system operates as a mobile platform capable of positioning at selected depths and initiating extraction through a minimal external input.

Once activated, the process becomes self-sustained through gas release and density-driven buoyancy, eliminating the need for continuous pumping. The approach offers a low-energy alternative to conventional extraction systems and reduces dependence on fixed infrastructure.

Although not a primary objective of this work, the presence of isotopic variants in natural systems suggests that pressure-driven extraction processes may exhibit sensitivity to compositional differences. Any potential enrichment effects, if present, would require dedicated investigation.

The findings demonstrate that dissolved gas reservoirs in high-pressure environments may be accessed through controlled positioning and phase-driven transport mechanisms. This framework provides a basis for further investigation and development of subsea systems that utilize intrinsic physical gradients for operation.

The proposed system demonstrates that extraction can be achieved through controlled state transitions rather than continuous mechanical forcing. By operating within natural pressure regimes, the system offers a low-energy and environmentally consistent alternative for accessing dissolved gas resources. Existing systems extract dissolved gas through continuous upward flow, whereas the present system operates

through discrete, trigger-activated phase transitions within a sealed volume.

In contrast to conventional subsea extraction approaches that rely on continuous upward flow or externally sustained pumping, the present system operates through discrete, trigger-activated phase transitions within a sealed volume. The extraction process is not maintained by steady transport, but is instead initiated as a controlled state transition, after which buoyancy-driven motion emerges intrinsically from pressure-dependent phase behavior. This distinction defines a different operational regime in which hydrostatic conditions are not overcome but utilized as the primary driving mechanism. While engineering challenges related to multiphase flow stability and system control remain and require further investigation, these considerations do not alter the fundamental physical basis of the concept. Rather, they define the pathway for practical implementation. In this sense, the proposed framework does not extend conventional gas-lift systems, but introduces a cyclic, activation-based approach to dissolved gas extraction governed by intrinsic thermodynamic transitions [10-15].

Author Contributions

Huseyin Murat Cekirge is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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