Changing State Technologies
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Changing State Technologies
White Paper - Moving Fluids in a Post Cavitation World

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August 2026

Executive Summary

Cavitation has long constrained the design, efficiency, reliability, and operating envelopes of fluid-handling systems. It occurs when local pressure in a liquid drops below the fluid's vapor pressure, forming vapor bubbles that collapse violently and cause erosion, noise, vibration, performance loss, and premature equipment failure.

This white paper explains the physics of cavitation, its causes and effects, and its specific impacts on the pump industry, HVAC/hydronic systems, and distillation processes. It reviews current mitigation strategies and their inherent limitations.

The core of the paper introduces Changing State Technologies MPR™ Stable Vapour Cavity capability which is based on its patent entitled **A Multi-Phase Rotor, System and Method for Maintaining a Stable Vapour Cavity (US Patent # 12,398,725 B2),** The described breakthrough approach fundamentally eliminates cavitation as a design and operational constraint. In a true "post-cavitation world," engineers gain unprecedented freedom to both utilise cavitation positively and to optimize for efficiency, compactness, higher speeds/flows, extreme conditions, and lower total cost of ownership across industries.

Prospective benefits accrue to the pump, cooling and distillation industries, and include more reliability in challenging conditions; flexibility to vary pressure and flow, and in solution design; simpler management; and simpler solutions with lower energy costs, less maintenance, and lower capital expenditures.

1. Understanding Cavitation

1.1 Definition and Physics

Cavitation is the formation of vapor-filled cavities (bubbles) in a liquid when the local static pressure falls below the liquid's vapor pressure at the prevailing temperature. These bubbles are carried into regions of higher pressure, where they collapse rapidly. The implosions generate intense localized shock waves, micro-jets, and high temperatures/pressures (often exceeding thousands of psi and hundreds of degrees Celsius momentarily).

This is governed by fluid dynamics principles, notably **Bernoulli's equation**:

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

High velocity ((v)) directly reduces pressure ((P)) and increases inertia-based pressure drop. Temperature also plays a key role because vapor pressure rises exponentially with temperature.

Cavitation can be hydrodynamic (flow-induced) or acoustic; the focus here is hydrodynamic, dominant in pumps, piping, valves, and process equipment.

1.2 Primary Causes

- **Velocity/Inertia-induced pressure drop**: Sudden accelerations around impeller vanes, valve seats, orifices, or pipe restrictions.
- **Insufficient inlet pressure:** Low system pressure, high suction lift, long/small suction piping, clogged strainers/filters, or partially closed inlet valves.
- **High fluid temperature:** Raises vapor pressure, shrinking the margin to cavitation.
- **Turbulence and flow disturbances:** Sharp bends, expansions/contractions, or poor inlet flow conditioning.
- **Entrained or dissolved gases/volatiles:** Can create nucleation points and exacerbate cavitation symptoms (especially in hot process fluids).
- **Pump-specific factors:** Operation below Net Positive Suction Head Available (NPSHa) compared to NPSH Required (NPSHr) by the pump.

1.3 Effects and Consequences

- **Material damage:** Pitting, erosion, and fatigue on impellers, casings, blades, valve seats, and pipe walls. Repeated micro-jet impacts remove material like “acid etching.”
- **Noise and vibration:** Characteristic “gravel,” “marbles,” or “rocks in the pump” sound; can transmit through systems and cause fatigue in piping/supports.
- **Performance degradation:** Reduced head and flow (pump curve shifts), efficiency loss, unstable operation, and “breakdown” at high flows.
- **Operational impacts:** Increased energy consumption, frequent maintenance/replacement, unplanned downtime, and safety risks in critical systems.
- **Economic costs:** Higher capital (oversized equipment, conservative designs) and operating expenses across industries.

2. Cavitation in Key Industries

2.1 The Pump Industry

Centrifugal pumps dominate fluid movement. Cavitation typically initiates at the impeller eye or leading edges of vanes on the suction side.

Specific causes: Inadequate NPSHa (system-side) versus NPSHr (pump-specific, increases with flow and speed). High specific-speed designs for efficiency increase risk.

Effects: Rapid impeller erosion (visible pitting), vibration leading to bearing/seal failure, head/flow drop, and characteristic noise. Manufacturers publish NPSHr curves; operation below them triggers damage.

Current mitigations:

- Maintain NPSH margin (typically 0.5–1+ m or more).
- Use inducers or double-suction impellers.
- Larger suction piping, lower fluid temperature, or degassing.
- Erosion-resistant coatings or harder materials.
- Variable frequency drives (VFDs) to stay within safe operating regions.

Limitations: These add cost, size, or complexity; trade off efficiency or head; are not foolproof under variable real-world conditions (temperature swings, fouling, altitude, or off-design operation). Conservative designs limit performance.

2.2 HVAC and Hydronic Systems

Closed-loop water (or glycol) circulation in heating, cooling, and chilled-water systems relies on circulator pumps and control valves.

Specific causes: Low system pressurization (PRV settings), suction-side restrictions (clogged strainers, partially closed valves), high water temperatures (common in hot-water or condenser loops), and high velocities in small pipes or orifices.

Effects: Noisy operation (complaints in occupied buildings), reduced flow and heat transfer efficiency, pump impeller damage, vibration in piping, and premature pump failure. Impacts occupant comfort, energy use (pumps run harder or fail), and maintenance budgets in commercial, institutional, and industrial facilities.

Current mitigations: Proper system pressurization, clean strainers, correct pump selection with adequate NPSH margin, differential bypass valves, and monitoring.

Limitations: System design constraints (pipe sizing, elevation), sensitivity to maintenance lapses, and inability to fully decouple performance from temperature or flow variations.

2.3 Distillation and Process Fluid Handling

In chemical, petrochemical, pharmaceutical, and refining distillation trains (atmospheric and vacuum columns), pumps handle feed, reflux, product, and bottoms streams.

Specific causes: High temperatures (elevated vapor pressure), vacuum operation (low absolute pressures), flashing or volatile components, and entrained gases from thermal cracking or flashing (e.g., vacuum tower bottoms pumps).

Effects: Inconsistent flow rates disrupt column hydraulics and separation efficiency, equipment damage in continuous processes (costly downtime), and indirect energy penalties (reboiler/condenser loads affected by unstable operation).

Current mitigations: Conservative NPSH calculations with large margins, quench systems or mixing to suppress gas evolution, specialized pump designs, and monitoring.

Limitations: Limits throughput and process intensity; requires oversized or derated equipment; vulnerable in variable feed or upset conditions.

3. Limitations of Existing Approaches

Traditional strategies manage symptoms or reduce probability but do not eliminate the fundamental pressure-velocity-temperature constraints. They often involve trade-offs in size, cost, efficiency, operating flexibility or a requirement for complex solutions and management systems. A true post-cavitation paradigm requires transcending these physical limits rather than working around them.

4. The Changing State Multiphase Rotor (MPR™) – Enabling a Post-Cavitation World

MPR / High-Level Overview

The MPR, Changing State's beyond cavitation fluid dynamics platform, uses non-tensional acceleration to maintain local pressures safely above vapor pressure enabling operation without impact from cavitation.

Technical Description and Integration

The formation of a stable-vapour-cavity (SVC) within the MPR. via ensuring greater outflow capability than inflow, facilitates the separation of intake and outflow processes within a fluid pumping device whilst facilitating maximal volumetric intake (flow) for a given inlet orifice size.

How It Works (Mechanism of Action)

The separation of the inflow from the outflow via the formation of the SVC – in which the outflow mechanism resides, causes the inflow to shift from being tensionally "pulled in" by the impellor to being "pushed in" via the pressure differential of the SVC (at vapour pressure) to the external ambient pressure.

With the fluid having been "pushed" (compressively accelerated) into and through the pump's SVC chamber it is added to the rotating fluid "pond". Thus, the rotating fluid is physically separated from the inflowing fluid via the SVC.

With a non-rotating pitot structure being positioned under the advancing fluid (pond) surface the fluid is compressively accelerated (pushed) through the outflow structure of the pump.

This shows how both inflow and outflow fluid bodies are able to be in a "non-tensional" - or compressive, acceleration state and as such the "low pressure" key requirement for cavitation events is no longer prevalent.

Why It Eliminates Cavitation Constraints

NPSH (net positive suction head) is the key indicator of how close to the cavitation threshold a pump can get before its performance becomes compromised, even to the point of complete failure to pump. Essentially there is a connectional continuum of inflow to outflow within the impeller – starting at the centre and progressing to the periphery, from tensional acceleration to compressive acceleration respectively. If the tensional acceleration zone progresses too far along the continuum the pump's performance will diminish or fail.

The CST's SVC methodology has neither tensional acceleration nor consequential connection between inflow and outflow. Thereby eliminating the typically understood NPSH constraints.

Given that increasing RPM characteristically exacerbates NPSH constraints, a typical centrifugal pump will have design RPM ranges and exceeding them will be detrimental to performance – if not catastrophic both to fluid flow and/or seals.

These characteristics are founded in fundamental physics whereby the fluid cannot support tensional force beyond its vapour-pressure traits.

The CST pump, however, has no such physics-based limitations as the fluid is not subjected to tensional accelerations. Clearly there are strength-of-materials and other practical constraints preventing unlimited RPM.

A fluid's temperature effects the vapour-pressure (Vp). High temperatures increase the Vp and hence exacerbate NPSH and other cavitation-based limitations.

However, the CST SVC system is not impacted from increasing Vp apart from reducing the pressure-differential between ambient and the internal SVC pressure which only reduces the flow rate and/or lift on intake capability. Its output pressure performance is not impacted by input characteristics.

Finally, as the CST SVC is compressional and can expel NC gases (non-condensable gases) it can seamlessly handle both entrained and dissolved gases without compromising output pressure performance or pump componentry life expectancy.

Not only does it eliminate any negative effects of cavitation our technology creates an environment where cavitation can be used constructively.

Proven Performance / Validation
Prototype systems incorporating the technology have been operated under controlled laboratory conditions for multiple years, consistently demonstrating reliable performance across a range of operating regimes. Outside the laboratory, self-priming capability has been verified to a suction lift of 9.5 m. Two independent field trials have been completed; in both cases, post-trial inspection showed no cavitation-induced damage to critical components. The technology has further been shown to operate independently of conventional NPSH constraints, maintaining stable performance where traditional pumps would be limited by available suction head. Within the validated operating envelope, pressure and flow have been varied without inducing the performance degradation, vibration, or material damage characteristically associated with cavitation. The system has also demonstrated robust tolerance to gas ingestion and intake blockage, both of which were accommodated with no adverse consequences to performance (other than the expected reduction in flow) or equipment integrity.

5. Implications of Changing State's MPR technology for Key Industries

5.1 Pump Industry

- **Design freedom:** Higher specific speeds, more compact and efficient pumps, operation at higher flows/heads without derating.
- **Reliability and maintenance:** Dramatically reduced or eliminated impeller erosion, vibration, and failures → longer mean time between repairs, lower spare parts inventory.
- **Performance:** Sustained peak efficiency across wider operating ranges; lower energy consumption.
- **New capabilities:** Viable pumping of hotter fluids, higher lifts, or more challenging media without oversized equipment.
- **Economic impact:** Lower total cost of ownership (capex + opex), higher uptime, and ability to offer differentiated high-performance products.

5.2 HVAC Systems

- **Quiet, comfortable operation:** Elimination of cavitation noise and vibration improves occupant experience and reduces acoustic engineering needs.
- **Reliability and uptime:** Fewer pump failures in critical environments (hospitals, data centres, commercial buildings).
- **Energy efficiency:** Sustained high pump and system efficiency; optimized flow without conservative margins.
- **Simplified design and installation:** Potential for smaller pumps, reduced piping diameters, or more flexible layouts.
- **Maintenance reduction:** Less strainer cleaning impact and fewer service calls.

5.3 Distillation and Process Industries

- **Throughput and flexibility:** Higher flow rates and more aggressive process conditions (temperature, pressure, feed variability) without cavitation risk.
- **Operational stability:** Consistent pump performance improves column control, separation efficiency, and product quality.
- **Reduced downtime and maintenance:** Critical in continuous processes where unplanned outages are extremely costly.
- **Energy and sustainability gains:** More efficient fluid movement; potential to optimize overall process energy balance.
- **Innovation enablement:** Opens doors to intensified processes, smaller footprints, or handling of previously difficult fluids.

6. Broader Impacts and Future Outlook

A post-cavitation world extends beyond the three industries highlighted. It enables advances in power generation (turbines, cooling), water treatment, oil & gas, and emerging fields like advanced manufacturing or renewable energy fluid systems.

Benefits include improved sustainability (less material waste from erosion failures, lower energy use), enhanced safety, and accelerated innovation by removing a fundamental physical barrier.

Conclusion

Cavitation has been an unavoidable compromise in fluid handling for over a century. **Changing State's MPR technology** changes that equation. By **creating a stable vapour cavity and separating intake from outflow**, it ushers in a post-cavitation era where fluid systems are designed for optimal performance rather than cavitation avoidance.

We invite collaboration to explore how this technology can transform your specific applications.

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